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FIELD EVALUATION OF AN EROSION HAZARD ASSESSMENT SYSTEM IN WEST CENTRAL ALBERTA

by

Carlos A. Llerena

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ABSTRACT

Lack of field evaluation is a limitation of most of the erosion-hazard ratings developed in Alberta. In this study Singh's (1983) method of erosion-hazard rating using forest cover types as indicators of erosion risk, based on infiltration rates, was assessed.

972 erosion pins in 54 small plots, with 25% mean slope, under 362 mm of rainfall, stratified in 3 soil associations and 2 forest cover types, were used as a erosion measurement method. The USLE's erodibility (K) factor was also used as an additional control and index of erosion susceptibility.

The study area was located in the foothills of the Edson Forest around Hinton, within the boundaries of the FMA of Champion Forest Products (Alberta) Ltd. Sixteen cut blocks in 6 compartments of the Athabasca and McLeod working circles, and two cut blocks in Cache Percotte were selected for monitoring erosion.

Erosion measurements obtained were low in terms of depth (0.49 mm/plot) of soil loss but important in volume (6 ton/ha). However, since disturbance and exposure of mineral soil is restricted to rather small portions of the cut blocks, these results and their implications, must be related to percentage of disturbed areas, and characteristics of the cut blocks.

Because of small differences in erosion among soil and forest stratifications, erosion variability, and no consistent agreement between the rating trends of erosion and erodibility testing methods, it was difficult to arrive at a definitive acceptance or rejection of Singh's system. However, the results of analyses of variance lead to acceptance of the null hypothesis and rejection of Singh's proposed system. Better criteria are needed for a reliable method of erosion risk assessment in west central Alberta.

The main soil variables controlling the amount of soil loss as determined by stepwise regression were : organic matter, calcium carbonate, sand, clay, and calcium content. Slope aspect was not correlated with erosion. The association between rainfall and erosion was best expressed by daily precipitation.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Serious efforts of observation and recording of soil erosion problems in the Alberta foothills began with the creation of the Eastern Rockies Forest Conservation Board (ERFCB) in 1947 (Hanson 1973). One of the main objectives of this program was the management of watersheds for water production and water supply protection (Swanson et al. 1986). As a consequence of this commitment a change in policy from optimum timber production to watershed protection occurred in 1948 (Kennedy 1949), and was maintained for the life span of the Board (Hall 1973). Thereafter this policy was continued by the Alberta Forest Service (Davis 1977), and the provincial government (Alberta 1984).

During its 25 years of existence the ERFCB carried out extensive reconnaissance work in the conservation units (ERFCB 1963, 1967, 1968, 1968a, 1968b, 1969, 1969a, 1970, 1971, 1971a). These field observations identified road construction and use, yarding, well-site operations and cattle grazing as the most damaging activities in the area.

Results of these surveys were supported by a study of the lease area of North Western Pulp & Power (now Champion Forest Products Ltd.) near Hinton, Alberta, (Hall 1969). This study pointed out that major soil erosion problems, and subsequent sedimentation of streams, resulted from roads. It was significant that no appreciable increase in overland flow or soil movement was observed on cut blocks after harvesting or scarification (Hall 1969, Crossley 1972, 1975).

Quantification of erosion in deforested lands was performed first in the Swan Hills from 1967 to 1971. In this area heavily affected by oil exploitation , runoff plots and suspended sediment sampling were used (Wyldman and Poliquin 1973). Suspended sediment sampling procedures were also used for measuring road erosion in the Hinton and Marmot Creek areas (Rothwell 1974, 1977, 1979). From 1967-1986, 12 quantitative studies on soil erosion were conducted in forested areas of Alberta. However, no quantitative measurements of soil loss in cut blocks were made.

During 1968 two erosion-hazard studies were reported. Rutter (1968) developed an erosion-hazard method for the Rocky Mountain Forest Reserve, and Jeffrey <u>et al.</u> (1968) a system for the Upper Oldman River Basin. The latter research was conducted as part of the Alberta Watershed Research Program initiated during 1960-1963 (Swanson <u>et al.</u> 1986). This program gave first priority to water yield and timing research. Soil erosion studies were given a second priority (Jeffrey 1967), probably because no major erosion problems had been detected in the forested areas, with the exception of roads and well-sites.

Since 1968, 23 erosion-hazard studies have been conducted in Alberta using 15 different methods. With the exception of one (Luk 1975), no field validation was carried out for any of these studies.

This study focussed on soil erosion in the Edson Forest. Quantitative measurements of summer erosion in clearcut areas using erosion pins were taken and used for testing an erosion-hazard assessment method proposed by Singh (1983) for west central Alberta. Singh's method ranks erodibility according to forest cover types using soil infiltration rates.

The purpose of this study was to assess the validity of the erosion hazard system proposed by Singh (1983). In particular I wanted to determine how effective the system is in identifying erosion hazard resulting from land use disturbances such as logging operations.

II. LITERATURE REVIEW

Soil erosion studies are abundant and diverse. In this chapter a condensed review to identify the main environmental factors related to soil loss is presented. The main relationships between logging and erosion are briefly reviewed, and the evolution of erosion research and erosion-hazard rating is summarized as well. The rather extensive literature about use and development of the erosion pin method is outlined as background for its use in this study. Pertinent Canadian, Albertan, and Rocky Mountain references are preferentially quoted .

A. Environmental factors affecting soil erosion

The magnitude of soil erosion on any hilly forested location is determined by the interaction of four factors : soil properties, precipitation, slope, and forest cover. Many studies have attempted to identify and to quantify the influence of each factor and to combine them into predictive equations for soil-loss.

A.1. Soil properties

The severity of surface erosion is strongly influenced or controlled by soil or regolith properties (Bryan 1976). Musgrave (1947) said that erodibility of different soils varied with their physical properties. According to Klock (1982), forest soil properties generally related to soil erosion are : texture, porosity, organic matter content, bulk density, moisture retention characteristics, pH, and aggregation. Dyrness (1966) added parent material type, and amount of exchangeable Ca, Mg, K, and Na. Schulco (1973), and Bayrock and Reimchen (1974) lumped several soil properties under the general denomination of soil stability, which included carbonate and clay content, texture and bedrock type. Rothwell (1978) and Twardy and Corns (1980), considered infiltration capacity and stability the two main properties influencing erosion. Evans (1980) indicated surface roughness, surface stoniness and soil profile characteristics were important. Bryan and Luk (1981) added slope microrelief to the list.

Soil properties considered for predicting soil erosion or erosion hazard are diverse. Rutter (1968) in the Rocky Mountain Forest Reserve of Alberta, included infiltration rate, texture, carbonate content, and the binding strength of silt and clay. The erodibility factor (K) of the Universal Soil Loss Equation (USLE) uses : soil texture, organic matter, soil structure, and permeability (Wischmeier and Smith 1978). In the Kootenay area of British Columbia surface erosion potential and slope failure potential indices were developed using soil texture, moisture content, and soil depth (Krag, 1980). The Terrain Sensitivity Classification Methodology for Alberta, considers soil genetic origin, soil texture, clast, organic matter, carbonate, and moisture content (Crockett and Shelford 1982). Singh (1983) in west central Alberta, used infiltration capacity. Knapik and Lindsay (1983) and Corns (1984) considered texture, structure, infiltration, and moisture content. The erosion hazard chart of the predisturbance watershed assessment manual (Alberta Forest Service) uses moisture content (Anderson et al. 1985).

Several reports single out soil factors explaining soil loss. Jeffrey et al. (1968) in the upper Oldman River Basin in Alberta, considered carbonate content to be the most important soil property controlling erosion. Balci (1968) analyzing differences in erosion in western Washington soils, pointed out the influence of organic matter on reducing erodibility. Meeuwig (1971) argued that in the intermountain area of the USA, organic matter helps stabilize clay soils but tends to decrease the stability of sandy soils. Hudson et al. (1985) indicated that in Alberta, organic matter does not appear to bind the mineral particles together and as such, either has no effect on erodibility, or tends to make the soil more dispersive. Dumanski et al. (1972) indicated that fine-textured lacustrine materials in Alberta are easily eroded by water even on gentle slopes.

Soil aggregation (aggregate stability) is considered by many to be the main soil property related to erosion (Bryan 1974, 1976, 1977, 1979; De Meester and Jungerius 1978, De ploey and Poesen 1985). De Meester and Jungerius (1978) considered aggregate stability to be mainly determined by soil properties inherited from the parent material. The cumulative effect of poorly consolidated bedrock is the main soil characteristics believed responsible for the spectacular erosion losses in the Red Deer Badlands (Campbell 1970) and in the Swan Hills of Alberta (Lengelle 1976). Trott and Singer (1983) also found parent material characteristics were important in the erodibility of the California uplands. Twardy and Reid (1984) in Alberta, considered surface texture. Egashira <u>et al.</u> (1985), studying fifteen granitic soil samples from Kyushu, Japan, found texture to be the most important soil factor related to erosion.

A.2 <u>Precipitation</u>

In order for water erosion to take place, there must be runoff or raindrop impact. Runoff occurs when the rate of precipitation exceeds the infiltration capacity of the soil. A direct relationship exists between runoff and soil erosion on steep slopes, where the rate and amount of erosion is affected by the intensity and duration of precipitation (Toy 1977). The other important factor contributing to erosion is detachment of soil particles caused by raindrop impact (Hudson 1971, Young and Wiersma 1973, Brown 1980). Caine (1976), and Bovis and Thorn (1981) found that surficial erosion is accomplished primarily by rainsplash in alpine areas. Even at low rainfall intensities (< 5 mm/h) measurable amounts of rainsplash soil movement took place (Kneale 1982). Morgan (1978) presented a different opinion, pointing out that on sandy soils only 0.06% of the rainfall energy contributes to splash erosion adding that the major role of splash action is in the detachment of soil particles prior to their removal by overland flow. Wischmeier and Smith (1978) used raindrop energy in developing a rainfall erosivity factor in the USLE. Experimentally they found the energy delivered by a rainstorm can be estimated from hourly rainfall intensity. Crockett and Shelford (1982) used precipitation amount and intensity in their terrain sensitivity classification methodology, to divide Alberta into five precipitation zones combining high, moderate, and low precipitation values. Toogood and Newton (1955) reported rainfall intensities in Alberta were low compared with other areas, and based on results from erosion plots concluded that water erosion in Alberta was not serious (Toogood 1963, Chanasyk 1983). Rutter (1968) in a study on the Alberta foothills, ranked precipitation as secondary in importance as a cause of erosion. Twardy and Corns (1980) reported rainfall from summer storms in the Wapiti area of Alberta was not intense or long-lasting enough to create runoff and erosion problems. Luk (1975), taking into account the soil moisture regimes in Alberta, suggested low intensity storms might cause some runoff in the spring but probably not in mid-summer. Wyldman and Poliquin (1973) and Campbell and Honsaker (1982), however disagreed and argued summer rainfall was the most important source of erosive shear stress in the Swan Hills and the Red Deer Badlands. Schulco

(1973) pointed out the high erosion potential of rainfall in the Edson Forest.

Snowmelt runoff is another form of precipitation contributing to soil erosion. Tigerman and Rosa (1949), said that melting snow on frost-penetrated soil on steep, sparsely vegetated slopes caused erosion from miniature mudflows on southwest exposures in northern Utah. Haupt (1967), points out that a rapidly melting snowpack over soil containing dense frost may accelerate on-site runoff and thus, increase erosion risk. Twardy and Corns (1980) stated that in the Wapiti area of Alberta the major erosion agent was spring snowmelt. Wischmeier and Smith quoted by Warrington (1980), observed that in the Pacific Northwest, up to 90% of the erosion on deep, loessal agricultural soil is associated with surface thaw and snowmelt runoff. McCool (1984), working in the same region, reported that about 50% of the annual soil loss was due to runoff from rainfall and snowmelt on frozen soil. Chanasyk and Woytowich (1983, 1986), in a study on agricultural lands in the Peace River region of Alberta, reported springmelt was a time of high erosion potential. The authors indicated 90% to 95% of the total annual soil loss occurred during springmelt.

In contrast to most observations in Alberta, Wyldman and Poliquin (1973) in the Swan Hills, and Campbell and Honsaker (1982) in the Red Deer Badlands, found that losses from snowmelt runoff were small. However, Kathol and

McPherson (1974), and Martz (1978) observed considerable erosion occurred during spring runoff in the Swan Hills, and Spring Creek, in north central Alberta, respectively.

A.3 Slope features

Slope provides elevational differences which allow gravity to supply energy for running water, rock falls, landslides, snow avalanches, etc. (Crockett and Shelford, 1982). According to Hudson (1971), the starting point for numerical expression of erosion was probably A.W. Zingg's work, "Degree and Length of Land Slope as it Affects Soil Loss in Runoff", published in 1940. Subsequent work resulted in the Slope-Practice Equation (Hudson 1971) which included slope and farming practices as the most important variables for soil erosion prediction. This equation was used for nearly 10 years until replaced in the late fifties by the USLE.

Slope angle, length, elevation, aspect and form affect soil erosion in different ways. As slope angle increases the downslope component of force acting on soil particles or water molecules increases. In the case of a water molecule, there is greater acceleration in the downslope direction. Consequently, the molecule is more likely to flow across the surface than to infiltrate into the soil (Toy, 1977). It is generally accepted that, other things being equal, the greater the angle the higher the soil loss (Musgrave 1947, Hudson 1971). But not all studies agree with this statement

(Evans 1980). Leopold et al. (1966) in New Mexico found that on certain hillsides the greatest rates of erosion occurred on the less steep slopes. He concluded that erosion increases with slope to a maximum at 40° and then decreases. Luk (1975) studying soil erodibility in southern Alberta, found no significant effect of slope angle on soil losses. Bryan (1979) pointed out that in a study by Horton (1945), a progressive decrease in soil loss with slope angles above 20° occurred. Bryan's explanation of this situation was a deficiency of erodible material and disappearance of uniform turbulent flow at higher slope angles. Morgan (1983) observed that slope angle appeared to influence soil loss at high erosivity conditions and on slopes that were either very steep (> 36%) or very shallow (< 5%) but on moderate slopes the relationship is unclear.

The role of length of slope is generally overshadowed by slope angle, but it may become important for slopes at moderate to low angles (Crockett and Shelford 1982), or during high intensity storms (Toy 1977). According to Brown (1980), elevation and aspect are physiographic variables which affect soil erodibility indirectly through their influence on soil development. Willen (1965) found that a granodiorite soil at 2300 m asl was 2.5 times more erodible than a similar one at 660 m. Diseker and Richardson (1962) in Georgia found aspect to have the most significant effect on erosion. Aspect can produce extreme microclimatic variability over short distances affecting the level of incoming radiation, the range of temperature and the availability and storage of moisture (Crockett and Shelford 1982). Spence (1972) studied the relationship between erodibility and aspect in south central Alberta, and found aspect was related to soil depth, infiltration rate, moisture content, soil strength, aggregate stability, carbon content, and percentage of bare ground.

Churchill (1982) observed that variations in geomorphic processes in the White River Badlands of South Dakota, can be explained in large part by aspect-induced differences in moisture regime. In this area, north-facing slopes maintain higher and less variable moisture levels, and greater drainage densities than south-facing slopes. Haigh and Wallace (1982) stated that the importance of slope aspect is a consequence of differential frost action.

The shape of a slope may be convex, concave, straight line or a combination of these. These shapes affect land use activities mostly because of their influence on water behavior (Hewlett 1982). The USLE's Length-Slope (LS) factor is considered to overestimate soil loss from concave slopes and underestimate the loss from convex slopes (Mitchell and Bubenzer 1980). Thornes (1980) stated that slope, as the interaction between angle and distance, had important effects on the total magnitude of erosion. He showed results where erosion rates on convex slopes were five times those on uniform slopes. The importance of slope as a parameter in erosion calculations is shown in several equations and methods like the USLE's LS factor (Wischmeier and Smith 1978). As mentioned before, slope is used by Krag (1980) for defining erosion-hazard classes for the Kootenay area, B.C. In Alberta, slope was used by Rutter (1968), Schulco (1973), Bayrock and Reimchen (1974), Kathol and McPherson (1974), Twardy and Corns (1980), Crockett and Shelford (1982), Knapik and Lindsay (1984) and Anderson et al. (1985). Rutter (1968) concluded that slope was the single most important external factor controlling soil erosion on vegetation free areas of the Alberta foothills.

A.4 Forest cover

Erosion is usually reduced on fully vegetated watersheds (Kittredge 1948, Colman 1953, Molchanov 1960). The forest canopy intercepts precipitation and usually reduces raindrop impact, but the most important protection against raindrop impact is provided by forest litter on the soil surface (Lowdermilk 1930, Chapman 1948, Hudson 1971).

Kiil (1971), Golding and Stanton (1972), and Hillman and Golding (1981) indicated that the spruce-fir forests of the eastern slopes of Alberta, have forest floor thicknesses of up to 61 cm. Hence, Alberta foothills on undisturbed state have high erosion protection because of thick litter layers.

Packer (1951), demonstrated that in relation to soil protection and erosion, not only the percentage cover of canopy and litter is important but also the maximum size of bare spots. Marston (1952) on an aspen site, found that a ground cover of at least 65% to be necessary for effective control of overland flow and erosion during major storms in northern Utah. Meeuwig (1970a) in mountainous rangelands of Utah, Idaho, and Montana found that the magnitude of soil erosion depends primarily on the proportion of the soil surface protected from direct raindrop impact. He also observed (Meeuwig 1971) that the amount of cover required to achieve a given level of soil stability is strongly influenced by slope gradient. Tsukamoto (1975) in a study at the Aichi Forest in Tokyo, found that 3 years after the removal of forest litter the H layer became very thin and hard, and that it had been washed away from one third of the watershed area. Also, infiltration capacity decreased drastically and peak runoff increased substantially. Evans (1980), noted than runoff and erosion increased rapidly on soils with less than 70% vegetative cover. Page (1974) observed in Newfoundland that cover type had a very strong influence on soil properties at or near the surface, but only a weak influence at greater depths. He pointed out that semi-mature black spruce stands induced the greatest accumulation of surface organic matter. Significant differences in soil properties also exist between clearcut areas, young stands, and semimature stands for both black spruce and balsam-fir cover types. Coats and Miller (1981) in northwestern California, said that accelerated erosion is more likely to occur if the slopes are vegetated with Douglas-fir rather than redwood, since redwood root systems remain viable, while Douglas-fir roots decay and lose their capacity to contribute to soil stability.

B. Soil erosion and timber harvesting

Erosion rarely occurs in an undisturbed, forested watershed. Surface or mass erosion on forested slopes usually occurs after intense rainstorms where the soil has been previously exposed by logging (Hillman 1971). The extent of erosion depends on the level of disturbance and exposure of mineral soil.

The particular method of logging employed can have a significant impact on the amount of soil disturbance and erosion. Tractor logging causes far greater soil disturbance than other methods (Dyrness 1966, Bell et al. 1974, Rothwell 1978, Siddle 1980, Klock 1982, Krag 1984). On-site impacts created by the use of this equipment depend greatly on operating conditions, type of machinery used, volume of timber removed, size of logs and post harvest soil treatment (Rice et al. 1972, Siddle 1980).

Smith and Wass (1976) found that 45% was the greatest exposure of mineral soil in the Nelson Forest, B.C. This amount of disturbance occurred with summer ground skidding, mostly from skidroad and haul road construction. Rothwell (1977) indicated that the average clearcut area exposed in Marmot Creek, Alberta, was 32%. Skid roads accounted for 58% of total disturbance, access roads 24%, and landings 18%. High soil exposure occurred where skidding and truck traffic completely removed the litter-duff layer. Krag (1984) in Nelson B. , found average soil disturbance percentages for groundskiding ranged from 40.4% to 45.4%. Wasilciw (1985) found 38.5% soil exposure in cut block 8 in Wampus Creek, Tri-Creeks, Alberta. Hudson et al. (1985) found that upland erosion in Tri-Creeks was largely limited to disturbed areas.

Post-harvest treatments for site preparation create high amounts of soil disturbance as well. Depending on the method of measurement, the area of mineral soil exposed by mechanical scarification in Alberta ranges from 40% to 65% (Ferdinand 1983). On level terrain, this practice does not have adverse environmental effects; on sloped areas with thin soil, soil erosion potential is high. Testing six forest-site conditions in eastern Texas, Chang et al. (1982) found soil losses increased as follows : undisturbed forest, thinned (50%), clearcut without site preparation, clearcut chopped, clearcut KG bladed, clearcut cultivated. However, soil disturbance and exposure does not necessarily generate soil erosion. Rothwell (1977) observed that in Marmot Creek, soil erosion on roads and cut blocks was very low. In this area summer precipitation averaged 356 mm and slope 18%.

If yarding is done with care, logging operations usually result in minor erosion compared to road construction, (Rice et al. 1972). Logging roads are the chief source of erosion and sedimentation in Alberta forests (Eastern Rockies Conservation Board 1968, Hillman 1971, Crossley 1972, 1975; Schulco 1973; Rothwell 1974, 1978, 1979, 1983). Road construction and use contribute 80-90% of total erosion in forested areas (Bell et al. 1974, Anderson et al. 1976). Lesser percentages have been reported by Swanson and Dyrness (1975) and McCashion and Rice (1983).

Swanson and Dyrness (1975) indicated that in the H.J. Andrews Experimental Forest in Oregon, road right-of-way and cut blocks contribute about equally to erosion by landslides. McCashion and Rice (1983) found that on 30,000 acres of commercial timberland in northwestern California, 40% of the total erosion was derived from the road system. Reid et al. (1981) in the Clearwater River basin in Washington, determined that surface erosion produced about 20% of the road-related sediment.

Another cause of disturbance is logging operator experience and efficiency (Rice and Datzman 1981, Hammond 1984, Brown and Beschta 1985). Poorly trained workers and poorly supervised logging can increase disturbance levels and erosion.

C. Erosion-hazard ratings and erosion research

According to Hewlett (1982), erosion hazard describes erosion potential by regions, localities and land use, and r[illegible]cts the combined effects of erodibility (the material subject to erosion) and erosivity (the erosive agent). In many erosion-hazard ratings studies where the study area is small the erosive agent is assumed to be constant, and erosivity is ignored in favor of soil erodibility ratings only (Anderson et al. 1982). In situations like this erosion-hazard ratings have strict local applicability.

From a practical point-of-view erosion-hazard ratings are planning tools for the land manager or forester (Dunne and Leopold 1978, Rice and Gradek 1984). Mitchell and Bubenzer (1980) indicated that soil loss prediction techniques have developed over many years as understanding of erosion processes has expanded. This process has evolved from qualitative and single-independent variable estimates to multiple factor equations and models now in use. Earliest developments occurred in agricultural areas and rangelands. Progress was easier in this conditions than in forest environments for a variety of reasons (Dunne 1983).

The accumulation of data and advances in soil erosion research in the United States culminated in the USLE equation (Wischmeier and Smith 1978), which is widely used and has been adapted to other countries and environments (Hudson 1971, Kirkby 1980). The USLE was developed to estimate water surface erosion by rainsplash and sheetwash on agricultural lands with gradients less than 20%. The formula describing the USLE is :

$$A = R \times K \times L \times S \times C \times P \quad , \quad \text{where :}$$

A = soil loss (tons/acre/year)

R = rainfall erosivity index

K = erodibility factor

LS = slope angle and length factor

C = cultivation practices factor

P = conservation practices factor

The USLE has recently been applied to forest lands (Dissmeyer and Foster 1980, 1985). However, this application is not accepted by some researchers, especially when used on steep areas (Kirkby 1980, Swanson et al. 1982). According to Swanson et al. (1982), overland flow is rare in (temperate) forested landscapes. The surface erosion processes that do operate may have very different relationships between transfer rate and slope length, rainfall characteristics, soil characteristics, and slope gradient than those relationships described by the USLE.

The necessity of methods to quantitatively estimate forest soil erosion potential was expressed by Dyrness (1967). Dunne and Leopold (1978) mentioned that the best way of predicting soil loss is using local field data representative of the range of conditions in the area of interest. Chisci (1981) observed that field measurements under natural conditions are necessary to validate forecasting models or to assess factors related to land management. Dunne (1983) stated that much remains to be understood about erosion in forests, and it is far from possible to put together a convenient but realistic technique for predicting erosion with little or no fieldwork. He felt that the prediction of erosion and sediment in forests at present is qualitative, or at best only semi-quantitative.

Rice and Gradek (1984) reviewed erosion-hazard ratings in California and reported those used from 1974 to 1982 were inadequate for estimating erosion potential. This was partially because none of the three ratings used were validated before adoption. They emphasized the importance of real data, and not merely codified professional opinion. To this, Dunne (1983) added that it is important to achieve more interaction between empirically-oriented fieldworkers and theoretical modelers. The cooperation of these groups from the earliest phase of a field project would greatly enhance the value of the results. He mentions there are reasons to believe that some models are not only inadequate, but that they grossly misrepresent processes of runoff and sediment delivery.

C.1 <u>The situation in Alberta</u>

Most water erosion research in Canada (including Alberta) relates to agricultural soils (Luk 1983). In the

Prairies wind erosion has been historically more important than water erosion (Palmer 1947, Goettel et al. 1981, Dumanski et al. 1986). Only recently, have concerns with soil losses related to water érosion developed. The first quantitative data were collected in 1949 in St. Albert from erosion plots (Toogood and Newton 1955). The results of these studies indicated water erosion in Alberta was not serious because of low rainfall intensities (Toogood 1963, Chanasyk 1983). Recent studies however, indicate that water erosion is a problem.

Quantitative studies aimed at erosion modelling and prediction began in 1981 in the Peace River region (Chanasyk and Woytowich 1983, 1984, 1986) including rainfall and snowmelt runoff erosion and erodibility. Other quantitative experiments are in progress in east central Alberta (Howitt 1985). Lately, several studies have focused on the adaptation of the USLE to Alberta and the Prairies (Tajek et al. 1985, Kachanoski and de Jong 1985). Computer maps of erosion potential throughout Alberta were developed using the USLE adaptation of Tajek and Pettapiece (1985), and provincial soil data (Desjardins et al. 1985).

The Swan Hills and the Red Deer Badlands are non-agricultural areas that have been studied intensively. The Swan Hills, have been highly disturbed as a consequence of natural gas and oil exploitation. Disturbance and erosion in the area have been described by St-Onge and Lengelle (1971) and Lengelle (1976). Quantitative measurements from erosion-runoff plots and from a suspended sediment monitoring program on the Swan River, were taken over a five year period by Wyldman and Poliquin (1973). Rates of erosion obtained in four plots from May to October of 1978, 1979, and 1970 ranged from 26.2 to 103.9 tn/acre. Surficial geology and erosion potential studies of the Swan Hills were done by Bayrock and Reimchen (1975), and erosion susceptibility maps were prepared by St-Onge (1974).

Badlands are areas almost devoid of vegetation in which a relatively unconsolidated but impermeable geological material enables an extremely fine drainage network and erosional and depositional forms to develop quickly under conditions of rapid runoff (Campbell 1970). The Red Deer Badlands located in south central Alberta, have been used as an ideal region for studying the operation and effects of geomorphic processes. Measurements of sediment yield, runoff characteristics and surface erosion rates have been taken (Campbell 1970, 1973, 1977, 1978; Campbell and Honsaker 1982). Data on erosion rates were mostly collected using erosion contour-plotting frames (Campbell and Honsaker 1982).

Laboratory and field experiments using rainfall simulators have also been conducted on Alberta soils (Bryan 1974, 1976, 1977; Luk 1975, 1977, 1979). Bryan (1974) considers field soil-loss rates can not reasonably be estimated in the laboratory. Nevertheless, as the controlling variables in the laboratory are similar to those in the field, it is reasonable to expect that the relative erodibility of field soils can be reproduced in the laboratory. Luk (1975, 1983) said that the results of field and laboratory experiments conducted using rainfall simulators suggest a reasonably high level of compatibility. However, Summer (1982) argued that field measurements are the most satisfactory method of estimating an erodibility index, and laboratory surrogates are not readily applicable.

Assessment of the erosion problem through sediment yield estimates has been performed in several Alberta watersheds (McPherson 1975, Neill and Mollard 1982).

Hudson (1983) used runoff plots to investigate the consequences of vegetation removal in the Muskeg River basin in northeastern Alberta, preceding oil sand mining. Runoff plot responses to summer convectional storms suggested that stripping of the muskeg cover would result in flashier runoff and increased erosion.

Among the reports dealing with erosion in forested land, the method most frequently used was sediment sampling. Rothwell (1974, 1977, 1979, 1983) measured suspended sediment resulting from seismic lines and roads in the Hinton area and in the Marmot Creek Experimental Watershed. The Hinton studies showed that the sediment contribution of road-stream crossings was twice the amount from seismic lines, mainly because roads were more constantly used and seismic lines were better reclaimed by surrounding vegetation. Average values of sediment sampling in Hinton ranged from 26 to 105 kg/ha/day during non-storm conditions, and from 161 to 400 kg/ha/day under storm events. In the Marmot Creek area the objective of the research was to demonstrate that water quality deterioration associated with clearcut harvesting could be prevented by careful planning of road construction and logging. Field observations revealed that mineral soil exposure affected 25% of the total area, and that 32% was the average soil exposure on cut blocks. Mean summer sediment yield was very low, averaging 30 kg/ha. Very little erosion and no sediment transport towards streams were reported in association with roads and logging. A comparison of Hinton and Marmot Creek areas shows the Hinton's erosion process more active and hazardous.

Luk (1975) in an extensive study of soil erosion characteristics in parts of the Bow basin in southern Alberta, included both field and laboratory tests of soil loss, covering both mountain and prairie areas. Rainfall simulation and natural rainfall experiments had good correlation. He found runoff plot erosion rates ranging from 6.1 to 94.5 g/m2. Forested areas were not sources of sediment supply.

Martz (1978), and Martz and Campbell (1980) studied the sediment regime of Spring Creek watershed in north central Alberta. Streamflow records, suspended sediment, solute concentration measurements, and geotechnical activities in the area were analyzed. They found that 76% of the annual sediment yield occurs during spring runoff and the sediment discharge of 18 days per year accounted for 90% of the annual sediment yield. When spatial and temporal aspects are considered, over 80% of the sediment yield is derived from 15% of the watershed area (112.7 Km2) in less than 5% of the time. Measured mean sediment yield of Spring Creek Watershed was 3483 tn/year.

Jablonski (1980), Wasilciw (1985), and Hudson et al. (1985) conducted erosion research in the Tri Creeks Experimental Watershed. Jablonski (1980) collected suspended sediment samples from the three sub-basins, Deerlick, Wampus and Eunice from spring break-up to the end of September, from 1968 to 1977. An access road was constructed in 1974 in Deerlick. Following road construction the sediment picture changed dramatically as the highly erodible lacustrine soil was moved by surface runoff into the creek. This happened even though the road was at least 100 m away from the creek. Wampus Creek also showed increasing turbidity and sediment concentrations in records taken downstream from old road crossings. Deerlick's response to a short, intense rain storm (16-fold increase in sediment concentration) in comparison with both Wampus and Eunice's response (drop in concentration), shows that undisturbed watersheds can buffer the effects of intense storms while roads in disturbed watersheds actually concentrate and funnel sediment into streams. Tri Creeks' soils are considered to be less stable than those of Marmot Creek.

Wasilciw (1985) in Wampus Creek found the only significant source of sediment to be a slump. He concluded the cutover areas did not contribute sediment to the stream because of low precipitation during the sampling period. Hudson et al. (1985) described the nature and locations of existing erosion processes in Tri Creeks and investigated the relationship between soil and landscape properties with observed erosion. Using the USLE's K factor he found erodibility indices ranging from 0.28 to 0.42.

Anderson et al. (1982) studied the erodibility of soil groups of the Grande Prairie Forest, and ~~reported a~~ wide variability within each soil group. They also found that sediment loss was not always inversely related to infiltration rate. Measured erosion averaged 569-1120 g/m2, and 8-26 mm in depth using rainfall simulation and erosion pins respectively.

Erosion-hazard ratings are part of many reports published by several institutions in Alberta. Twenty three were reviewed in this literature survey with about fifteen different erosion-hazard rating methodologies, most of them developed for local use. Three methodologies are of provincial scope. The first study was published in 1968 and the latest one in 1986. A common characteristic of the assessment systems reviewed (with the exception of only one (Luk 1975)), is their lack of practical validation. Field observation and surveying, soil properties and background information are the main basis for these studies. Three reports are based on quantitative data. None were validated after their formulation.

Rutter (1968) developed a method for non-geologists to forecast potential water erosion hazards in the Rocky Mountain Forest Reserve. It is a qualitative method and requires airphoto interpretation and field reconnaissance for determining erosion potential of soils based upon internal and external factors. Important soil properties considered are infiltration rate, texture, carbonate content, and the binding strength of silt and clay. External factors included slope angle and precipitation. Currie (1976) used Rutter's method in Tri Creeks.

Jeffrey <u>et al.</u> (1968) presented a land-vegetation typology for the Upper Oldman River Basin. The authors did not intend an erosion potential classification of the soils. However, they note that the most important distinction found among surficial deposits and soils was between calcareous and non-calcareous deposits; the former being resistant and the latter more susceptible to erosion when subjected to disturbance activities. Gradations between carbonate-rich and carbonate-poor materials are presented.

Dumanski et al. (1972) in their soil and land evaluation of the Hinton-Edson area, presented a local potential erosion classification that is the model for several others. They define potential soil erosion as the expected rapidity and amount of soil loss by wind or water, that can be expected following removal of protective vegetation without proper erosion control measures. The authors rated soil erosion into classes of high, moderate, and low. Besides soil properties they also considered precipitation, slope, and nature and permeability of soil parent material.

Schulco (1973) reporting on the environmental effects of logging in the Edson and Grande Prairie Forests, present two types of erosion prediction : erosion sensitivity and watershed sensitivity. Erosion sensitivity uses the combined effects of material stability and slope. Watershed sensitivity was obtained by the introduction of summer precipitation (erosivity) as an additional factor. Forty watersheds within the project area were classified in terms of soil stability, summer precipitation, location relative to summer storm tracks, and intensity of storm precipitation. A watershed sensitivity index for harvest planning was developed on the basis of these combined variables and the watersheds were rated from high sensitivity (H) to low sensitivity (L).

Kathol and McPherson (1974) studied the stability of geologic deposits in the House Mountain area of north central Alberta. They rated the erosion susceptibility of these materials from least erodible to most erodible as follows : muskeg, gravel, coarse sand, till, clay, shale, fine sand, and sandstone. They presented a map of erosion potential and suggested it may be used as an aid in formulating local land use plans. However, on-site inspections are recommended wherever development occurs in order to assess the erosion hazards of particular sites. The factors they consider to affect the susceptibility of geologic deposits to erosion are : geologic materials, slope, cover, soil type, groundwater, time and climate.

Luk (1975) developed relative erosion rates for parts of the Bow River basin, based on mean soil erodibility, mean ground slope, mean vegetative cover density and relative rainfall erosivity (relation between slope and lab simulated soil loss). Reasonable consistency was found between computed results and available sediment yield records. Quantitative field and laboratory erosion measurements were used to support the erosion ratings.

Bayrock and Reimchen (1975) developed an erosion potential classification for the Alberta foothills north of 52°N latitude. They defined erosion potential as the probability of a certain deposit to undergo significant erosion following removal of vegetation and/or general disturbance of the surface. In this erosion-hazard study, soil stability and slope steepness were considered. Using 243 field observations, erosion was classified into three groups: no erosion, erosion just beginning, and severe erosion. Percentages of instability (i. e. erosion) were determined using the combined erosion groups. Materials with less than 10% are considered stable, between 10 and 50% materials are considered metastable, and materials > 50% are unstable. Erosion potential maps were produced combining slope classes (0-14%, 15-44, > 45%) with surficial material stability classes.

Twardy and Corns (1980), Turchenek and Lindsay (1982), Knapik and Lindsay (1983), and Twardy and Reid (1984), studied the Wapiti area, the AOSERP area, the Iosegun Lake area, and the Bonnie Lake area respectively. They all presented soil units stratified by slope steepness and, in general, followed the Dumanski et al. (1972) approach. Twardy and Corns (1980) gave special consideration to the phases of soil units and Twardy and Reid (1984) to surface texture.

Anderson et al. (1982) reported on a quantitatively based erosion-hazard ranking of seven soil groups in the Grande Prairie Forest using rainfall simulation and point erosion plots. They found moderate to severe levels of erosion potential that compare favorably with Twardy and Corns (1980) results in the same area.

Crockett and Shelford (1982) proposed a technique for classifying the landscape into areas of similar "inherent sensitivity" : the capacity of a physical unit of land to withstand external forces acting on it and, if disturbed by these factors, the ability to recover and establish a new equilibrium. It is emphasized that the resulting sensitivity information does not replace investigation for site-specific decisions. The inherent site factors this technique considers are : genetic origin, texture, clast, soil organic matter, carbonate, and moisture content, slope characteristics, bedrock and overburden instability, and water table level. The external site factors are : amount and intensity of precipitation, wind, temperature, vegetation density and type, hydrologic factors, and geographic position. All these factors are considered individually and then are combined following a defined procedure to produce the sensitivity rating for each physical land unit.

This method has been applied to the assessment of three areas. Shelford <u>et al.</u> (1982) present a case study for demonstration purposes of two sites in Township 61, Range 3 west of the 6th meridian. McDade (1983) uses this method for predicting the effect of oil and gas exploration and timber harvesting in Bull Creek watershed in the Grande Prairie Forest. Kocaoglu and Hay (1985) use the terrain sensitivity classification with some modifications in the Dry and Easy

Creeks watersheds. In this study surface texture and slope angle are the main factors considered. Overburden instability and drainage characteristics (organic units) are also taken into account. The combined effect of erosion related factors is qualified by the addition of their respective codes. Series of erosion potential rating classes from 1 to 7 for vegetated and unvegetated conditions are presented. Major and minor factor codes for each site are displayed.

Hudson (1983) in his study in the Muskeg River basin, presents an erosion prediction system using the USLE, with supporting of quantitative data. Three runoff plots established in representative surficial material areas provided the data. He found that sediment yield is reasonably well predicted by the USLE using a single storm approach. The fact that snowmelt and gully erosion are not considered in the USLE prediction is mentioned as a deficiency of the method.

Corns and Annas (1984) presented an erosion-hazard rating for an area encompassing the Wapiti, Iosegun, Hinton-Edson, and part of the Mount Robson areas of west-central Alberta. They developed the ratings using soil texture, infiltration and permeability, soil structure, soil wetness, and slope angle, where surface organic layers have been removed. They indicated that generalized relative erosion-hazard ratings for soils under a plant association must be made assuming average rainfall intensity and rate of spring snowmelt.

Hudson et al. (1985) developed a erosion potential classification for Tri Creeks, by means of a detailed soil survey and analyses of soil properties. They used the USLE's K index in combination with the LS factor. The soils were classified from moderately to very highly erodible.

Anderson et al. (1986) presented an erosion-hazard chart whose purpose is to assist when detailed cut-block planning is required in sensitive areas. The chart is a simple combination of slope angle and moisture content (dry or frozen, and wet). Three levels of hazard are identified, low, moderate and high. The low rating includes slopes less than 25% in dry or frozen areas. Moderate risks are assumed for dry or frozen soils in slopes up to 45% and wet soils of up to 25% steepness. High erosion potential is assumed for dry or frozen soils in terrain steeper than 45%, and on wet soils on slopes over 25%.

SINGH'S EROSION-HAZARD RATING METHOD

Singh's (1983) method is the latest regional erosion-hazard method developed in Alberta for forested areas. Its simplicity makes it a potential tool for land use and harvest planning in west central Alberta. The fact that the forests in this area are accessible, well studied, and have been logged for more than 30 years, make this method suitable for analysis and testing .

A. <u>Description</u>

Singh's (1983) method uses forest cover types as indicators of erosion hazard. Three forest types are identified in Singh's method which in turn are stratified into 18 soil associations, for which infiltration rates are determined. Erosion hazard is estimated based on infiltration rates. High hazard was equated to low infiltration rates and low hazard was equated to high infiltration rates.

Infiltration rates were determined with a double-ring constant head infiltrometer (Adams <u>et al.</u> 1957) under each forest cover on undisturbed litter surfaces. Six runs were made for each soil association in each forest cover type. Steady state infiltration rates were usually obtained within the first hour. Second-hour rates were assumed to be the steady state infiltration rate. Analysis of variance of the infiltration rates was used to test for significant differences between soil associations and forest types.

Three forest types were utilized in Singh's study : lodgepole pine (*Pinus contorta* Doug. var. *latifolia*), spruce-fir (*Picea glauca* (Moench Voss, *Picea mariana* (Mill.) B.S.P. - *Abies lasiocarpa* (Hook) Nutt), and aspen (*Populus tremuloides* Michx.). Mean infiltration rates for lodgepole pine, spruce-fir, and aspen vegetation types were respectively 14.20, 2.08, and 7.19 cm/hour. These results suggested low erosion susceptibility for lodgepole pine sites, very high susceptibility for spruce-fir forests, and moderate susceptibility for aspen forests.

Singh concluded that a soil type often has a different infiltration rate under a different forest cover due to the modifying influence of vegetation.

Singh recognized the simplicity of his system and the influence of other site and climatic factors on erosion, but considered that reasonable estimates and rating of erosion susceptibility can be obtained from the infiltration capacities of the soil types under a dominant vegetation cover, and that such rating of land units can serve as a first approximation for planning purposes.

B. Weaknesses of Singh s method

1. Use of forest tree species as an indicator of erosion susceptibility.

This characteristic of Singh's method is not a weakness by itself but a technique virtually not used, perhaps because plant indicators are not exact indices. However, plant species are considered an expression of total environment (Singh 1969), and have been used as indicators for ecological studies (Hill et al. 1975, Kojima 1984, Anderson 1986), forest site quality assessment (Brinkman 1936, Pluth and Corns 1983), soils and land use classification (Wilde and Leaf 1955, Duffy and Nemeth 1969, Prokopchuk and Archibald 1976, King 1977), slope stability indexes (Rice 1977, Thomas 1985), evaluation of stream channel processes (Gurnell and Gregory 1984), water table levels and groundwater flow regime (Currie 1976), soil permeability characteristics (Arnett 1976), soil moisture and dynamic source area interpretations (Satterlund 1967, Gurnell 1978, 1981; Winkler and Rothwell 1983).

Satterlund (1967) believed forest types may be useful indicators of potential runoff areas only on a local basis. He mentions vegetation indicators should be used with discretion. King (1977) emphasizes plant indicators can only be used after very careful ecological studies.

Reports of plants as indicators of surface erosion are rather uncommon in North America. However, Korzhenevskii et al. (1983) in a complex study of ecological conditions and floristic composition of plant communities in the Flysch low-mountain region of Crimea, Soviet Union, established a relationship between the rate of slope processes and vegetation, which suggests vegetation may be used as a local indicator of the current slope denudation rate, with complementary information.

2. Forest types are more a reflection of differences in soil moisture or site wetness than erodibility.

Early studies of forest types in Alberta (Brinkman 1936, Moss 1953, Duffy and Nemeth 1969) reported the association of lodgepole pine with dry sites and spruce-fir with wetter sites. Later studies supported these observations (Dumanski <u>et al.</u> 1972, Currie 1976, Prokopchuk and Archibald 1976, Corns 1983, Pluth and Corns 1983, Kojima 1984, Hudson <u>et al.</u> 1985). A more likely conclusion from these reports is that lodgepole pine indicates drier, better drained sites, and spruce, especially black spruce, indicates higher soil moisture contents and wetter sites. Thus, it would be easier to state that forest types in Singh's study are direct indicators of soil moisture rather than of erosion susceptibility.

3. Use of ring infiltrometers and variability of infiltration in forest soils.

Infiltration measurements obtained with ring infiltrometers are different from those under natural conditions (Singh 1979), but are considered acceptable for comparative purposes (Branson <u>et al.</u> 1972, Hibbert 1976). Measured infiltration responds to the actual conditions of soil, among which antecedent soil moisture is important, (Molchanov 1960, Hillel 1982) especially in relation to rainwash erosion (Luk 1985). A lack of consideration of antecedent soil moisture confounds Singh's observations and may have increased the variability of his results. Infiltration is a highly variable soil property (Sharma et al. 1980, Luk 1985). Average prediction errors calculated by Singh (1970) in a linear regression model for predicting infiltration, indicate greater variability in forest lands (12.1%) than for grasslands (8.7%) or shrublands (2.6%). Extreme variability can be observed in Singh's (1983) steady state infiltration rates for soils under lodgepole pine stands. He presents two soil types with the same clay-loam texture which have very different mean infiltration values of 0.75 and 44.40 cm/h. Conditions like these might be related to factors other than vegetation, such as antecedent moisture content or special conditions like soil water repellency (Gifford 1970, Meeuwig 1970, 1971a), soil crusting (Loope and Gifford 1972), or percolation limitations (Molchanov 1960, Lee 1980).

Johnson and Beschta (1980) measured infiltration capacity and erodibility on logged and unlogged watersheds in Oregon. They found heavily disturbed areas had reduced infiltration capacity and increased surface erodibility. In this area equating high erosion hazard with low infiltration was correct, but this relationship is far from universal as noted by Rice (1984) in California and Anderson et al. (1982) in Grande Prairie, Alberta.

4. Infiltration was measured on undisturbed soils.

The main weakness of Singh s approach lies in the fact that he measured infiltration on undisturbed forest floor which is not representative of bare mineral soils. Infiltration rates for bare mineral soils and disturbed soils associated with logging and roads are usually significantly less than rates for undisturbed conditions (Meeuwig 1970a, Bell et al. 1974, Tsukamoto 1975, Johnson and Beschta 1980). Infiltration is also affected significantly by soil properties such as bulk density, aggregation, and moisture content. These properties are strongly affected by removal of forest cover, disturbance of forest floor in harvesting, and post-harvesting operations (Siddle 1980, Chang et al. 1983). Steinbrenner and Gessel (1955) found permeability rates decreased by 35% after logging on cutovers and 93% on forest roads. Donnely and Shane (1986) reported up to a 6.5 times reduction in infiltration capacity after artificially inducing compaction to simulate harvesting operations.

Forest floor characteristics of the Alberta foothills (Brinkman 1936, Kiil 1971, Golding and Stanton 1972, Hillman and Golding 1981) can make undisturbed-disturbed differences even more noticeable. After the forest floor is removed or disturbed, and mineral soil is exposed by logging operations, a totally new microenvironment is created in the open area. On bare soils raindrop impact becomes a factor to consider (Brown 1980). Other microclimatic characteristics at and near the ground related to more direct sunlight, temperature and moisture (Powell 1971, Bell et al. 1974, Sims 1975, Lee 1978, Singh 1986), depth of soil freezing, infiltration and overland flow (Hillman 1971, Harris 1972, Sartz 1973, Bell et al. 1974), may also be important. Therefore, it is not logical to assume that relative differences in infiltration among bare soil units follow the same pattern that they did before harvesting. In particular, infiltration on undisturbed forest soils will not be related to that on disturbed ones, nor to erosion on disturbed forest soils.

5. Snowmelt, erosivity, and slope are ignored.

Another shortcoming of the Singh's proposal is the omission of snowmelt in the erosion rating. As was pointed out before (Kathol and McPherson 1974, Martz 1978, Chanasyk and Woytowich 1983, 1986; Chanasyk 1986) snowmelt possesses a high erosivity potential in Alberta. Freezing of the soil in a saturated or a near saturated condition, will significantly influence infiltration rates (Dunne and Black 1971, Singh and Hillman 1972). Temperature effect of snowmelt on infiltration and soil water retention can also be important (Klock 1972, Lee 1980). Thawing and rainfall during early spring on frozen soils, may develop overland flow and thus erosion hazard. Molchanov (1960) indicates that when there is an ice crust, infiltration on treeless terrain does not exceed 20% of the thaw water within the catchment area, but on forested areas 87% of the waters seeps in.

Erodibility is markedly influenced by erosivity (Morgan 1983). Rainfall intensity and variability are characteristics of erosivity which need to be further considered. Studies dealing with rainfall and summer storms consider rainfall intensity in the area to have erosion potential, and to be highly variable from year to year. A frequency analysis of maximum daily precipitation (Schulco 1973) showed that during the summer about 75% of the heaviest 24 hour rainfall events exceed 12.7 mm and 35% exceed 25.4 mm. Such high frequencies were considered to indicate a high erosivity potential in the area. Webb (1969) points out that summer rainfall is the most variable of all meteorological elements measured at forest fire lookout stations. Powell and MacIver (1976) observed that rainfall amounts in the study area tend to be greater north of the Athabasca River. Hillman et al. (1978) indicate that during 1972-1975, storms in most of the Hinton-Edson area varied between 25 and 60 mm, but extreme events above 100 mm were recorded.

The importance of slope in soil erosion has been considered in the section 4.3. According to Horton (1945), Leopold et al. (1964), Rutter (1968), and Bryan (1979) the high local relief of the foothills and the mean slope angle (25%) of the study area would strongly influence surface erosion processes. According to Morgan (1983), the relationship between slope and erosion on 25% slopes would be rather unclear. In any case, an interaction exists, and the range of slope steepness in the area should be taken into account in any erosion-hazard method to be applied there.

6. Use of soil associations as erosion units.

Soil associations (Dumanski <u>et al.</u> 1972) should not be used as soil erosion units for erosion-hazard ratings. The variability of properties within soil associations is extensive and their distribution over large areas of different topographic configurations, makes them highly heterogeneous. Similar infiltration values for 33 watersheds in the Hinton-Edson area summarized by Hillman <u>et al.</u> (1978), suggest less variability within the Marlboro association (4-5 cm/h) than either the Obed or Robb (5-20 cm/h) soil associations. Several studies in west central Alberta present erosion-hazard ratings for the soil associations considered in this study. A comparison among these reports including Singh's (1983) study is shown in Table 1.

The wide range of qualitative estimates of erosion risk in Table 1, is noticeable for all soil associations. This variability is probably due to the use of soil association subdivisions as erosion units by all authors except

Singh. Variability within soil associations according to Singh is caused by the influences of different forest covers. Infiltration runs performed on these soil association reflect their heterogeneity.

Table 4 Erosion-hazard ratings for the Obed, Marlboro, and Robb soil associations in west central Alberta

Study		Obed	Marlboro	Robb
Dumanski et al.	(1972)	M-H	M-H	M; M-H
Twardy-Corns	(1980)		L-H	
Corns-Annas	(1981)		L	
Hudson	(1985)		L-H	M-H
Singh	(1983)	L-M	M-VH	L

L Low M = Moderate H = High VH = Very High

7. Lack of practical validation

The lack of field testing and practical validation are drawbacks of all except one (Luk 1975) erosion-hazard rating proposed for Alberta. The quantitative field erosion measurements taken in this study provide a first step towards field testing for validation of Singh's system.

IV. STUDY HYPOTHESIS

Due to practical restrictions, the assessment of Singh s work was limited to only 3 out of 12 soil associations, and 2 out of 3 forest cover types he studied. The soil associations considered in this study were Obed, Marlboro, and Robb; and the forest types were pine, and spruce-fir. The null (Ho) hypothesis proposed for testing Singh s method was:

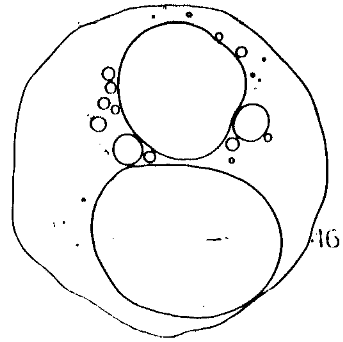
There is no difference in amount of erosion among the Obed, Marlboro, and Robb soil associations under pine and spruce-fir forest types.

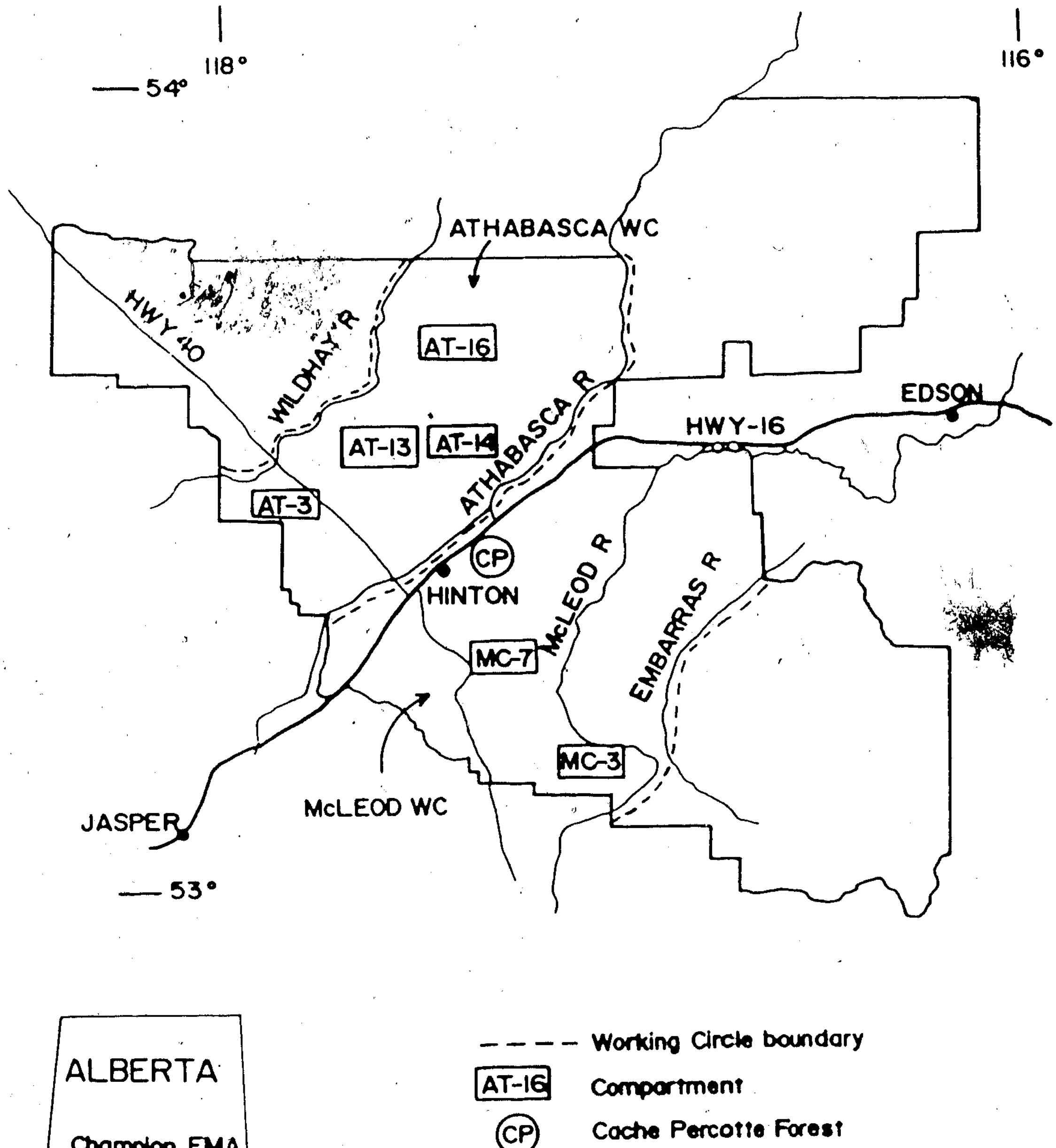
V. METHODS

A. Study area

The area selected for study was in the Edson Forest, on the forest management area (FMA) operated by Champion Forest Products (Alberta) Ltd. The area is around Hinton, which is located 286 Km west of Edmonton, between latitudes 53° and 54° N and longitudes 116° and 118° W (Figure 1). Elevation ranges from 853 m in the eastern portion to about 2621 m in the southwestern part (Hillman et al. 1978). The area is forested with lodgepole pine, spruce-fir, and aspen forests typical of the foothills section of the Boreal Forest Region. According to MacArthur (1968), growing stock over the FMA by areal percentage is 53% lodgepole pine, 19% white spruce ,9% aspen, 8% black spruce, 6% standing dead trees, and 5% alpine fir. The company cuts approximately 4450 ha per year consisting of 60% pine, and 40% spruce-fir (Singh et al. 1974).

The FMA (7770 km^2) is divided into five working circles (WC) for management purposes of which two (Athabasca and McLeod) were considered in this study. Each WC is further divided into compartments and cut blocks (harvesting units). Cut blocks normally are 16-24 ha in size but may be 200 ha or more (Johnstone 1984) depending on economic and silvicultural considerations, stand age, topography and the degree of erosion hazard (Singh et al. 1974). After logging, scarification operations are carried out to facilitate





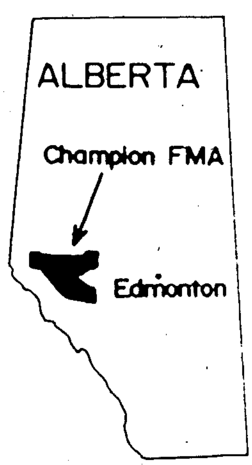


Fig 1 Study area within the Champion Forest Products (Alberta) Ltd. FMA

regeneration. All the cut blocks considered in this study had been scarified. The area has been intensively studied and extensively logged providing background information and a wide range of cut blocks on different forest types and soil conditions for the study. Furthermore the area was an ideal control as it is the site of Singh s (1983) field work.

The climate is continental with long, cold winters and short, cool summers. Annual precipitation averages between 500 and 550 mm of which 70% occurs as rainfall between May and September. Mean annual and summer temperatures are 2-3 and 8-12^{o} C respectively (Swanson and Hillman 1977).

B. Study design

The general study design was to identify a number of logged areas in which soil disturbance and erosion could occur as a consequence of harvesting and site preparation, and to compare levels of natural rainfall erosion on them with the erosion hazard ratings suggested by Singh s (1983) method. To accomplish this a number of conditions were imposed to identify suitable cut blocks.

Conditions considered were :

- Forest types. Three forest types were identified by Singh (1983). In this study only pine and spruce-fir were considered because of the absence of logged aspen stands.

- Soil associations. Three soil associations were identified for testing of the system : Marlboro, Obed, and Robb. Only three associations were considered because of spatial difficulties in identifying similar cut block-soil-vegetation combinations and the logistical problems in sampling a larger number.
- Slope. The sampled cut blocks were restricted to slopes of about 25% to minimize sampling variability and to encompass a commonly found slope type in the foothills area. The slopes of the cut blocks considered in the final results ranged from 21 to 28%. More than 80% of them were 24 to 28%, with a mean slope of 25.13% (CV=7%).

With 1 slope class, 2 forest cover types, 3 soil associations, and 3 replications, identification of 18 cut blocks was required. These cut blocks were located throughout Champion's FMA north and south of the Athabasca River in the Athabasca, (9 cut blocks) and McLeod (7 cut blocks) working circles, and in the Cache Percotte Forest (2 cut blocks), of the Forest Technology School at Hinton (Table 2).

The soil map of the Hinton area prepared by Dumanski _et al._ (1972), maps and field information from Champion Forest Products (Alberta) Ltd., and a Cache Percotte map were used to locate different soil association-forest cover-slope combinations.

Table 2 Cut blocks and plots included in this study

	Soil Association		
Forest cover	Obed	Marlboro	Robb
Pine	AT3-3 (31,32,33) MC3-8 (13,14,15) MC7-70(19,20,21)	AT14-330 (67,68,69) CP 1 (70,71,72) CP 2 (73,74,75)	AT16-847 (34,35,36) AT16-850 (37,38,39) MC7 -57 (25,26,27)
Spruce	MC3-20(16,17,18) MC3-35(28,29,30) MC7-65(22,23,24)	AT14-757 (52,53,54) AT14-758 (49,50,51) AT14-759 (46,47,48)	AT13-772 (43,44,45) AT13-773 (40,41,42) MC7 - 61 (64,65,66)

AT Athabasca working circle
MC McLeod working circle
14-330 (67,68,69) Compartment - cut block (plot numbers)
CP 1 Cache Percotte block located 450 m NE of the main CP road along the CP flume road, on its right side.
CP 2 Cache Percotte block located 300 m SW of the main CP road along a short road, located 50 m ahead the CP flume road, on its left side.
(MC3 Tri-Creeks)

Measurement of erosion was performed by establishing a network of erosion plots on the cut blocks. The plots contained a 0.6 x 0.6 m grid (Figure 2a) of 18 erosion pins 0.25 m long and 8 mm thick with washers, set into the ground. Each plot was 1.4 by 3.2 m in size including a buffer zone of 0. on each side, with all surface vegetation and litter rem to expose bare mineral soil.

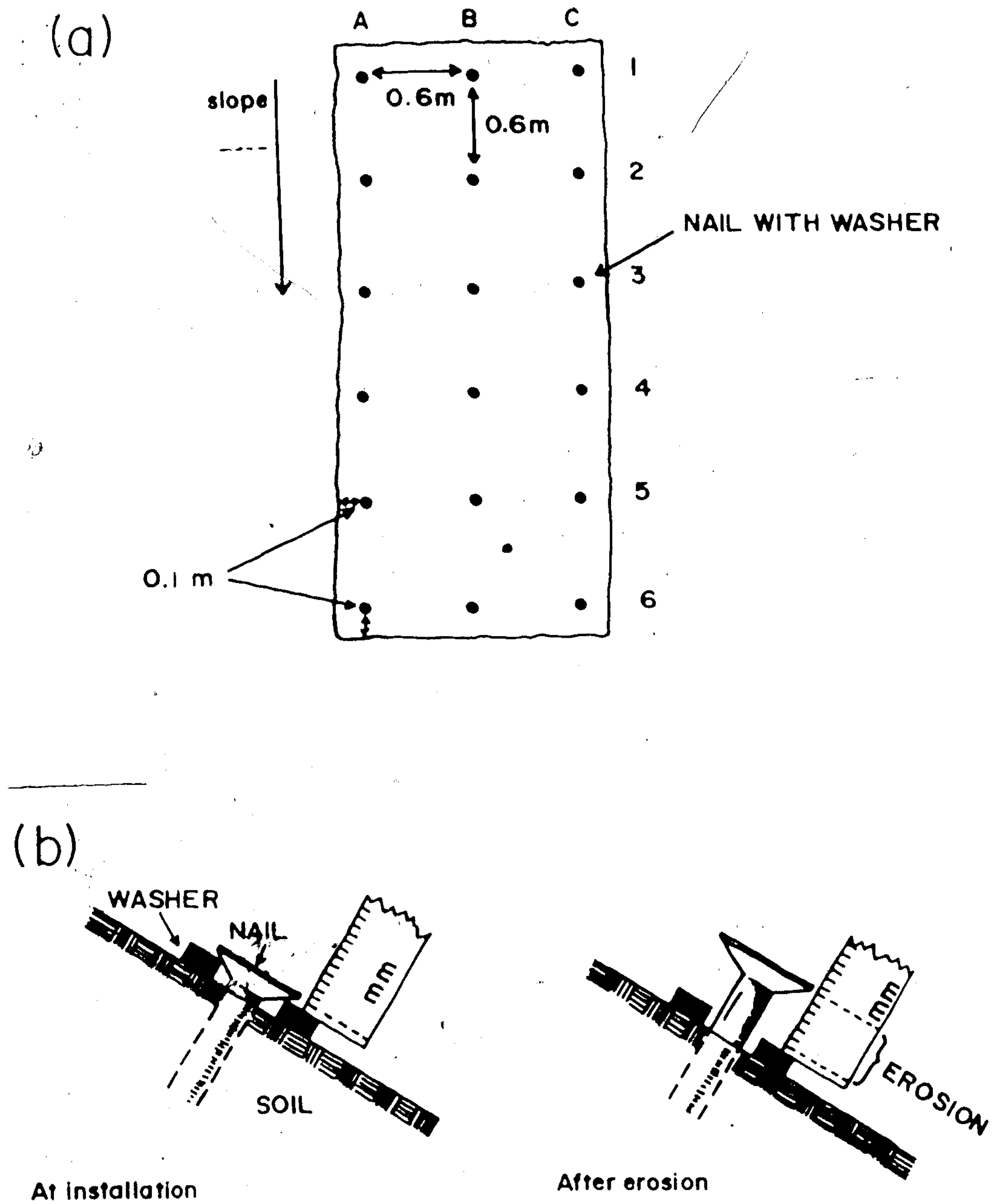


Fig 2 2a Plot layout

2b Measurement of erosion (modified from Dunne 1977)

This was done to simulate logging disturbance and to remove any differences due to different post-logging treatments and different cut block ages and harvesting seasons. Within each sampled cut block, 3 erosion plots were established yielding a total of 54 plots for all 18 cut blocks (Table 2). Time constraints prevented installation of more plots per cut-block.

At the time of installation, the pins were driven into the ground with their heads and washers flush with the ground surface. The initial distance from the head of the nail to the top of the washer was then measured. Erosion was defined as material eroded from around the pin and beneath the washer, which was displaced to a lower position.
Soil loss was calculated by subtracting the initial nail-washer distance from the nail-washer distance after erosion occurred (Figure 2b). The average soil depth washed away in each plot was obtained in mm (Appendix 1). Measurements were taken using a metallic tape with millimetric scale.

Field work began in the summer of 1984 with cut block location and preparation. Plots were installed in early summer of 1985 after frozen soil thawed and dried to an operable condition. During the summers of 1984 and 1985, 75 plots were prepared (on 21 cut blocks) from which 54 were finally chosen. Samples of surface soils (0-10 cm) were taken at each plot for physical and chemical analysis. A qualitative assessment of soil structure (Wischmeier and

Smith 1978) was also made and site parameters of slope steepness using a hand level, and exposure with a hand compass, were also recorded. During the last week of July 1985 a precipitation network using Tru-Check wedge-shaped rain gauges (Huff 1955) was installed.

All plots were ready in an uniform condition on June 23 1985, and were inspected periodically until erosion measurement was carried out September 23, 24 and 25, 1985. Excellent weather and low soil moisture at this time made measurements easier. There was also a field reconnaissance on May 8, 1986 which gave some additional information.

The statistical analysis used in this study consisted of a test for normality (Anderson and McLean 1974), 2 way analyses of variance (ANOVA), a least significant difference (LSD) test, stepwise multiple regression analyses, and a comparison between means (Zalik 1983).

The basic unit of data used in the ANOVAs was the average depth of soil loss per plot in mm and the USLE s erodibility (K) factor. Data were grouped in 3 soil associations, each with 2 forests cover types. In the regression analyses 11 quantitative, independent variables were tested against the erosion values obtained as plot averages. Regression tests were carried out for the whole experiment (n=54 plots), for 3 soil associations (n=18), 2 forest cover types (n=27), and 6 soil-forest combinations (n=9). Stepwise regression analyses were performed assuming that soil, weather, and site characteristics would permit prediction of the amount of soil erosion or would show in a quantitative way, the functional relationships among these independent variables and erosion.

The independent variables tested were : amount of rainfall, slope steepness, texture (M parameter from USLE s K factor), percent of organic matter, USLE's K factor, magnesium content, calcium content and calcium carbonate equivalent percentage. A comparison between means was used for testing differences in aspect classes grouped as potentially erosive and potentially non-erosive. Most of the statistical tests were done using the SPSSx system (SPSSx Inc. 1983).

C. Measurement of erosion using erosion pins

There are several simple and practical methods for measuring erosion. Among them erosion pins established as reference points about which soil loss is measured, is probably the simplest and the most commonly used.

According to Haigh (1977), an erosion pin (nail, spike, rod, stake, peg, or angle rod) is essentially a benchmark. It is generally an iron or steel nail some times slipped through a loose washer of the same material, and driven into the ground with the bottom of the washer flush with the ground surface. The washer should be loose so it will descend as erosion washes away the soil underneath, exposing the nail (De Ploey and Gabriels, 1980).The main advantage of using the washer is that it gives a firm surface from which to measure (Dunne 1977). Washers also allow measurement of deposition and net erosion. Should any deposition occur after maximum erosion, the fill will be deposited on top of the washer. The difference between the amount of erosion indicated by the downward displacement of the washer and the amount of fill on top of the washer is the net erosion at the nail location (Emmett 1965). Gleason (1957) points out that the washer functions much as a maximum-minimum thermometer. To avoid problems with rustable materials and frost lifting Haigh (1978) recommended using very loose fitting washers, and non-rustable materials.

The head of the pin is taken to be a fixed reference datum, and changes in its elevation above the soil are interpreted as changes in the height of the surrounding ground surface. A reduction in the erosion pin exposure is termed "ground advance", and an increase is termed "ground retreat" (Haigh 1977). Advance and retreat may occur independently of erosion or deposition as a result of cyclical expansion and contraction of the ground surface due to heating and cooling, wetting and drying, freezing and thawing, hydration of clay minerals, soil creep or compaction (Haigh 1977). Emmett (1965), and Dunne (1977) mentioned level surveys from a bench mark as a protection against the effects of frost heaving or trampling. Schumm (1967) emphasizes that the pins must be installed with a minimum of ground disturbance and in a fixed position. The pins should be long depending on local conditions, thin, smooth, strong, and easy to locate in the field. If long, they will not be affected by surficial creep or frost action; if thin, their effect on surficial runoff and erosion will be minimized; if smooth the may resist frost heaving; and if strong they can be driven into weak bedrock. If a washer is used the initial distance from the head of the nail to the top of the washer (depending on the kind of nail used) must be recorded at the time of installation (Dunne 1977). Emmett (1965) recommends after each measurement, washers and pins should be lowered to the ground surface.

In Appendix 2, 31 erosion pin studies with quantitative results are presented, with rates of pin exposure ranging from fractions of a mm to dozens of centimeters during periods of measurement ranging from hours (storm events) to months (seasonal rainfall), to years. These studies represent 30 years of research around the world in a variety of environments and sites.

Types of pins used in these reports included wooden stakes, brass welding rods, angle-iron rods, iron construction rods, and iron or steel nails or spikes. Washers used were plastic or metallic, fixed or removable. Arrangements of pins were mainly in clusters and contours. Most of the experiments were carried out using pins 25 to 45 cm long, without washers and leaving a known initial pin exposure.

The measuring techniques used varied from simple metric sticks or tapes, to special devices with micrometers accurate to 0.02 mm, and use of computer programs for erosion calculation and contour plotting (Sams and Rogowski 1984).

The effectiveness of erosion pins have been evaluated in a number of different ways. Hadley and Lusby (1967) found erosion estimates from pins compared favorably with amount of sediment delivered to a reservoir, and with the USLE's K factor. McKenzie and Utgard (1978) obtained 30% higher values of spoil-bank erosion using stakes than fabric dams. White and Wells (1979) reported agreement between pin measurements and sediment amounts collected in traps. Millington (1981) used erosion plots finding no correlation due to deposition. Anderson <u>et al.</u> (1982) found different trends in their results using rainfall simulation and erosion pins. Haigh (1982) found no association between a modified version of the USLE for surface-mined lands and erosion pins on three slopes. Toy (1983), comparing a newly developed "linear erosion/elevation measuring instrument" (LEMI) with erosion pins, concluded that erosion pins were more reliable and easier to use. Haigh (1984) monitoring changes in road bank surfaces over a period of 5 years, found soil losses measured using pins confirmed values predicted by the USLE. Sam and Rogowski (1984) reported favorable agreement between data obtained from pins with soil loss measured in runoff samples using rainfall simulation. Rogowski et al. (1985), testing soil erosion measured by sampling sediment load, erosion pins under simulated rainfall, the USLE, and a erosion-deposition model found that erosion pins yielded the highest value. They concluded the erosion pins overpredicted because of the increased amount of rain collected by each pin, and the likelihood of enhanced turbulence in runoff.

In summary, comparisons of erosion pins with more elaborate methods mostly show good agreement. In some cases comparison is difficult or no correlation is found. In others, overestimation is reported specially under intense rainfall. The main pros and cons of the erosion pin method found in the reviewed papers and during the field work are :

Advantages:

- Direct measurement
- Simplicity
- General applicability
- Cheapness, availability and durability
- Less risk of vandalism
- Effective, easy to install and good local estimation

Disadvantages:

- Alterations of micro-environment around pin
- Potential disturbances at installation and measurement

- Risk of frost heaving, soil wetting-drying, creeping
- Potential problems of [illegible]pling or animal damage
- Difficulties at recording and resurveying
- Risk of not enough natural rainfall

Some of these disadvantages can be overcome following the suggestions and examples of Schumm (1967), Dunne (1977), Haigh (1977), and Sams and Rogowski (1984).

D. <u>Evaluation of soil properties</u>

Soil properties described on each plot (0-10 cm sample) included : soil texture, soil structure, permeability class, percentage of calcium carbonate equivalent, organic matter percentage, and exchangeable amounts of calcium and magnesium. These soil parameters were chosen in accordance with their importance as soil factors controlling or influencing erosion as suggested in the literature. A second criterion was the availability of data and equipment, and the possibility of performing reliable field sampling and analysis in a short period of time. Bulk density was another soil property initially sampled but later discarded from analysis because of poor sampling procedures.

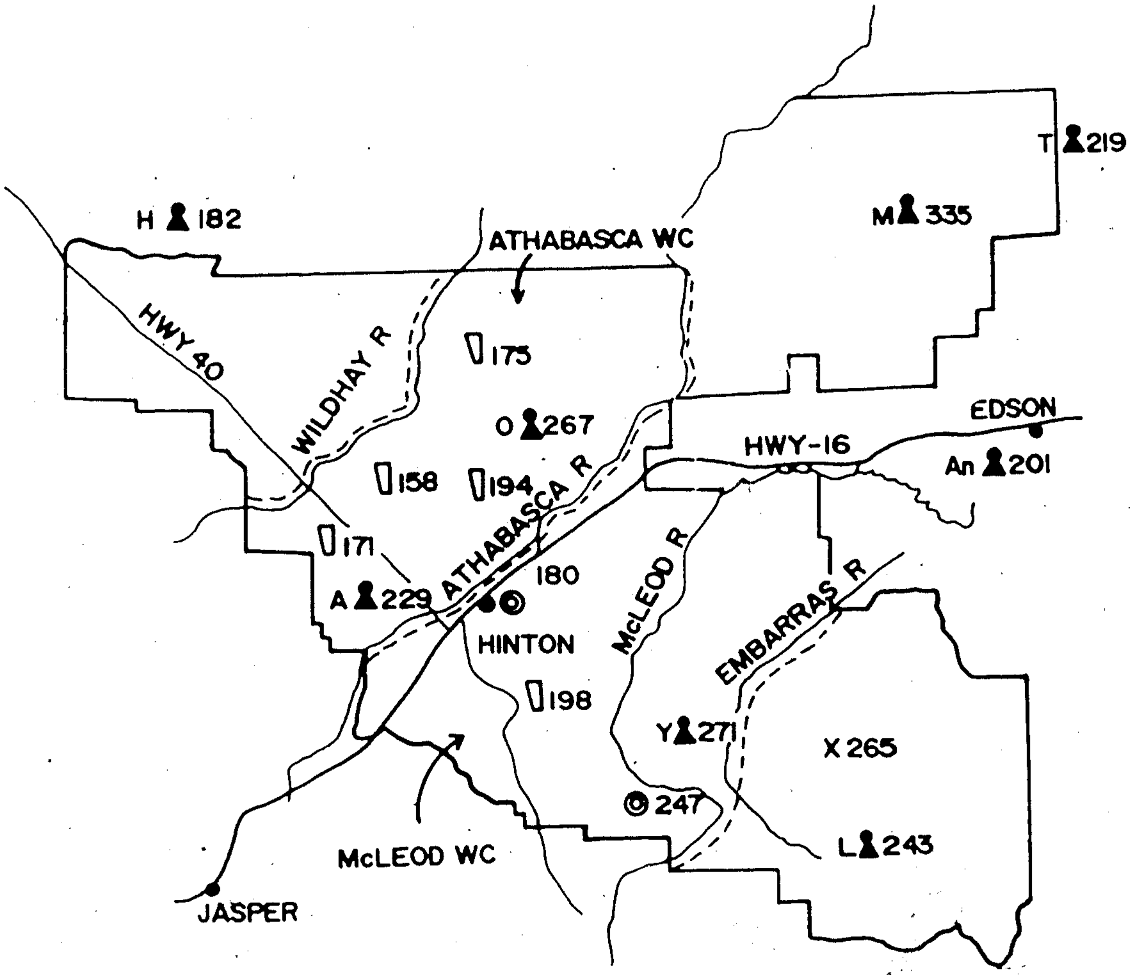
Soil texture for the fraction finer than 2 mm was determined by the Bouyoucos hydrometer method (McKeague 1978). Soil structure classes (size of peds) were defined in the field according to the USDA Soil Survey Manual (USDA 1951) adapted to the USLE specifications. Permeability classes for the K factor, were defined by relating textural types to tables presented by Lee (1980). $CaCO_3$ content was analyzed using the acid neutralization method (Allison and Moodie 1965), in samples showing effervescence to diluted (10%) HCl. Organic matter was calculated through the determination of organic carbon. Organic matter is assumed to contain 58% carbon, so the amount of organic matter could be estimated by multiplying the organic carbon value by 1.724 (Twardy and Corns 1980). Organic carbon was assumed to equal total carbon when $CaCO_3$ was not present. In samples containing $CaCO_3$, organic carbon was determined by subtracting inorganic carbon, as calculated from the $CaCO_3$ equivalent determination. Total carbon calculation was carried out by dry combustion using a resistance furnace with a gasometric detection of evolved CO_2 in an infrared detector (Leco Corporation, 1979). The exchangeable amount of Ca and Mg was measured by the ammonium acetate method (McKeague 1978). The physical properties of the soil associations were determined by the author and all chemical tests were conducted by the Department of Soil Science, University of Alberta, soil laboratory.

E. <u>Collection of rainfall data</u>

Summer precipitation records (June-September) from forest fire lookouts, standard rain gauges, ranger stations (Alberta Forest Service 1985, 1985a), and Tru-Check wedge-shaped rain gauges installed for this study, were collected and used in the discussion of results. Lookouts in the study area were : Athabasca (1630 m asl) and Obed (1580 m asl) in the Athabasca working circle, and Yellowhead (1460 m asl) in the McLeod working circle. Data for the McLeod working circle were also obtained from 14 standard rain gauges in the Tri-Creeks area (1280-1555 m asl) and one in Hinton (1010 m asl). Eight Tru-Check rain gauges were installed in the cut blocks of the Athabasca WC (1 at AT-3, 2 at AT-13, 3 at AT-14, 2 at AT-16), and 4 were installed in the McLeod WC (at MC-7). Data for total amount of rainfall from these rain gauges were collected from August 1-September 25, 1985. Because of late delivery, the Tru-Checks were installed after the study had begun. Location of these rain gauges is shown in Figure 3.

Huff (1955) showed that the Tru-Check rain gauge compares favorably with the U.S. Weather Bureau standard eight inch stick gauge.

Precipitation information from 2 additional lookouts in the FMA (Mayberne and Lovett), 3 outside it (Huckleberry, Tom Hill and Ansell), and 1 ranger station located at Robb. Since plots were ready on June 23, 1985 lookout records were considered only from that date up to September 4 (closing time for some stations), or up to the erosion measurement time in September. Location of lookouts and rain gauges are presented in Figure 3.



Lookout (Jun 23–Sept 4)

H= Huckleberry, M= Mayberne, T= Tom Hill, O= Obed

An= Ansell, A= Athabasca, Y= Yellowhead, L= Lovett

Tru-Check rain gauge (Aug 1 – Sept 25)

Standard rain gauge (Aug 13 – Sept 25)

X Ranger station (Jun 23 – Sept 4)

Fig 3 Rain gauge locations and rainfall records (mm)

F. USLE's erodibility (K) factor

The K factor of the USLE (Wischmeier and Smith 1978) was used as an additional parameter to assess soil loss. The K factor for each plot was calculated using the following equation:

$$K = 2.1 \times 10^{-6} \, (12 - OM) \, M^{1.14} + 0.0325 \, (S-2) + 0.025 \, (P-3)$$

OM = Percent organic matter

M = (% silt + % very fine sand) (100 - % clay)

S = Structure code (1 to 4)

P = Permeability code (1 to 6)

The K factor was used for comparing erodibility features among plots and soil associations-forest cover combinations.

VI. RESULTS AND DISCUSSION

A. Measured soil loss, K factor, and Singh's method

Erosion measured on the plots was relatively low and highly variable within and between soil associations and forest cover types (Table 3). Only 5 out of 54 plots had erosion rates above 1 mm. Average soil loss for all plots combined was 0.49 mm and ranged from 0 to 1.44 mm . Erosion for both the Marlboro and Robb associations averaged 0.52 mm, and was 0.43 mm for the Obed soil association. Erosion among the forest cover types averaged 0.49 mm for both pine and spruce-fir.

Evaluation of erosion hazard by the USLE s erodibility (K) factor, used as a dimensionless index, showed plot values ranging from 0.13 to 0.42. These values are similar to those reported by Hudson <u>et al.</u> (1985) (0.28 to 0.42, ranging from "Low" to "High") for Tri Creeks. Only slight differences were apparent between the forest cover types, with pine and spruce-fir averaging 0.27 and 0.25. Maximum 2 values for erodibility factor (K) occurred in the Obed soil association with a mean of 0.31. K values in the Marlboro and Robb associations were equal, averaging 0.24. The pattern of K values between the soil associations was opposite that indicated by measured erosion (Figure 4).

Table 3 Soil loss (mm) and USLE's erodibility (K) factor index per plot and soil-forest unit

	OBED				MARLBORO				ROBB			
	PINE		SPRUCE		PINE		SPRUCE		PINE		SPRUCE	
	Soil loss	K	Soil loss	K	Soil loss	K	Soil loss	K	Soil loss	K	Soil loss	K
	.44	.28	.17	.23	.39	.32	.67	.15	.39	.23	1.28	.27
	.39	.33	.72	.34	.44	.30	.39	.20	1.17	.27	.06	.19
	.11	.36	.94	.37	.28	.17	.56	.13	.78	.15	1.11	.35
	.11	.32	.33	.23	.78	.13	.44	.27	.00	.20	.17	.18
	.39	.27	.33	.36	.50	.24	.67	.22	.06	n/d	.67	.20
	.22	.34	.61	.31	1.44	.41	.22	.33	.61	.29	.44	.27
	.56	.42	.78	.26	.61	.13	.11	.25	.61	.26	.22	.16
	.44	.42	.83	.30	1.22	.17	.17	.37	.17	.31	.44	n/d
	.17	.34	.17	.28	.06	.14	.44	.36	.78	.31	.39	.20
$\bar{x}$	.31	.34	.54	.28	.64	.22	.41	.25	.51	.25	.53	.23
CV%	52	15	56	18	70	45	49	36	76	39	79	33

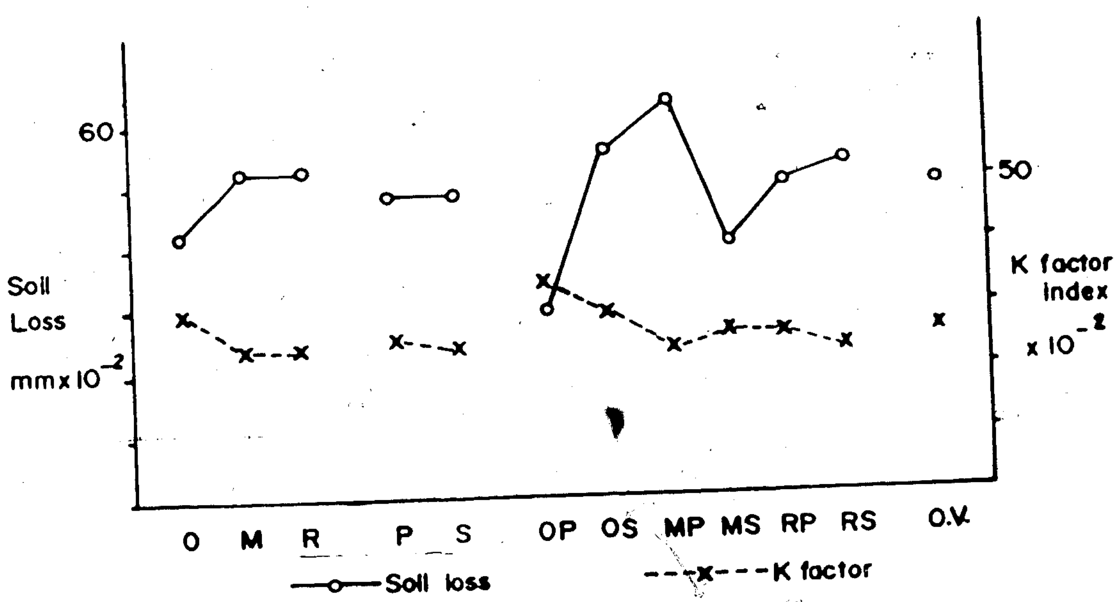


Fig. 4 Comparison between measured erosion and calculated erodibility (K)
O = Obed M = Marlboro R = Robb P = Pine S = Spruce - fir
O.V. = Overall values

Analysis of variance of both data sets (Tables 4 and 5) indicated no significant differences in measured erosion or K values between forest cover types. No significant interactions were found in rates of erosion or in K values. No significant differences in erosion were measured between soil associations. However, a significant difference was detected in K values among soil associations. Since K only involves soil properties, the highly significant calculated F for soil associations was not unexpected. A LSD test of the means found erodibility in the Obed soil associations to be different than in the Marlboro and Robb associations.

Table 4 ANOVA of soil loss stratified by soil association and forest cover type

Source of Variation	DF	SS	MS	F	Signif F
Soil assoc.	2	0.102	0.051	0.450	0.640
Forest types	1	0.001	0.001	0.007	0.033
Soil x forest	2	0.469	0.234	2.067	0.138
Error	48	5.441	0.113		
Total	53	6.013			

Table 5 ANOVA of erodibility factor K stratified by soil association and forest cover type

Source of Variation	DF	SS	MS	F	Signif F
Soil Assoc.	2	0.078	0.039	6.417	0.003 **
Forest Types	1	0.004	0.004	0.674	0.416
Soil x forest	2	0.021	0.011	1.734	0.187
Error	48	0.291	0.006		
Total	53	0.394	0.007		

A comparison of Singh's system to these results was conducted even though the statistical analyses indicated no real differences in erosion between soil associations-forest types. The aim of the comparison was to see if there was any agreement in rankings or trends between the three assessment systems (Table 6).

Table 6 Ranking of erosion hazard, measured erosion and erodibility factor K

	EROSION HAZARD					
	LOW		MODERATE		HIGH	
	1	2	3	4	5	6
SINGH'S	RP	OP	MP	OS	RS	MS
MEASURED EROSION	OP	MS	RP	RS	OS	MP
K FACTOR	RS	MP	RP	MS	OS	OP

O = obed M = marlboro R = robb P = pine S = spruce-fir

The comparisons, in general, were inconclusive. No real trends or consistent patterns were identified between the different assessment systems. Matching Singh's ranking to measured erosion revealed some agreement in the low and moderate erosion classes, but no agreement in the high hazard classes (Table 6). Comparison between Singh's rating and the K factor showed little agreement, especially in the high and low hazard classes. Measured erosion showed some correspondence with the K values for specific soils, but also did not agree for either the high or low hazard classes. It can be said that theoretically a better agreement should exist between Singh's rating and K factor since both are only related to soil properties. "Differences" between soil loss and K values can be partially explained by the fact that measured soil loss included the rainfall effect which is not considered in the erodibility factor, and according to Morgan (1983), because soil erodibility varies non-uniformly with erosivity.

Table 7 and Appendix 1, present a better description of the kind of erosion process measured by pins on the plots. Table 7 shows that measured soil loss occurred at only 257 (26%) out of a total of 972 pins. In all plots minimum soil erosion was nil (0 mm) and the maximum of 8 mm occurred only once. Erosion figures from 3 to 7 mm were also scarce. Erosion measurements of 1 and 2 mm were most abundant, representing 77% of the total erosion observations (257).

Sixty-two percent (599) of the pins did not show signs of sheetwash erosion. Measurable soil displacement (erosion + deposition) was observed at 373 (38%) pins. Erosion was unequal and very localized as illustrated by plots 36, 17, and 47 (Figure 5).

Table 7 Frequency of erosion and deposition detected by erosion pins in each soil association - forest cover combination

	NO CHANGE No.	%	EROSION No.	%	DEPOSITION No.	%	MEAN EROSION mm
OBED PINE	116	72	42	26	4	2	0.31
OBED-SPRUCE	97	60	52	32	13	8	0.54
MARLBORO-PINE	83	51	41	26	37	23	0.64
MARLBORO-SPRUCE	107	65	32	20	25	15	0.41
ROBB-PINE	106	65	37	23	19	12	0.51
ROBB-SPRUCE	92	57	52	32	18	11	0.53
TOTAL	599	62	257	26	116	12	

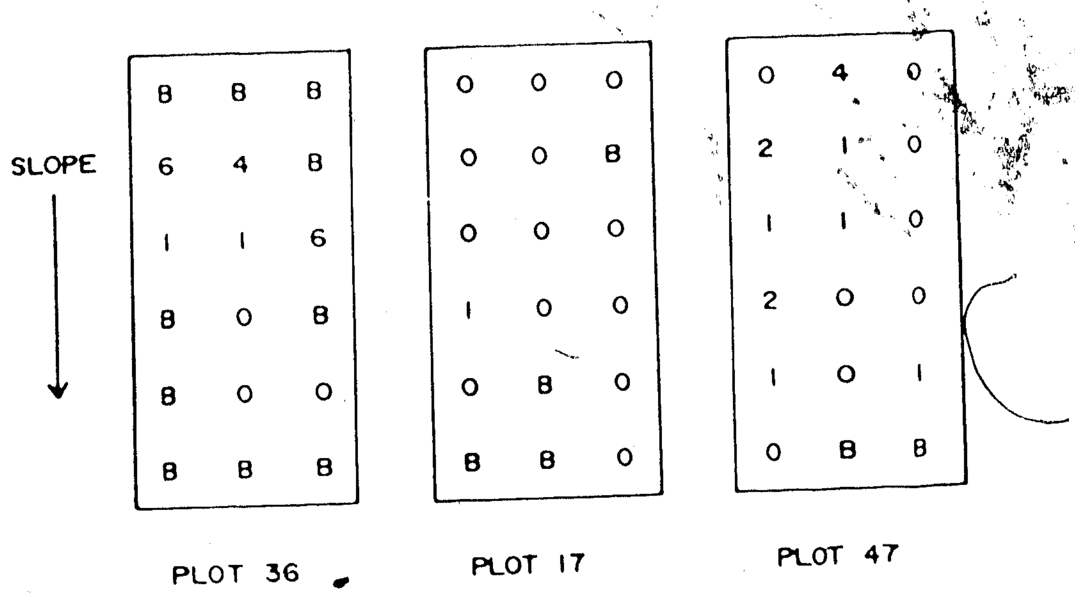


Fig 5 Examples of soil loss patterns (mm) on plots
(B = buried pin)

The apparently low average of erosion observed (0.49 mm or 0.16 mm/month), was comparable to other studies. Campbell (1982) obtained mean plot values in the Red Deer Badlands of 0.63 mm/month. Bovis and Thorn (1981) in an alpine region of Colorado, found average soil loss values of 0.1 mm/year. Llerena <u>et al.</u> (1987) reported similar erosion rates using simulated rainfall in the Hinton area. Erosion at Hinton was intermediate between the highly erodible Badlands, and the slowly eroded alpine hillsides.

Assuming the overall mean, 0.49 mm, as representative of erosion on the cut blocks, it was possible to estimate soil loss as a volume or mass. Thus, 4.9 m^3/ha, or 6.4 ton/ha (assumed average bulk density = 1.3 g/cm^3) would be washed away from the disturbed parts of the cut blocks, during the rainfall season. This amount of erosion is greater than the highest annual soil loss tolerance for deep soils in Alberta (Tajek et al. 1985). However, given the rough surface characteristics of the cut blocks (revegetation, contour scarification trenches, amount of slash) very little of the material will be removed off the cut blocks.

In this study a greater number of plots would undoubtly have improved the reliability of the results. However, as stated before, practical constraints made that goal impossible. To sample with a precision of ±10% from the mean, it would have been necessary to use 188 plots (Zalik 1983). With only 54 plots the theoretical accuracy level drops to about ±20% .

Soil is a highly variable entity (Mader 1963, Beckett and Webster 1971). The variability encountered in this study was similar to values reported in other studies. Bryan (1981) reported a coefficient of variability (CV) of 39.1% under laboratory conditions. Bovis and Thorn (1981) obtained CV values over 100 % for an alpine environment. Anderson et al. (1982) presented extreme annual point erosion values (0 and 89 mm) within only one soil group.

One hundred sixteen (12%) pins (Table 7, appendix 2) were covered by soil deposition, and most of them occurred in the two bottom rows. These pins were buried (B) by material coming from outside plot boundaries or from the upper parts of the plot. Inspection of the plots showed deposition happened before any soil loss was detected. This suggested that a threshold level of erosion may be required before reliable estimates of erosion can be detected by erosion pins. The low depths of erosion and high variability measured, may also have been influenced by the low frequency and variability of precipitation in the Hinton area in summer 1985.

Spatial variability was particularly evident during the snowfall event of June 23. During this day almost 60 cm of snow were measured around plots 64, 65, and 66 of MC7-61; 10-20 cm around plots 19, 20, and 21 of MC7-70; and no snow at all in cut block MC7-57 located almost in the middle of MC7-61 and MC7-70, not more than 2 Km away. Variability in time and space can be observed looking at the daily records of rainfall higher than 10 mm from June 23 to September 11, 1985 at the Athabasca, Obed, and Yellowhead lookout stations (Table 8). On August 8, 1985 when the most intense summer storm occurred, the Obed lookout registered 42.4 mm/24h. This figure was 63% and 19% higher than the records of Athabasca and Yellowhead respectively.

Table 8 Days with rainfall higher than 10 mm/24 h (lookout stations) from June 23 until September 1985

		ATHABASCA	OBED	YELLOWHEAD
JUNE	23 AM	7.0	6.8	Trs.
	PM	1.6	4.2	2.6
	24 AM	8.4	14.2	8.4
	PM	1.4	13.0	5.0
	25 AM	7.0	12.0	2.8
	PM	0	0	0
JULY	19 AM	1.2	16.0	14.2
	PM	0.4	Trs.	0.2
	24 AM	2.0	2.2	17.0
	PM	0	0	0
AUGUST	3 AM	Trs.	15.4	0
	PM	0	0	0
	8 AM	25.4	41.4	34.4
	PM	0.6	1.0	1.6
	10 AM	9.2	5.0	0
	PM	0.9	0.4	11.0
	12 AM	12.0	16.4	0
	PM	1.8	2.0	17.8
	[illegible] AM	15.0	18.2	23.8
	PM	[illegible]	5.7	3.6
	20 AM	14.0	16.0	13.0
	PM	8.8	7.0	8.4
SEPTEMBER	5 AM	3.6	(Closed Sept. 4)	2.8
	PM	9.0		2.2
		(Closed Sept 11)		(Closed Sept 11)

Source : Alberta Forest Service (1985)

Rainfall energy thresholds (Fairbridge 1980) capable of producing erosion on most of the plots occurred. Field observations clearly indicated that the rainfall threshold for erosion occurred in August. Inspection of plots before August revealed no measurable signs of erosion around pins.

Rainfall distribution during 1985 was different than normal. July is usually the wettest month followed by June (Schulco 1973, Hillman et al. 1978) but in 1985, August and September received the heaviest rainfall, as shown below :

Table 9 Total montly rainfall during the summer of 1985

Month	Rainfall (mm)	% of total
May	42	12
June	74	20
July	39	11
August	117	32
September	90	25
	362	100

This unusual pattern of precipitation distribution suggested a relatively dry period in June and July. August would be a period of sequential wetting, rainsplash, and sheetwash; and September a period of sheetwashing and rilling. In the final survey, sediment accumulation at the bottom of the plot was evident, with fan shaped deposits and small rills on some of them. A more usual distribution of the same amount of rainfall would have probably caused higher erosion as a consequence of the combined effects of springmelt and rainfall.

A.1 Precision of erosion measurement

Soil erosion in this study was measured in order to detect differences among certain soil units, therefore the main concern during the field work was to treat all the samples as uniformly as possible.

Differences existed among the selected cut blocks with regard to harvesting year and season, post harvesting treatment method, amount of slash left on the ground, regeneration cover, and other variables. Preparation of small plots prior to setting of erosion pins was carried out to eliminate these differences, and provide uniform samples in each soil unit under analysis. Furthermore, the plot size was selected to represent spots of bare soil resulting from logging. Bordering was avoided because it would have altered this simulation.

Erosion measurements were also affected by the type of erosion pins and washers used. The nails used were relatively thick (8 mm), and appeared to be obstacles to water and sediment flow, in a similar way that pebbles, plants, or slash of comparable size. However, during erosion measurements, it appeared that the washers reduced erosion because of a reduction in raindrop impact. Better results and probably higher erosion rates might have been recorded using removable washers with headless pins of smaller diameter (Haigh 1977).

The main consideration in relation to the use of the erosion pin method is linked to its reliability with the amounts of erosion most frequently detected in this study : 77% of the total soil loss was only 1-2 mm deep. Obviously in measuring amounts of erosion like this with a metallic tape, the magnitude of error will be greater than in measurements of 7 or 8 mm of soil loss. In case of low erosion rates a refinement of the measuring procedure is thus desirable. A convenient alternative would have been to use the type of micrometer used by Sams and Rogowski (1984) or suggested by Haigh (1977).

B. Factors affecting soil loss

Multiple regression analysis was used in an attempt to identify the factors controlling erosion in this study. The mean erosion, soil properties, rainfall amounts, and site characteristics for each plot (Appendix 3) were used in stepwise multiple regression analyses. A logarithmic an a linear model were tested.

Stepwise regression analyses with erosion as the dependent variable were carried out for the experiment as a whole (n = 54 observations), and on forest cover types (n = 27), soil types (n = 18), and soil-forest types combinations (n = 9). A confidence level = 80% was used because it was considered appropriate for the highly variable data, and from a land management viewpoint in assessing erosion. A summary of the statistics is presented in Table 10.

Table 10 Stepwise Multiple Regression parameters.
$\hat{y} = b_o + b_1 x_1 + \ldots + b_n x_n$

n	Step	Independent Variable	Mult. r	r^2	Partial r	Equation Coefficients b_o	$b_1 \ldots b_n$
All = 54	1	OM	.2314	.0536	-.3322	.8124	- .0516
	2	CaCO3	.2966	.0880	-.2766		-1.3491
	3	Slope	.3467	.1202	-.1890		- .0325
	4	Mg	.3929	.1544	.2577		.1024
	5	Rain	.4470	.1998	.2317		.0026
P = 27	1	Ca	.2655	.0705	-.2655	.7243	- .0185
S = 27	1	Sand	.2712	.07[illegible]	[illegible]8	.9029	- .0119
	2	CaCO3	.3948	[illegible]	-.2981		-1.6105
O = 18	1	CaCO3	.4760	[illegible]	[illegible]576	3.7171	-1.9329
	2	Sand	.6360	[illegible]	[illegible]4863		- .0132
	3	Rain	.6896	[illegible]	-.3456		- .0151
M = 18	1	[illegible]	.3375	.1139	-.5179	3.1860	- .0116
	2	[illegible]	.5408	.2924	-.4488		- .0325
R = 18	1	[illegible]	.5759	.3316	-.6596	-.2341	- .0832
	2	[illegible]in	.7359	.5415	.5603		.0050
OP = 9	1	Sand	.5306	.2815	-.5306	.6901	- .0149
OS = 9	1	Ca	.8162	.6662	-.8162	2.0592	- .0805
MP = 9	1	Clay	.5214	.2718	-.8062	2.8066	- .0922
	2	OM	.8269	.6837	-.7521		- .1671
MS = 9	1	K	[illegible]	.3937	-.6275	-.7850	-1.4891
RP = 9	1	OM	.[illegible]144	.3772	-.6092	-.2146	- .0348
	2	Mg	.7544	.5691	.9220		1.7053
	3	[illegible]	.8623	.7436	-.9025		- .1724
	4	Clay	.9592	.9201	-.8297		- .0735
RS = 9	1	K	.6794	.4616	.8280	-1.5097	3.9528
	2	Clay	.8838	.7811	.7704		.0649

$\hat{y}$ = depth of soil loss (mm)
Forest cover types : P = pine, S = spruce-fir
Soil association : O = Obed, M = Marlboro, R = Robb
Soil-forest combinations : OP, OS, MP, MS, RP, RS.

Linear regression models gave the best results which were highly variable; coefficients of determination ranged from 7 to 96%. Comparisons were restricted to similar data sets, as the magnitude of coefficients of determination are affected by sample size. Partial correlation coefficients were used in order to identify the relationships between erosion and each independent variable, separately of the accompanying variation due to additional independent variables (Zalik 1983).

B.1 Soil properties

The most important soil parameters explaining soil erosion in the regression analyses were percentage of organic matter (OM), calcium carbonate content ($CaCO_3$), sand and clay, and calcium content in me/100g. These variables were repeatedly selected in the stepwise regression analyses and had partial correlations from 0.28 to 0.90. Magnesium content was also selected in the analyses as having a direct relationship with erosion in two equations (n = 54, n = 9). K-erodibility as an index, was only identified as important in two equations (n = 9). K showed an inverse relationship with erosion probably due to the differences in erosivity observed in the study area. Soil parameters not identified as important were the M factor, and the textural component silt plus fine sand (SIFS).

The inverse relationship among OM and erosion opposes the observation of Hudson et al. (1985) for Tri Creeks.

Clay and $CaCO_3$ respectively follow in importance to OM, both of them tending to reduce erosion susceptibility with the exception of clay in the Robb - spruce-fir soil-forest unit. Sand and $CaCO_3$ are variables apparently tending to act together against erosion.

In the soil-forest units under pine OM and sand are the most important factors. In the soil-forest units under spruce-fir Ca, K, and clay together are the factors explaining most of the erosion variability. The Robb-Pine soil-forest unit presents the regression with the highest coefficient of determination (96%).

In summary, five soil variables were detected as having an influence on erosion in this study : OM, clay, $CaCO_3$, Ca, and sand.

B.2 Slope angle and aspect

Slope steepness is the only site factor included in the regression analyses. This factor is only present in the first equation (n = 54), and has a negative correlation with erosion because it is almost constant; the minus sign is a random result. Leopold et al. (1966), and Luk (1975), found similar results.

Aspect was not included in the regression analyses. It was tested by comparing 2 soil loss means obtained from plot values. Previously, plots were grouped in erosive and non-erosive exposures as defined by field observation and literature sources (Spence 1972, Rothwell 1978, Crockett and

Shelford 1982, Churchill 1982). North and east (24 plots) were judged colder and wetter and thus more susceptible to erosion processes, than hotter and drier south and west exposures (30 plots).

A Student's t-test indicated no difference between aspect groups, therefore, it was concluded that in this study aspect did not play any role in the erosion results. Probably, under the conditions of the study area, more contrasting aspect units should be used in order to detect differences in erosion associated to this slope feature.

B.3 Rainfall characteristics

The amount of erosion variability explained by the inclusion of rainfall in the equations ranged from 5 to 21%. Surprisingly, Obed and Marlboro equations contain rainfall variables with negative coefficients. This is presumed to result from the fact that the 5 plots having the largest amount of erosion happened to be in the lower rainfall areas (as expressed by the closest Tru-Check rain gauge) in the Obed units. Additionally, the rainfall amount in this unit was the most constant with a CV of 3%. In the Marlboro unit, where rainfall also had a low variability (CV = 10%), something similar occurred. The plot with the highest erosion value of the whole study area was found in the cut block with the second lowest rainfall record. Also, the two lowest plot erosion values in the Marlboro unit occurred in the area with the highest rainfall record. This situation was clearly shown by the low coefficient of determination (r^2) of the experiment as a whole (20%). This low value might also be revealing the variability of rainfall.

A closer examination of soil and site characteristics of plots with low erosion rates in locations under heavy rainfall, could lead to find other soil and site properties (microtopography, stoniness, amount and type of slash, plant regeneration) influencing soil loss.

C. Additional findings

During the summer of 1984 some plots were prepared and pins were established. In the early summer of 1985 pins were checked for frost heaving problems. Evidence of frost heaving was detected in only 12% of the pins. The method used consisted in leveling the nails in the plot rows (3 pins/row) during installation, with a spirit level, and remeasurement the following spring. Heaving was indicated if the nails were not level on remeasurement. By measuring pin exposures in the frost heaving plots in 1985, and checking some plots during early summer of 1986, it was possible to observe much more soil entrainment after snowmelting than after the rainfall season. Close observation of the soils affected by the incipient erosion process show widespread needle ice activity. From these observations it was estimated that, on average, the amount of soil eroded during springmelt might easily be 5 times higher than the amount of soil loss found during the rainfall season.

VII. CONCLUSIONS

Singh's erosion hazard rating was compared to measured erosion and the USLE's erodibility (K) factor. Erosion was measured using pins on plots representing segments of harvested cut blocks on slopes 25% steep, on 3 soil associations, under 2 forest cover types, in the Hinton, Alberta, area. The K factor was calculated following the guidelines of Wischmeier and Smith (1978).

Results obtained in the field showed small depths of soil loss of mostly 1-2 mm among pins and averaging 0.49 mm in plots, representing a mass of about 6 ton/ha. The kind of variability obtained was considered to reflect the normal variability found in forest soils under logging operations. Part of it was due to the distribution and magnitude of summer rainfall in 1985.

Statistical results indicated no differences in erosion between forest types and among soil-forest combinations, leading to rejection of Singh s method. However, given the closeness of erosion measurements, and no consistent agreement in patterns between them and K-erodibility results, it is difficult to make any conclusive judgement on the effectiveness of Singh's system. A larger sample size, improvements in the erosion pin method, and greater control of environmental variables perhaps would have provided a more conclusive test of the Singh method. A fair conclusion for this study was that better descriptive criteria were needed for a reliable erosion hazard rating system.

The main soil variables which were found to influence the amount of soil erosion were : organic matter, calcium carbonate, sand clay, and calcium content.

Correlation, between rainfall and soil erosion was more clearly observable using data for daily rainfall than total amount of rainfall. No correlation was found between aspects and erosion.

Some concurrent findings deserve further attention :

- The relationship among soil moisture content-erosion-forest type-infiltration.
- The amount of raindrop impact effect on summer soil erosion.
- The improvement of the erosion pin method and its use together with other quantitative methods.
- Defining threshold rainfall amounts for soil detachment.
- The amount of soil erosion due to snowmelting.
- The effects of frost heaving and needle ice in soil erosion.

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APPENDICES

Appendix 1 Depth of Soil Erosion at Each Pin and Plot Mean

	Plot No.	* 1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	Mean mm
	67	0	1	0	0	1	0	0	1	0	1	0	0	0	0	0	1	3	0	.44
	68	0	0	0	0	0	1	0	0	0	0	0	0	4	0	0	0	B	2	.39
	69	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	.11
	70	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	[illegible]1
OP	71	1	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1	0	1	.39
	72	0	1	0	0	0	0	0	0	0	0	0	1	0	1	B	1	0	0	.22
	73	1	2	0	0	1	0	0	0	0	0	0	1	1	1	1	0	1	1	.56
	74	0	0	1	0	1	0	0	0	1	0	0	0	0	2	2	0	0	1	.44
	75	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	B	B	.17
	46	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	.17
	47	0	4	0	2	1	0	1	1	0	2	0	0	1	0	1	0	B	B	.72
	48	0	2	1	0	0	0	0	1	0	B	0	0	4	0	5	0	B	B	.94
	49	1	0	0	0	0	0	1	2	0	0	0	0	0	0	0	1	B	1	.33
OS	50	0	0	0	2	0	0	0	0	0	1	1	1	0	1	0	B	0	0	.33
	51	0	0	3	0	2	0	2	0	0	2	1	0	0	1	B	B	B	B	.61
	52	0	0	0	1	1	0	3	4	1	1	1	0	0	0	1	0	0	1	.78
	53	0	0	3	2	1	1	1	0	5	1	0	0	0	1	0	B	0	0	.83
	54	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	.17
	25	0	1	0	0	1	0	0	2	0	0	1	0	0	1	0	0	0	1	.39
	26	0	0	0	0	1	1	2	1	0	B	1	B	B	1	1	0	0	0	.44
	27	1	0	0	0	1	0	1	B	1	0	0	B	[illegible]	1	0	B	0	0	.28
	34	B	B	2	0	B	0	B	0	0	2	0	3	0	[illegible]	2	B	B	B	.78
MP	35	0	0	B	1	0	0	5	0	B	B	3	0	0	0	0	0	B	B	.50
	36	B	B	B	6	4	8	1	1	6	B	0	B	B	0	0	B	B	B	1.44
	37	0	0	0	0	0	0	0	B	0	4	4	0	0	0	0	B	3	0	.61
	38	0	B	B	B	5	4	5	0	0	3	0	0	3	0	2	B	B	B	1.22
	39	0	0	0	0	0	B	0	0	0	0	1	0	0	0	0	B	B	0	.06

MS	40	0	0	0	0	0	0	0	0	0	6	3	0	0	3	0	0	0	0	.67
	41	0	4	0	0	0	0	0	0	0	0	B	1	1	B	1	B	0	0	.39
	42	0	0	B	0	2	4	B	0	0	0	1	1	0	0	2	0	B	0	.56
	43	1	0	0	1	1	0	4	0	0	0	1	0	0	0	0	B	B	B	.44
	44	0	0	0	3	0	0	4	2	3	0	0	0	0	0	0	B	B	0	.67
	45	B	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	B	B	.22
	64	0	B	0	0	0	B	0	B	B	0	B	0	1	1	0	0	B	0	.11
	65	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	B	B	.17
	66	4	B	0	0	0	0	1	1	B	2	0	0	0	0	B	0	0	0	.44
RP	13	B	1	0	0	1	0	0	0	2	0	1	2	0	0	0	0	0	0	.39
	14	0	1	0	3	1	0	3	4	1	5	1	0	B	1	0	B	1	0	1.17
	15	0	0	0	3	0	3	0	0	0	0	0	4	0	0	0	4	0	0	.78
	19	0	0	0	B	0	0	0	B	B	0	0	0	0	0	0	0	0	0	.00
	20	1	0	B	0	B	0	0	B	B	0	0	0	B	0	0	0	0	B	.06
	21	1	0	0	1	B	B	0	0	0	0	0	1	4	0	1	0	B	0	.61
	31	0	0	0	2	0	0	0	0	0	0	4	0	0	0	0	1	4	B	.61
	32	0	0	0	B	B	0	B	0	0	1	1	0	0	0	0	0	1	0	.17
	33	0	0	0	0	0	0	4	0	2	2*	0	0	0	0	0	2	4	0	.78
RS	16	0	1	0	0	2	3	0	4	1	3	1	B	2	3	0	0	1	2	1.23
	17	0	0	0	0	0	B	0	0	0	1	0	0	0	B	0	B	B	0	.06
	18	4	0	0	1	0	0	0	0	B	1	1	1	1	0	B	1	5	0	1.11
	22	0	0	0	1	B	0	B	0	0	1	B	1	0	0	0	0	0	0	.17
	23	B	0	6	0	0	5	2	0	0	0	0	0	1	1	B	1	1	1	.67
	24	1	0	0	1	0	0	0	3	0	0	0	0	0	1	0	2	0	0	.44
	28	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	B	B	.22
	29	0	0	0	1	0	0	1	1	B	1	1	4	0	0	0	0	0	B	.44
	30	1	2	0	1	0	0	1	0	0	1	0	0	0	0	1	B	B	0	.39

* See figure 2a

B = buried pin

Appendix 2 Erosion pin studies

AUTHOR	LOCATION & LAND TYPE	SLOPE %	RAINFALL mm	EXPOSURE mm	PERIOD
*Colbert (1956)	Cameron Ariz Badlands			111-273	2 years
*Schumm (1956)	Perth Amboy NJ Spoil banks	115	1072	13-40	Jun-Sept
Schumm (1956)	Wall SD Badlands	65-97	812	20-38	2 years
Gleason (1957)	Colusa CA Brushlands burns			3.2	
*Hadley & Schumm (1961)	Sioux Co. NE Badlands			8-46	12-16 months
Diseker & Richardson (1962)	Catersville GA Roadside cuts	35-77	1020-1150	44-70	year
Emmett (1965)	NM and WY Arid lands	21-62	203-254	5-16	year
Leopold et al. (1966)	Slopewash NM Semi-arid lands	11-78		4-9	year
Hadley & Lusby (1967)	Badger Wash CO Arid-semiarid	38-46	28	3.7	6 hs. storm

Bridges (1969)	South Wales UK Barren lands	7-188		2-8[illegible]	6 months-year
*Clayton & Tinker (1971)	Little Missourri Badlands ND			3-9	year
Rapp et al. (1972)	Morogoro Tanzania Cut grass		8-890	2.5	Mar 22 -Apr 5
Temple & Murray-R. (1972)	Uluguru Tanzania Regen. bush			1-17	year
*Imeson (1971,1974)	North York UK Bare peat,min.soil			41-64	year
*Harvey (1974)	Westmorland UK Hillsides			0.8-6.4	year
Fitzgibbon (1974)	Estevan Sask Spoil mounds	27-65	305	6-15	May 28-Oct 10
Lengelle (1976)	Swan Hills Alta Barren lands	73	457	51	Year
Haigh (1978)	Blaenavon UK Spoil banks, infill		1430	3-9	year
McKenzie & Utgard (1978)	Appalachians OH Spoil banks			20	year
White & Wells (1979)	Tex Burned forest	8-22	825	2-5	year

Finley & Gustavson (1980)	Panhandle Tex Semi-arid lands	0-115	508	5-31	5 months
Takei et al. (1981)	Tanakami Japon Bare Land	53-69	1650	9-13	year
Anderson et al. (1982)	Grande Prairie Road cuts Alta	5-65		8-26	year
Haigh & Wallace (1982)	La Salle IL Strip-mine dumps	42-70	1111	29-33	May 78-May 79
Rendell (1982)	Basento, Italy Clay hillsides	30-42	678	6.2-115	year
Toy (1983)	Glenrock WY Hillslopes			1	Aug 80-Jun 81
Collins et al. (1983)	Mt St Helen WA Tephra deposits	34-42		11-31	year
Haigh (1984)	Cleveland OK Road banks	51	875	33	year
Sams & Rogowski (1984)	Karthaus PA Reclaimed land	5-20	RS-220-315	0.4-4.6	3-4 months
Rogowski et al. (1985)	Pine Glen PA Erosion plots		RS	0.5	
This study (1987)	Hinton Alta Erosion plots	25	362	0.3-0.6	Jun-Sept 85

* Source : Haigh (1977) RS rain simulation

Appendix 3 Soil Loss and Soil, Site, and Rainfall Characteristics for Plot

*	PLOT No.	EROS mm	RAIN mm	SLOPE %	M	OM %	K	Mg me/100g	Ca me/100g	CaCO3 %	SIFS %	SAND %	CLAY %	TEXT	P K codes	S K codes	ASPECT
OP	67	.44	193	27	4089	2.6	.28	2.10	17.79	.00	47	40	13	L	4	2	E
	68	.39	193	27	4264	1.6	.33	1.40	10.65	.00	52	30	18	L	4	2	SE
	69	.11	193	27	4959	2.3	.36	1.32	15.37	.07	57	32	11	SiL	4	2	SE
	70	.11	180	24	3690	1.3	.32	1.60	14.94	.06	45	37	18	L	4	3	SW
	71	.39	180	25	3234	2.0	.27	3.66	27.40	.12	42	35	23	L	4	3	NW
	72	.22	180	26	4165	1.8	.34	1.89	16.14	.17	49	36	15	L	4	3	W
	73	.56	180	23	5494	1.8	.42	1.81	14.65	.16	67	15	18	SiL	4	2	NW
	74	.44	180	24	5220	1.0	.42	1.15	17.26	.06	60	27	13	L	4	2	NW
	75	.17	180	26	4505	1.8	.34	1.77	16.19	.22	53	32	15	L	4	2	NW
OS	46	.17	181	26	4582	5.3	.23	4.07	25.00	.30	58	21	21	SiL	4	2	E
	47	.72	181	26	5394	3.7	.34	3.37	18.16	.00	62	25	13	SiL	4	2	E
	48	.94	181	25	5330	2.7	.37	2.14	13.70	.00	65	17	18	SiL	4	2	E
	49	.33	181	24	3485	4.6	.23	3.37	19.21	.00	41	44	15	L	4	2	SE
	50	.33	181	26	4698	4.6	.26	2.96	19.66	.00	54	33	13	SiL	4	2	E
	51	.61	181	27	3480	5.2	.21	2.88	19.31	.00	40	47	13	L	4	3	E
	52	.78	181	26	4350	5.0	.26	2.39	16.72	.00	57	30	13	SiL	4	3	NW
	53	.83	181	27	4250	3.6	.30	1.77	18.01	.00	50	35	15	L	4	3	NW
	54	.17	181	28	4000	3.8	.28	2.30	19.86	.00	50	30	20	L	4	3	NW
MP	25	.39	194	26	4930	3.4	.32	2.22	11.33	.00	58	27	15	SiL	4	2	S
	26	.44	194	25	4158	2.2	.30	3.42	17.34	.00	54	23	23	SiL	4	2	S
	27	.28	194	27	2765	3.8	.17	2.18	11.60	.00	35	44	21	L	4	2	S
	34	.78	166	24	1659	1.6	.13	.66	7.48	.00	21	58	21	SCL	4	2	SW
	35	.50	166	23	4018	4.1	.24	2.68	11.83	.00	33	49	18	L	4	2	S
	36	1.44	166	25	4785	1.2	.41	1.07	5.09	.00	55	32	13	SiL	4	3	S
	37	.61	184	24	2214	2.6	.13	1.77	12.40	.00	27	55	18	SL	4	2	SE
	38	1.22	184	23	3780	6.4	.17	2.59	14.25	.00	42	48	10	L	4	2	S
	39	.06	184	23	3230	6.7	.14	2.06	12.50	.00	38	47	15	L	4	2	S

MS	40	.67	158	26	3002	5.6	.15	3.42	13.25	.00	41	28	21	L	4	2	NW
	41	.39	158	26	2948	2.9	.20	3.21	11.10	.00	44	23	33	CL	4	2	NW
	42	.56	158	21	3634	7.5	.13	3.42	13.25	.00	46	33	21	L	4	2	NW
	43	.44	158	26	4424	3.9	.27	2.55	7.51	.00	56	23	21	SiL	4	2	NW
	44	.67	158	28	3397	3.2	.22	2.10	10.50	.00	43	36	21	L	4	2	NW
	45	.22	158	22	5056	3.4	.33	1.85	9.86	.00	64	15	21	SiL	4	2	NW
	64	.11	204	26	3915	3.3	.25	1.65	7.83	.00	45	42	13	L	3	2	SW
	65	.17	204	25	4320	1.2	.37	1.23	7.28	.00	48	42	10	L	4	3	W
	66	.44	204	27	4100	1.2	.36	1.32	5.64	.00	50	32	18	L	4	3	W
RP	13	.39	251	26	3200	3.8	.23	2.02	6.41	.00	40	40	20	L	4	3	E
	14	1.17	251	28	3465	1.1	.27	2.55	7.66	.00	45	32	23	L	4	2	E
	[illegible]	.78	[illegible]	[illegible]	[illegible]	3.4	.15	3.83	13.00	.27	33	37	30	CL	4	2	SE
	19	.00	188	26	3772	5.1	.20	2.35	12.15	.00	46	36	18	L	4	2	S
	20	.06	188	27	3567	n/d	n/d	2.22	13.20	.00	41	46	13	L	4	2	SW
	21	.61	188	25	3915	3.0	.29	2.22	10.98	.00	45	42	13	L	4	3	SW
	31	.61	171	26	3318	1.3	.26	2.10	7.34	.00	42	37	21	L	4	2	SW
	32	.17	171	24	4080	1.5	.31	1.44	5.79	.00	48	37	15	L	4	2	SW
	33	.78	171	22	4089	1.7	.31	1.85	6.34	.00	47	40	13	L	4	2	SW
RS	16	1.28	271	21	3600	3.1	[illegible]	1.85	7.78	.00	48	27	25	L	4	3	SW
	17	.06	271	21	4080	7.2	[illegible]	.78	3.44	.00	48	37	15	L	4	3	W
	18	1.11	271	23	4674	2.0	.35	1.56	4.14	.00	57	25	18	SiL	4	2	W
	22	.17	206	26	3002	4.2	[illegible]	2.11	9.73	.00	38	41	21	L	4	2	W
	23	.67	206	24	3034	3.0	.20	1.60	7.66	.00	37	45	18	L	4	2	W
	24	.44	206	24	3230	2.1	.27	[illegible]	[illegible]	.00	38	47	15	L	4	3	W
	28	.22	219	27	3612	6.5	[illegible]	[illegible]	.44	.00	42	44	14	L	4	2	NW
	29	.44	219	26	3510	n/d	n/d	.78	3.27	.00	45	33	22	L	4	2	NW
	30	.39	219	25	4100	5.5	.20	.58	3.72	.00	50	32	18	L	4	2	NW

RAIN Aug.1st.-Sept.25, M = SIFS (100% clay) SIFS = % silt + % very fine sand
K = USLE's erodibility factor P = permeability . S = structure OM = organic matter