The role of hydrometeorological and soil conditions in soil erosion and fluvial sedimentation

R. P. RUDRA[1], W. T. DICKINSON[1], and G. J. WALL[2]

[1]*School of Engineering, University of Guelph, Guelph, ON, Canada N1G 2W1; and* [2]*Land Resource Research Centre, Agriculture Canada, Guelph, ON, Canada N1H 6N1.* *Received 30 August 1988, accepted 12 April 1989.*

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Field observations from two small watersheds in Southern Ontario link the frequency and magnitude of significant soil erosion and sediment transport loads from January through April to particular sets of hydrometeorological and soil conditions. Rainfall, and a combination of rainfall and snowmelt, occurring on soil in which the surface has thawed but subsurface layers are still frozen, account for most of the major stream sediment load events. Laboratory and field data verify that both low soil density and high soil water content are present during these events resulting in the associated soil erodibility of the surface soil being high and the shear strength being low.

INTRODUCTION

The accelerated loss of productive soil due to erosion by water, and subsequent sedimentation in downstream river and lake systems, have become acknowledged as serious problems in many regions of the world, including the land adjacent to the Great Lakes (International Joint Commission 1978; Sparrow 1984). The severity of this problem has focussed attention on the need to quantitatively characterize soil loss more adequately in spatial extent and in temporal dimensions. Although much has been accomplished in this respect in the recent years, soil erosion still remains a complex phenomenon which is not yet sufficiently well understood to allow its precise prediction, particularly in subhumid regions like Southern Ontario.

The principle sources of stream sediments are generally considered to be inter-rill and rill erosion from upland fields and streambank erosion from natural and manmade drainage courses. Recent studies have indicated that erosion from upland agricultural fields is a major source (70 - 98%) of stream-suspended sediment loads in Southern Ontario (Dickinson 1989). Moreover, about 75% of the annual suspended sediment yield is transported in January through April, when the soil has been left relatively bare by agricultural practices (Wall et al. 1982).

Precipitation, runoff, topography, vegetation cover, biological activity, and the inherent ability of a soil to resist erosion, i.e., its erodibility, have been identified as factors which explain much of the variation in the annual soil loss (Olson and Wischmeier 1963; Olson et al. 1963). Moreover, research has also identified wide seasonal variability in soil erosion patterns in some climates (Wall et al. 1982). Some of the factors noted above allow for consideration of such variability; and qualitative linkages between observed erosion patterns and seasonal changes in precipitation, runoff and vegetative cover have been developed. However, the role of soil erodibility in combination with hydrometeorological characteristics is quite unclear. In fact, a method for measuring or indexing soil erodibility, let alone the possible variability in time, has not yet been agreed upon.

Wischmeier et al. (1971) related soil erodibility to soil texture, organic matter, permeability and soil structure. Although their K factor provides a statistically validated and highly reliable index of average annual erodibility, it does not explicitly consider seasonal variation in soil conditions such as bulk density, soil water content, or surface soil strength.

Many researchers, including Middleton (1930), Gerdel (1937), Peele et al. (1938), Anderson (1951), Andre and Anderson (1961), Woodridge (1964), Willen (1965) and Bryan (1968) have developed and explored a number of possible indices of soil erodibility based on soil properties affecting dispersion or dispersion and water transmission. Some of the more significant of these indices are dispersion ratio (i.e., the ratio of the amount of silt and clay in the dispersed phase to the amount of silt and clay in an undisturbed sample), erosion ratio (the ratio of dispersion ratio to collodial content), clay ratio (ratio of sand content to that of silt and clay), surface aggregation ratio (ratio of content of material bound to that of material binding), aggregate stability, and indices based on soil mechanical properties. None of these indices considers seasonal variations in soil conditions, though now it is being recognized that soil erodibility changes during the year (Mutchler and Carter 1983; Kirby and Mehuys 1987; Coote et al. 1988; Wall et al. 1988).

The purpose of the present study is to identify and characterize soil and hydrometeorological conditions for the winter period (November to April) when more than 75% of the annual suspended sediment load in the Great Lakes Basin is transported from the land to the stream system. Watershed, field and laboratory investigations were employed to achieve the stated objectives.

STUDY AREA

Data on soils and hydrometeorological characteristics from two drainage basins, Big Otter Creek and Big Creek have been considered. These adjacent basins lie in the most southern part of Ontario, as shown in Fig. 1. Southern Ontario has a temperate climate which is moderated by Lake Erie to the south. These watersheds have an annual frost free period of 147 d and an average annual precipitation of 975 mm distributed uniformly over the year. The average annual temperature is 8.1°C, with the maximum average daily temperature of 21.2°C occurring in July and the minimum average daily temperature of −4.9°C occurring in January.

The Big Otter Creek watershed has an approximate area of 712 km^2. The topography of the basin is dominated by two

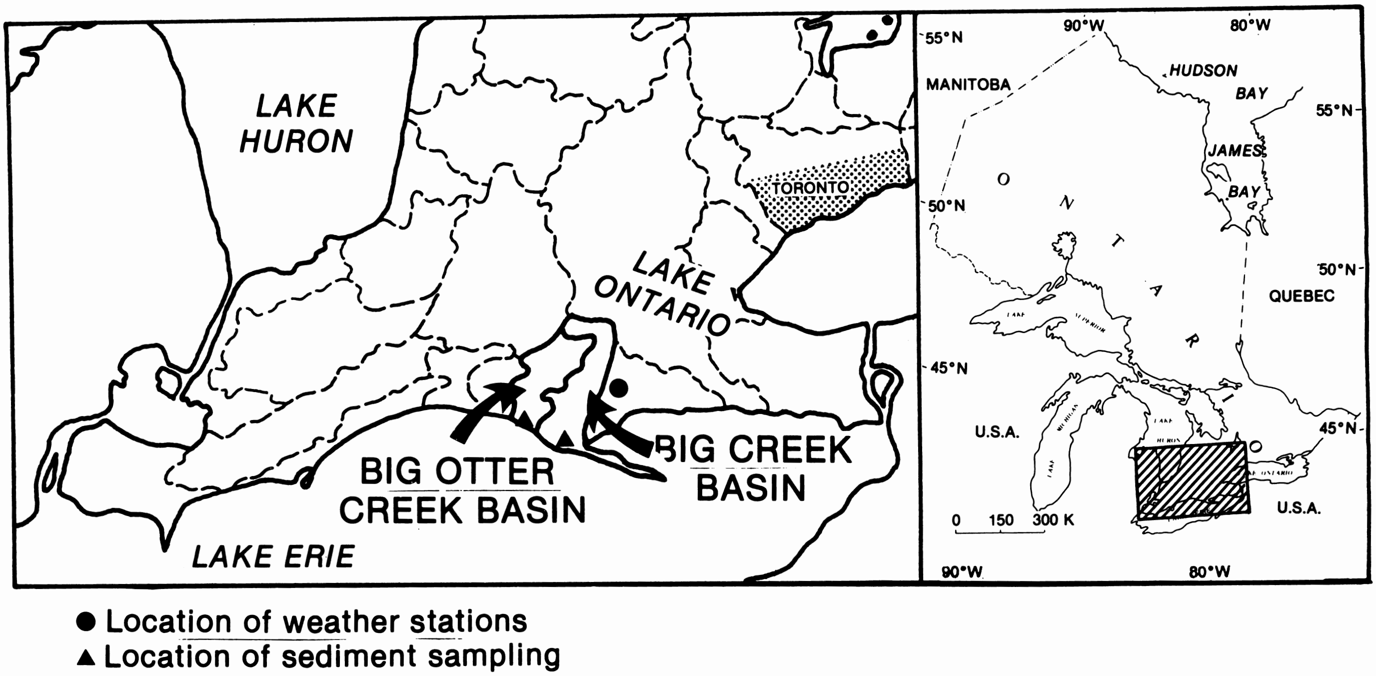

Figure 1. Location map of the Big Otter Creek and Big Creek study basins in Southern Ontario.

physiographic forms: the Mount Elgin Ridges (glacial till) and the Norfolk Sand Plains (glacial lacustrine) (Chapman and Putman 1966). The moranic ridges cover the north and northwest part of the watershed, while the sand plains cover the south and southeast portion. The elevation of the drainage basin varies from 174 to 335 m above mean sea level.

Approximately 60% of the Big Otter Creek basin is arable land. Agriculture during the study period (1970 - 1977) on the loam- and silt-loam-textured soils of the end moraines included primarily corn, with some small grains, hay and pasture. Tobacco is grown on the sands and loamy sand plains as a continuous crop or in rotation with small grain or corn as a market crop.

Big Creek Basin has an approximate area of 725 km^2. The topography of this basin is characterized by a broad, flat sand plain, interrupted sporadically by prominent beach ridges and deep stream valleys, resulting from erosion and deposition during glacial and postglacial periods (Chapman and Putman 1966). Soil textures in this basin include loamy sand, loams, sandy loam and fine sandy loam. The economy of this basin during the study period was essentially agriculturally based with 70% of the area as improved agricultural land. The main crop was tobacco followed by rye or wheat as a rotational crop.

METHODOLOGY

Watershed Studies

Sediment data for 8 yr, 1970 through 1977, were extracted from Sediment Data for Canadian Rivers, reported by Water Survey of Canada for Big Otter Creek near Calton and Big Creek near Walsingham. Meteorological data were obtained from the nearby Canadian Atmospheric Environmental Service for the station at Simcoe. Sediment events at the outlet of the watershed were categorized according to (i) the nature of precipitation (i.e., only rainfall (R), only snowmelt (S), rainfall and snowmelt (RS), and unknown (U); (ii) soil temperature conditions at the ground surface (i.e., frost (F) and no frost (NF)); and (iii) soil temperature conditions at shallow depth, between 5 and 20 cm below the ground surface (i.e., frost (F) and no frost (NF)). Sediment and runoff events which occurred in the absence of rainfall and for which there was snow cover on some portion of the watershed with air temperature above 0°C were considered to be snowmelt events. Soil temperatures above 0°C at the surface and in the subsurface were considered as indicator of no frost conditions.

Soil Studies

To explain possible variations in sediment loads with hydrometeorological conditions, field and laboratory studies examined soil properties affecting soil erosion, such as soil erodibility, bulk density, soil water conditions and surface shear strength. Three soil series (Colwood silt loam, Haldimand silty clay and Fox sand) were selected to study the nature of possible relationships between soil erosion and seasonally variable properties of soil. The three soils selected were representatives of the Gray Brown Luvisol, Gleyed Gray Brown Luvisol and Orthic Gleysol great groups (Canada Soil Survey Committee 1978). Textural analysis and organic matter content of these soils, determined by standard method (McKeague 1978) are given in Table 1. Particle size distribution was determined, after distruction of organic matter and dispersal with calgon, by pipette analysis. Organic matter was determined by the wet combustion titration method.

Table I. Textural and organic matter analyses of soils used in the field study.

Soil type	Sample depth (cm)	Sand (%)	Silt (%)	Clay (%)	Organic matter (%)
Haldimand Silty clay	0 – 2.5	8	50	42	8
Colwood Silt loam	0 – 2.5	22	54	24	5
Fox sand	0 – 2.5	89	7	4	1

Laboratory Studies

The laboratory studies involved estimation of effective erodibility of the three soils under simulated rainfall and simulated seasonal conditions. Seasonal conditions included winter thaw conditions representative of late winter and early spring, spring conditions representive of middle to late spring, and summer conditions representative of the summer period. The surface soil under winter thaw condition had a high water content, shallow (25 mm) depth to the frost layer and restricted internal drainage. The soil had a loose freshly tilled surface, good internal drainage and a soil water content near field capacity under spring conditions. For summer conditions the soil had a compacted surface, good internal drainage and a water content halfway between field capacity and the wilting point. A laboratory facility, consisting of a rainfall simulator, a soil erosion flume and an automatic sediment collection device, was used to collect soil loss data under simulated rainfall and simulated seasonal soil conditions. Details regarding the construction and calibration of the rainfall simulator have been described by Pall et al. (1983). The soil erosion flume used in this study was 150 cm long, 70 cm wide and 15 cm deep. The frost layer was simulated by placing a thin sheet of metal at 25 mm depth.

Five runs were performed on the three soils under a rainfall intensity of 20 mm h^{-1}. This rainfall intensity represents a 2-yr return period spring storm in Southern Ontario. The first run was conducted for summer conditions with a compacted surface soil. The water content for this condition was maintained halfway between field capacity and the wilting point. For spring conditions, the upper 25-mm layer of soil was raked and reworked carefully to form a smooth surface, and the water content was established close to field capacity (−33 kPa matric potential). For winter thaw conditions, a metal sheet was installed at 25-mm depth, and the soil above the sheet was reworked to form a smooth uncompacted surface. The water content of the soil above the sheet (simulated frost layer) was maintained between field capacity and saturation (−10 kPa matric potential). All the runs were performed at a 6% slope and the total time for each run was 30 min. Runoff and sediment load samples from each run were collected and the soil loss for each run was estimated by determining the mass of sediment in the runoff. The effective erodibility (an index similar to the K factor of the Universal Soil Loss Equation) was determined by using the Universal Soil Loss Equation appropriate to individual storms. The rainfall erosivity index (R factor) was computed for an individual storm according to the type II storm equation given by Ateshian (1974). Other factors of the USLE were computed according to the procedure outlined by Wischmeier and Smith (1978).

The seasonal K factors of the soils under study were also determined using the nomograph presented by Wischmeier and Smith (1978). Although the nomograph was developed and used for the computation of annual K, the nature of variations in structure and permeability codes can give an indication of seasonal variations (Dickinson et al. 1982). The first approximation of K was made on the basis of soil texture and organic matter content. The estimation of the seasonal K (K_s) was made from a first approximation and seasonal adjustment of structure and permeability codes. The seasonal variations of structure and permeability codes suggested by Cook et al. (1985) were used for the three soils.

Field Studies

Field data on shear strength, soil water content, and bulk density of the surface soil were collected five times during the spring of 1981. Six replications were made for shear strength and soil water content sampling. Bulk density sampling was replicated three times. The surface soil was sampled and soil water content was determined gravimetrically according to the procedure outlined by Gardner (1965). Soil bulk density was determined from core samples by the method described by Blake (1965). A vane shear methodology (Youssef et al. 1965) was used to determine surface shear characteristics of field samples and remoulded laboratory samples of the selected soil texture described earlier.

RESULTS AND DISCUSSION

Watershed Studies

The general structure of the watershed part of the study was to relate sediment load events and hydrometeorological events, with regard to rainfall, snowmelt and soil temperature. Sediment loads were used as qualitative indicators of the occurrence and relative order of magnitude of soil erosion. Although this assumption may not be strictly correct, it is considered to be a reasonable approximation for the study of watershed soil erosion and sedimentation patterns in relation to the hydrometeorological characteristics. Bank erosion did not comprise a major portion of the suspended sediment loads in these watersheds (Wall et al. 1982), and thus sediment events were considered to be justifiable indicators of upland erosion events.

Since it is likely that sediment transport factors from field to stream change from event to event, an event exhibiting a relatively large sediment load can be considered to indicate considerable soil erosion. A small sediment load event can indicate the occurrence of relatively little erosion and very limited transport of eroded material. Qualitative field observations on the study watersheds have confirmed that whenever widespread erosion has occurred, a sediment load event of at least moderate magnitude has resulted. Storms causing only localized erosion activity have not led to noticeable sediment loads.

Seasonal suspended sediment discharge statistics for Big Otter Creek and Big Creek are reported in Table II. For the 8 yr of record analyzed, from 1970 to 1977, the sediment loads for the accumulated winter period (1 November to 30 April) were approximately 75% of the total loads for Big Otter Creek and 67% of the total loads for Big Creek.

Table II. General sediment discharge characteristics for Big Otter Creek and Big Creek watersheds in Southern Ontario

Statistics parameter	Big Otter Creek	Big Creek
Basin area (km^2)	712	725
Total sediment load for the period Dec. 1970 to Dec. 1977 (t/km^2)	1.05	0.20
Total sediment load for the winter periods 1 Nov. - 30 Apr 1970 to 1977, (t/km^2)	0.78	0.13
Sediment load accounted for by winter storms (t/km^2)	0.74	0.08
Winter period load as percent of total load (t/km^2)	75	67
Winter event load as percent of total load (t/km^2)	71	39
Winter event load as percent of winter period load (t/km^2)	95	58

Table III. Sediment yield from significant events during eight winter seasons (1 Nov. to 30 Apr., 1970 to 1977) *occurring in* two small watersheds in Southern Ontario†

Precipitation event type	Surface conditions	Number of sediment events	Mean load per event (t/km)	Subsurface conditions	Number of sediment events	Mean load per event (t/km)
			Big Otter Creek drainage basin			
R	F	2	8.6	F	1	3.9
				NF	1	13.3
	NF	17	27.8	F	5	39.1
				NF	12	21.1
RS	F	2	5.9	F	2	5.9
				NF	–	–
	NF	20	25.1	F	13	32.4
				NF	7	11.5
S	F	–	–	F	–	–
				NF	–	–
	NF	2	21.5	F	2	8.6
				NF	1	36.2
U	F	2	8.8	F	2	8.8
				NF	–	–
	NF	–	–	F	–	–
				NF	–	–
			Big Creek drainage basin			
R	F	–	–	F	–	–
				NF	–	–
	NF	7	7.0	F	3	9.8
				NF	4	5.0
RS	F	–	–	F	–	–
				NF	–	–
	NF	5	12.5	F	4	12.5
				NF	1	12.9
S	F	–	–	F	–	–
				NF	–	–
	NF	1	5.5	F	1	5.5
				NF	–	–
U	F	–	–	F	–	–
				NF	–	–
	NF	2	6.3	F	2	6.3
				NF	–	–

†R = rain, S = snowmelt runoff, RS = rain snowmelt association, U = unknown, F = frost, NF = no frost.

Table III presents the sediment yield from major events for the winter period and associated soil surface, subsurface and precipitation conditions for both study watersheds. For Big Otter Creek, 95% of the sediment loads were associated with rainfall and rainfall on snowmelt, and were very evenly distributed between these two categories. Only 5% of the sediment loads were due to snowmelt events. Fifty percent of the sediment load events occurred when the ground surface showed no frost but when there was a frost layer in the subsoil. The average event load for precipitation events was 25.5 t/km^2 for "no frost" soil surface conditions, and 7.25 t/km^2 for "frost" surface conditions. The average event load for "no-frost" surface and "shallow frost" subsurface conditions, when depth to the frost layer was between 5 and 20 cm, was 34.4 t/km^2. For "no frost" surface and "deep frost" subsurface conditions, when frost layer was at a depth greater than 20 cm, the average event load was 16.7 t/km^2.

Results for Big Creek were somewhat different from those for Big Otter Creek. Approximately 38% of the sediment loads were associated with "rainfall only" conditions, while rainfall in association with snowmelt resulted in 48% of the sediment loads. Only four percent of the sediment loads were due to snowmelt conditions. Many of the sediment events were associated with no-frost surface conditions and a frost layer in the subsurface. The average event load pattern relative to soil conditions was very similar to that for Big Otter Creek, but the magnitude of event loads was much lower. The average event load for the no-frost surface condition was 8.6 t/km^2, for no-frost surface and shallow frost subsurface conditions 9.8 t/km^2, and for deep frost conditions 6.6 t/km^2.

The analysis of the sediment load data for Big Otter Creek indicated a significant difference in the event loads at the 0.05 level, when the soil surface changed from frost to no-frost conditions. In the case of Big Creek, all the sediment load events occurred when there was no frost at the soil surface. The interaction between type of precipitation event and soil conditions did not show any significant effect on the event load. The analysis also revealed that the change in sub-surface conditions for both watersheds had no significant effect on the event load.

Table IV summarizes the annual major winter sediment loads, and the associated precipitation and soil conditions. For Big Otter Creek, the predominant event type for extreme winter sediment loads involved a combination of rainfall and frost at shallow depth (R-F). For Big Creek, the association of rainfall with snowmelt and frost (RS-F) was equally common as the rainfall and shallow surface frost (R-F) event.

The following summary observations were made from the tabulated results obtained from the watershed data:

1. Larger sediment loads and a greater number of sediment events occurred in the Big Otter Creek basin, the watershed with the larger percentage of morainic soils.
2. Virtually all of the sediment events resulted from rainfall or a combination of rainfall and snowmelt conditions. Very few events resulted from snowmelt alone.
3. Most sediment load events observed on the study watersheds occurred when the surface soil temperature was above freezing.
4. Subsurface soil temperature varied with conditions causing sediment load events. Most of the events resulting from rainfall conditions alone exhibited little or no frost in the surface layers, while most of the sediment load events that occurred as a result of combined rainfall and snowmelt conditions showed evidence of a frostlayer.
5. Most of the substantial sediment loads occurred as a result of rainfall or a combination of rainfall and snowmelt when the surface soil had no frost and the subsurface showed the presence of a frost layer.

Soil Studies

The seasonal erodibility (K) values for the Colwood silt loam and the Fox sand were computed by a nomographic procedure and determined from laboratory experiments (Fig. 2). Although laboratory experimental data were available only for a limited number of soils, the results indicate a seasonal pattern in soil loss variation. The variability of seasonal K is similar for each soil used in the experiment. The highest values occurred under simulated winter thaw conditions, and lowest values under simulated summer conditions. Nomographic estimates also gave a similar variability pattern for both the silt loam and the sand. However, the range of effective seasonal K values for the silt loam were considerably greater than the estimates obtained by using the nomographic approach. Surface shear strength, bulk density and soil water content data for these soils are given in Table V. A two-variable linear model,

$$SS = A + B\,(\zeta) + C\,(\theta)$$

where: SS = surface shear strength, (kPa)
ζ = dry bulk density, (kg/m^3)
θ = volumetric water content, m^3 m^{-3} × 100, and
A,B,C = regression parameters,

was fitted to these data, and the parameters and statistics of the fitted equation (Eq. 1) for the three soils are given in Table VI. These equations were used to estimate shear strength values for winter thaw, spring and summer conditions for sand, silt loam and silty clay. The results on estimated seasonal variation in surface shear strength along with effective seasonal K and nomographic seasonal K are presented in Figs. 3–5. These results suggest a strong negative correlation between seasonal K (nomographic or laboratory values) and seasonal surface shear strength. This indicates that, if other conditions remain unchanged, the soil erodibility increases with a decrease in surface shear strength.

To examine possible variations in surface shear strength with soil water content at a known density, the surface shear strength of remoulded soil was plotted against soil water content and the results are presented in Fig. 6. A two-stage linear model was fitted to the data points. The point of inflection on these curves was named the "break point". This "break point" has been interpreted as an indication of the soil water content at which the soil passes from a plastic to a liquid state, becoming considerably more susceptible to movement as a result of any applied force by rainfall and/or runoff. The water content at the "break point", the slope of the relationship for soil water content below the "break point", and the change in slope of the function on either side of this point have been found to be a function of clay content of the soil (Green 1982). A soil with a greater clay content exhibits a higher soil water content at the "break point" and exhibits a surface shear strength which approaches this point more rapidly and changes more abruptly at the "break point". Further, the "break point" occurs at a water content somewhat greater than that determined by traditional liquid limit (indicated by LL on Fig. 6) techniques, the difference between break point and LL decreasing with clay content. For each soil other than the sand, the soil water content at saturation was determined to be near or somewhat below that of the "break point" as identified in Fig. 6. Water content much above these values would not normally be achieved under natural slow wetting conditions. However, during winter thaw periods in Southern Ontario, water content in surface soils can be expected to be near and in excess of the "break point", indicating high erosion susceptability.

Further analysis was conducted on the field data to investigate variations in surface shear strength with soil water content. The two-variable linear model relating surface shear strength, soil water content and bulk density described earlier (Eq. 1) was used to estimate variations in surface shear strength with soil water content at a known bulk density for the Colwood silt loam soil. The results, along with experimental observations, are presented in Fig. 7. Although the data to date are sparse at high water content, it is evident from these data that the water content at which the surface shear strength approaches low values is considerably lower at lower soil densities. In other words, when the soil is less dense, low shear strength values can be achieved more readily with an increase in soil water content. The vulnerability of surface soils at low density to erosion in Southern Ontario during winter thaw periods appear to be validated by these studies.

Table IV. Major sediment load events and associated precipitation and soil temperature conditions for November 1 to April 30, period 1970 to 1977†

Year	Big Otter Creek					Big Creek				
	Event type†				Sediment load (t/km^2)	Event type†				Sediment load (t/km^2)
	R-F	S-F	RS-F	RS-NF		R-F	S-F	RS-F	RS-NF	
1970-1971		X			32.2	X				2.9
1971-1972	X				33.2			X		2.5
1972-1973	X				57.4			X		3.7
1973-1974	X				47.3	X				5.4
1974-1975			X		43.8			X		3.1
1975-1976				X	36.8				X	7.0
1976-1977	X				28.0	X				3.9

†R = rain, S = snowmelt runoff, RS = rain snowmelt association, F = frost, NF = no frost.

Table V. Surface shear strength, bulk density and moisture content of three soils during spring 1981

Soil type	Water ((kg/kg) × 100)	Degree of saturation (%)	Bulk density (kg/m^3)	Surface shear strength (kPa)
Haldimand	25.7	60.3	1245	33.5
Silty clay	27.6	67.4	1270	31.1
	30.6	80.2	1317	14.4
	35.1	88.0	1287	10.9
	30.8	100.0	1477	6.8
$\bar{X}$†	30.0	79.1	1319	19.3
S‡	3.6	15.9	92	12.2
Colwood	15.9	30.5	1120	15.1
Silt loam	20.0	47.1	1283	17.4
	27.1	65.2	1260	9.9
	26.7	77.8	1387	15.1
$\bar{X}$	22.4	55.2	1262	14.4
S	5.5	20.7	110	3.2
Fox Sand	5.3	19.5	1540	6.1
	6.3	20.3	1467	6.8
	7.0	19.7	1363	1.8
	7.2	21.2	1393	4.3
	9.6	30.4	1445	4.2
$\bar{X}$	7.1	22.2	1442	4.6
S	1.6	4.6	69	2.0

†$\bar{X}$,mean. S,standard deviation.

The watershed study indicated that many sediment load events occurred under conditions when the surface soil was not frozen and the subsurface soil was frozen. These conditions were more common during the months of late February through early April in the study watersheds. From watershed and field observations, and laboratory results, it seems that during this period the impermeable or partially permeable frost layer at a shallow depth results in a decrease in infiltration rate and cumulative infiltration. These conditions help to create a saturated to supersaturated soil water matrix in the top soil layer. Observations of Kay et al. (1985) indicated low surface soil densities, as a result of freeze thaw cycle, during this time of the year. Bryan (1971) observed a decrease in aggregate stability due to frost aciton. Due to low density and high soil water content, the surface soils in the study watersheds were probably very unstable under these conditions, and any disturbance at the surface caused by rainfall and/or runoff would result in considerably detachment and transport of soil particles.

The erosion processes during spring conditions, when the frost layer was at a great depth, was probably influenced by soil layering due to changes in bulk density in the soil profile. Such layering conditions and changes in soil profile density during the month of April have been observed by Groenevelt and Kay (1979) and Kay et al. (1985). It appears that vertical variations in bulk density in the watershed study may have created temporary soil layering, with a relatively permeable, low density and low strength soil. These conditions would result in restricted water flow into the lower soil overlaying less permeable, higher density and higher strength soil. These conditions would result in restricted water flow into the lower soil profile and consequently high water content of the surface layer.

The rain storms during this period are generally of low intensity and long duration (Dickinson 1976), but their runoff potential and transport capacity are generally high. A 20 mm/h spring storm occurring on soil with a 50-mm depth to an impermeable frost layer could generate runoff equal to that for a 100 mm/h

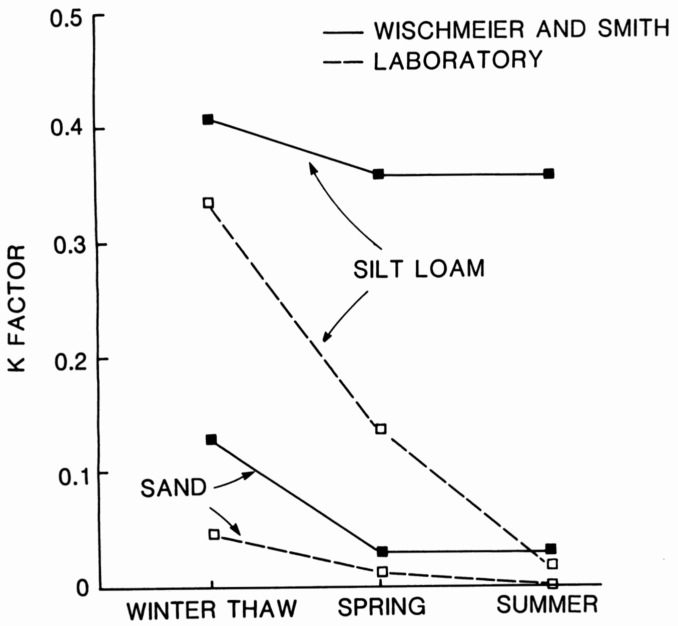

Figure 2. Estimates of seasonal erodibility values based on Wischmeier's nomograph and laboratory measurements.

Table VI. Coefficient of determination and regression papameters determined for soil shear model

Soil type	A	B	C	Coefficient determination
Colwood silt loam	−27.18	0.048	−0.66	0.966
Haldimand silty clay	113.40	−0.018	−1.79	0.960
Fox sand	−27.74	0.023	−0.06	0.672

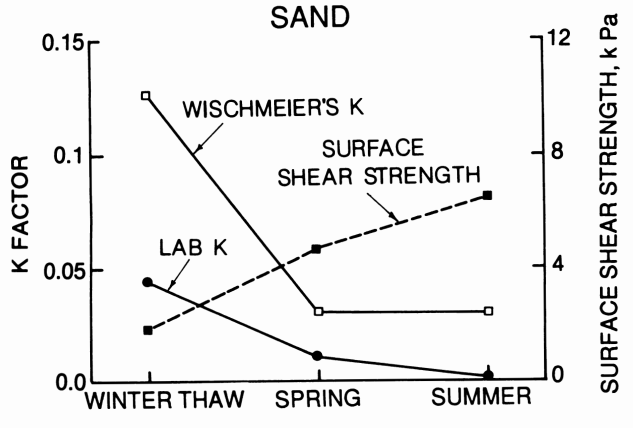

Figure 3. Estimates of seasonal erodibility and surface shear strength values for Fox sand.

storm occurring on relatively dry soil during the summer in Southern Ontario (Rudra et al. 1986). The combination of low density surface soil at high water content, high runoff and high transport capacity was responsible for high erosion and high sediment loads during late winter and early spring.

CONCLUSIONS

The watershed, field and laboratory studies have provided a useful perspective to focus attention on the apparent hydrometeorological conditions surrounding major erosion and sediment events. This study has also drawn attention to the possible significance of soil bulk density, soil water content, surface shear strength and depth to frost layer, and to the manner in which these soil parameters become important. Soil shear strength may or may not be a key index of soil erodibility for winter and early spring periods. It is certainly easily determined, and is a good indicator of temporal variations in soil properties.

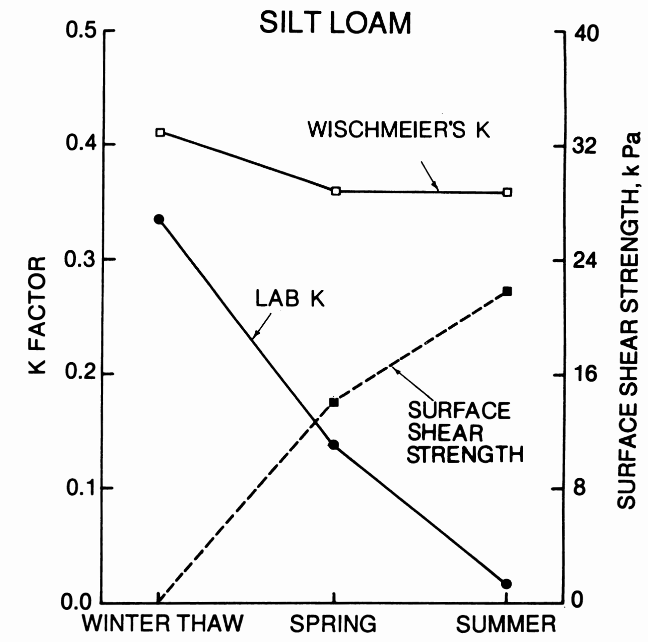

Figure 4. Estimates of seasonal erodibility and surface shear strength values for Colwood silt loam.

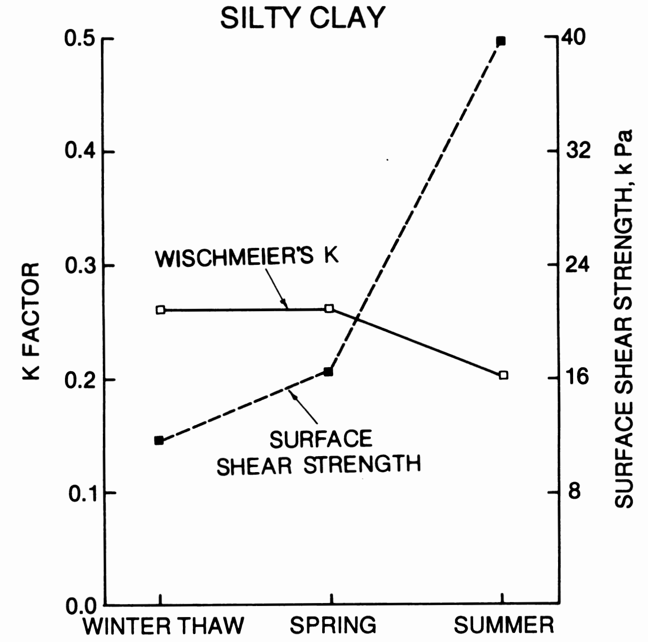

Figure 5. Estimates of seasonal erodibility and surface shear strength values for Haldimand silty clay.

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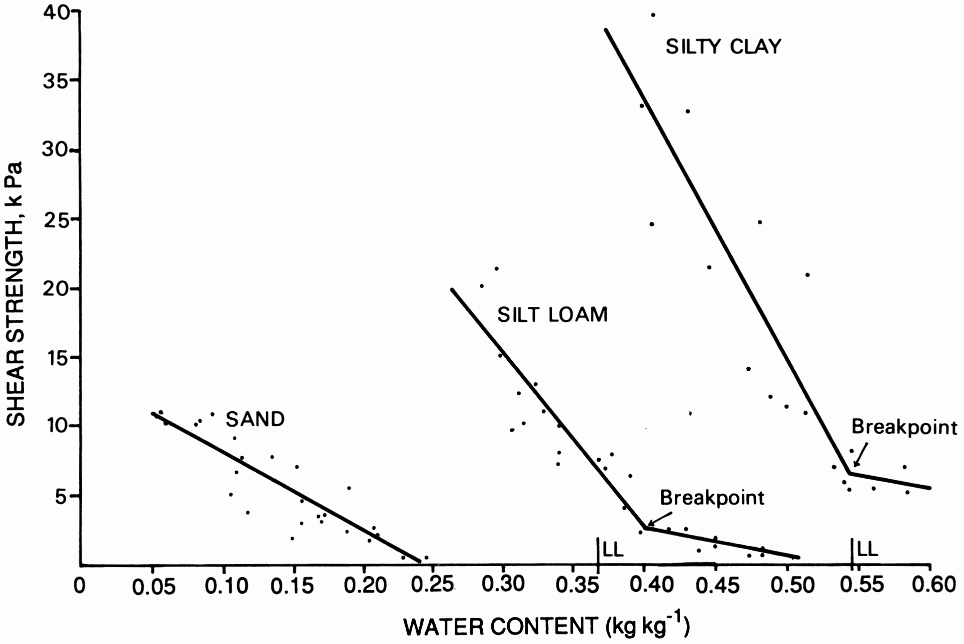

Figure 6. Surface shear strength and water content relationships for three Southern Ontario soils

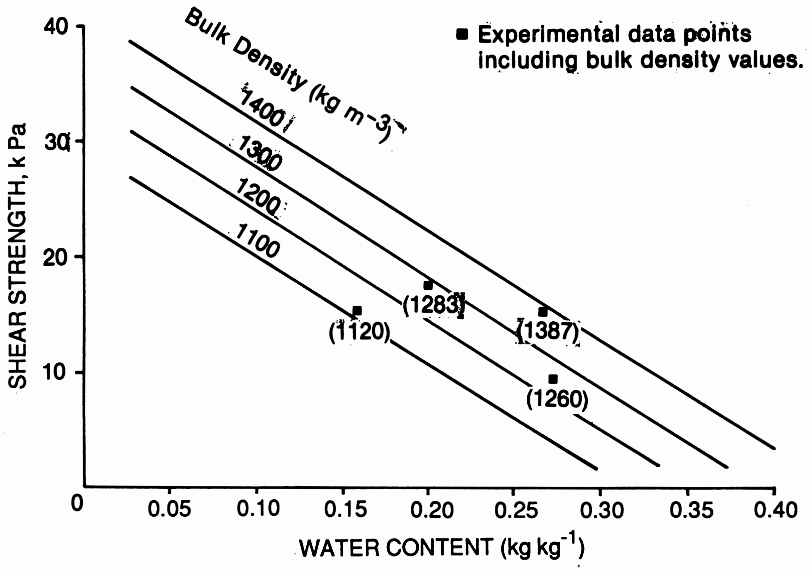

Figure 7. Estimated and measured surface shear strength, bulk density and water content for Colwood silt loam during spring 1981.

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