Spatial variability of soil redistribution processes in a small agricultural watershed

by John Cornelius Pings

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Physical soil redistribution processes were studied in a small (61 ha) watershed in a region of dryland winter wheat agriculture in north-central Montana. Two approaches were used, a model approach using the Universal Soil Loss Equation (USLE) and Wind Erosion Equation (WEE) soil erosion models, and a field sampling approach using 137Cs. The 137Cs was used as a tracer of erosion and deposition from upland sites (hilltops, midslopes and footslopes) to depositional zones (channels and a pond reservoir bottom). Cesium-137, a fallout product of atmospheric nuclear testing, is strongly adsorbed to clay and has been proven to trace sediment movement. A volumetric approach, developed by De Jong and associates of the University of Saskatchewan, was used to estimate erosion rates of eroding sites and deposition rates of the depositional sites. Landscape units, labelled topographic positions and depositional zones, were defined from a 1:2500 scale plane table topographic contour map, and analyzed for areal concentration of 137Cs to attain erosion rate estimates.

A 125 m random sample grid was used to generate USLE and WEE erosion rate estimates. USLE estimates were calculated using the point method of Griffin et al. (1988). WEE estimates were calculated using equations of Skidmore (1988) which were developed to fit the nomographs conventionally used in WEE applications. The model approach yielded an erosion estimate of approximately 9.0 Mg ha-1 yr-1; combining a USLE average estimate of 4.5 Mg ha-1 yr-1 with a WEE average of 4.5 Mg ha-1 yr-1. A site by site comparison of combined model and 137Cs estimates for the 137Cs sample sites yielded a regression output of .07, possibly indicating poor model performance. However, problems in assessing the spatial and temporal variability of soil redistribution indicate a need to further refine the cesium method to reduce variances.

Using the 137Cs method, hilltops, midslopes and footslopes were found to be eroding at 22.9, 28.1, and 0.5 Mg ha-1 yr-1, respectively, for a total net erosion rate of 10.4 Mg ha-1 yr-1. Ponds and channels were found to have deposition rates of 243.9 and 43.0 Mg-1 ha-1 yr, respectively, for a total net deposition rate of 5.0 Mg-1 ha-1 yr. The USLE estimated 90 % of the measured value while the WEE predicted only 44 % of the measured wind erosion. The poor model performance and low precision of the cesium method suggests that the use of the models needs to be considered carefully, especially with regard to watershed scale soil erosion assessments.

SPATIAL VARIABILITY OF SOIL REDISTRIBUTION PROCESSES
IN A SMALL AGRICULTURAL WATERSHED

by

John Cornelius Pings

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1990

APPROVAL

of a thesis submitted by

John Cornelius Pings

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency and is ready for submission to the College of Graduate Studies.

6-15-90
Date

Chairperson, Graduate Committee

Approved for the Major Department

6-15-90
Date

Head, Major Department

Approved for the College of Graduate Studies

June 15, 1990
Date

Henry L Parsons
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Dean of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature [signature]

Date 7-20-00

I dedicate this thesis to my wife, Laura, to my daughter, Lauren Michelle and to my great uncle Robert W. O'loughlin.

ACKNOWLEDGEMENTS

I would like to thank the members of my thesis committee for their assistance and guidance. My committee included Dr. Katherine Hansen-Bristow, Dr. Joseph Ashley, Dr. William Locke III and Dr. Gerald Nielsen. I would especially like to thank my thesis advisor and committee chairperson, Dr. John Wilson, for his guidance and for impressing upon me the principles of sound scientific research. I would like to thank Drs. Douglas Sherman and Bernard Bauer for their help, advice and friendship.

I would like to acknowldge the Department of Earth Sciences at Montana State University for their support including teaching and research assistantships. I also want to thank Dr. Wilson for supporting my research with funds from his National Science Foundation grant. I would like to thank my field assistants, Loretta Thomas and Forrest Sanderson; Artem Vartanian and Lee Murray for their drafting; and my fellow graduate students, in particular Jon Aspie, Chet Clarke and Mike Trombetta for their help and comradery.

I would like to express my appeciation and gratitude to Mr. and Mrs. Norman W. Jackson for allowing me to use their farm for my research. I would like to thank Mr. Raymond McPhail, SCS District Conservationist of the Choteau County Conservation District, for his help in finding a suitable study area and for access to government data and Mr. Ron Nadwornick, SCS State Agronomist, for estimating wheat residue values.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF FIGURES

LIST OF FIGURES--Continued

Figure | Page

ABSTRACT

Physical soil redistribution processes were studied in a small (61 ha) watershed in a region of dryland winter wheat agriculture in north-central Montana. Two approaches were used, a model approach using the Universal Soil Loss Equation (USLE) and Wind Erosion Equation (WEE) soil erosion models, and a field sampling approach using ^{137}Cs. The ^{137}Cs was used as a tracer of erosion and deposition from upland sites (hilltops, midslopes and footslopes) to depositional zones (channels and a pond reservoir bottom). Cesium-137, a fallout product of atmospheric nuclear testing, is strongly adsorbed to clay and has been proven to trace sediment movement. A volumetric approach, developed by De Jong and associates of the University of Saskatchewan, was used to estimate erosion rates of eroding sites and deposition rates of the depositional sites. Landscape units, labelled topographic positions and depositional zones, were defined from a 1:2500 scale plane table topographic contour map, and analyzed for areal concentration of ^{137}Cs to attain erosion rate estimates.

A 125 m random sample grid was used to generate USLE and WEE erosion rate estimates. USLE estimates were calculated using the point method of Griffin et al. (1988). WEE estimates were calculated using equations of Skidmore (1988) which were developed to fit the nomographs conventionally used in WEE applications. The model approach yielded an erosion estimate of approximately 9.0 Mg ha^{-1} yr^{-1}; combining a USLE average estimate of 4.5 Mg ha^{-1} yr^{-1} with a WEE average of 4.5 Mg ha^{-1} yr^{-1}. A site by site comparison of combined model and ^{137}Cs estimates for the ^{137}Cs sample sites yielded a regression output of .07, possibly indicating poor model performance. However, problems in assessing the spatial and temporal variability of soil redistribution indicate a need to further refine the cesium method to reduce variances.

Using the ^{137}Cs method, hilltops, midslopes and footslopes were found to be eroding at 22.9, 28.1, and 0.5 Mg ha^{-1} yr^{-1}, respectively, for a total net erosion rate of 10.4 Mg ha^{-1} yr^{-1}. Ponds and channels were found to have deposition rates of 243.9 and 43.0 Mg^{-1} ha^{-1} yr, respectively, for a total net deposition rate of 5.0 Mg^{-1} ha^{-1} yr. The USLE estimated 90 % of the measured value while the WEE predicted only 44 % of the measured wind erosion. The poor model performance and low precision of the cesium method suggests that the use of the models needs to be considered carefully, especially with regard to watershed scale soil erosion assessments.

CHAPTER 1

INTRODUCTION

Scope and Purpose

The increasing scale of human impact in agricultural areas and a desire to reduce soil erosion problems have provided the impetus for soil erosion assessments in recent years. The U. S. Department of Agriculture (USDA) Soil Conservation Service (SCS) regularly utilizes models such as the Universal Soil Loss Equation (USLE) and a version of the Wind Erosion Equation (WEE) to guide the implementation of conservation procedures, and recent work has focused on improving the methods of estimating model inputs to produce erosion estimates that are spatially variable. In the State of Montana there is a need for large scale soil erosion studies to assist in the development of soil erosion/crop productivity assessments. Similarly, there is a need to collect soil erosion data independent of these modeling efforts so that the contribution of the modeling efforts, themselves, can be evaluated.

This study addresses both needs by quantifying soil erosion and deposition in a small agricultural catchment. Two approaches have been used. The first approach uses the USLE and WEE to estimate soil losses from water and wind, respectively, in the watershed. The second approach uses the spatial variability of Cesium-137 (^{137}Cs) detected in soil samples to quantify erosion from both water and wind and deposition by water.

The USLE and WEE have emerged as the most widely used soil erosion models in North America. It has been used for many national and state/provincial assessments in the United States and Canada and for watershed- and plot-scale studies in both countries (Trimble, 1974, 1977, 1983; van Vliet and Wall, 1979, 1981; Coleman, 1982; Snell, 1984, 1985; Wilson, 1989). USLE and WEE soil loss estimates are also used by the USDA SCS to determine qualification and maintenance requirements for Conservation Reserve Programs (C.R.P.) in Montana.

The techniques used in this study to estimate erosion and deposition rates from ^{137}Cs areal concentrations were developed by Brown and associates (1981a, 1981b) and later refined by De Jong and associates (1983). The ^{137}Cs isotope acts as a tracer of physical soil redistribution processes by its adhesion to fine soil grains. It is a by-product of atmospheric nuclear testing and is delivered through precipitation and wind-carried sediments. Its use as an indicator of erosional and depositional processes has been widespread (Ritchie et al., 1974; Pennington et al., 1976; McHenry and Ritchie, 1977; McCallan et al., 1980; Wise, 1980; Brown et al., 1981b; De Jong et al., 1983; Arnalds, 1984; Arnalds et al., 1989; Dibb, 1989).

Using these approaches, the objectives of this study were twofold. The first objective was to estimate soil losses with the USLE and WEE for a small agricultural watershed. The second objective was to quantify soil erosion and deposition using ^{137}Cs and to use these results to evaluate USLE and WEE performance in the same watershed. The following kinds of data were generated and analyzed to answer these research questions: 1) analysis of climatic, soil, topographic and vegetative cover factors to produce USLE and WEE soil loss estimates at multiple sites; 2) analysis of ^{137}Cs samples to define total and incremental ^{137}Cs areal concentrations for several sites, and determine relative erosion and deposition; and 3) extrapolation of USLE and WEE estimates and ^{137}Cs areal concentration averages by landscape units to obtain erosion and deposition rates for those units and the entire watershed.

Previous Watershed Scale Soil Erosion Studies

Model Studies and Applications

The USLE was derived from 10,000 plot-years of data at locations throughout the United States. This model estimates erosion through the quantification of factor values for rainfall-erosivity (R), soil erodibility (K), topographic factors defined by slope length (L) and slope steepness (S), cover management (C) and supporting practices (P). The USLE is frequently used by the SCS as a tool to determine conservation practices for the control of fluvial erosion, including contour strip-cropping and terracing (Wischmeier, 1976; Wischmeier and Smith, 1978).

Some recent studies have tried to improve the USLE by developing new methods of estimating factor values, particularly the topographic factors, L and S. Williams and Berndt (1977), for example, proposed a method of generating slope frequency data by using a third-order natural spline function developed by Greenville (1967) for points defined by horizontal distances and elevations of contours that cross grid lines on topographic maps. Slope in the direction of the grid lines was determined by differentiating the spline function at each grid intersection point. Wilson (1986a, 1986b) developed a different approach using topographic map input data and Greenville's (1967) spline function to estimate slope length, shape and steepness for slope profiles that cross the elevation contours perpendicularly. Statistical analysis of slope segments was used to divide computer generated slope profiles into segments and the irregular slope method of Foster and Wischmeier (1974) was used to estimate LS values. Griffin and his associates (1988) developed a method of estimating LS factor values for a series of random points. Their method used the distance downslope from the top of the slope profile as well as cumulative and slope segment gradients to estimate LS values for specific points in a landscape.

A more comprehensive revision of several factors will result in the publication of a computer program and manual for the Revised Universal Soil Loss Equation (RUSLE) in 1990 (Renard, 1989, personal communication). The original USLE and RUSLE will most likely be replaced by a completely new physically-based modeling technology in the mid-1990s (Foster, 1989, personal communication).

The Wind Erosion Equation (WEE) was developed at about the same time as the USLE to assess the susceptibility of field soils to wind erosion and to help with the selection and design of wind erosion control practices (Chepil et al., 1962; Woodruff and Siddoway, 1965). This equation estimates erosion as a function of magnitude and direction of wind as well as soil erodibility (I), soil ridge roughness (K), vegetation orientation and cover (V), and field fetch length (L). The WEE equation was used in early conservation applications. Skidmore and Woodruff (1968) later compiled pertinent climatic data for many stations from existing sources to assist in the application of the WEE throughout the country. The model and climatic data were published for farmers and conservation program workers. In one of the most innovative applications of the WEE to date, Bondy et al. (1980) estimated wind erosion by cropstage period as a function of wind energy distribution. Their method used temporally variable vegetative residue equivalents, soil tillage conditions and soil erodibility to estimate wind erosion for 10 different cropstage periods in a winter wheat/summer fallow system in Kansas and a spring wheat/spring wheat/fallow system in North Dakota. Skidmore (1988) substituted equations to estimate WEE factor values for the tables and nomographs of Woodruff and Siddoway (1965). These equations, first proposed by Williams et al. (1984), eliminate the need to interpolate factor inputs and reduce the time and effort needed to apply the WEE. The SCS Agricultural Research Service developed a version of the WEE, the WEQ, for use by SCS personnel in field applications.

Previous Cesium-137 Studies

Cesium-137 is a widely dispersed radioactive isotope that is a by-product of atmospheric nuclear testing which the United States, Soviet Union and United Kingdom began on a frequent basis in 1954 (Campbell et al., 1982). These tests are still carried out on a much smaller scale by France and China (Anonymous, 1989). The period of most intense atmospheric dispersion occurred between 1962 and 1965 immediately before the United States, Soviet Union and 41 other nations signed a treaty suspending atmospheric testing of nuclear weapons in 1966 (Campbell et al., 1982). Cesium-137 has a regional distribution that is linked to precipitation sources and quantities. The isotope is transported through the stratosphere and troposphere by global circulation patterns and delivered to soils through two methods. One method involves delivery through precipitation, and the second method involves dry deposition of ^{137}Cs with atmospheric particulate matter from the atmosphere. Its local concentration is dependent upon the available amount of the isotope in the atmosphere at the time of precipitation events, its altitude, and prevailing regional and local meteorological conditions (McCallan et al., 1980).

Several assumptions govern the use of this isotope as a tracer of soil redistribution process analysis. It is assumed that: 1) the isotope has been delivered to the watershed uniformly; 2) the ^{137}Cs becomes adsorbed to the clay- and silt-sized soil particles when it reaches earth; 3) these sediments have not undergone any sorting; and 4) the redistribution of ^{137}Cs by winter winds, plant and animal life has been minor (< 5 percent) and/or at least uniform throughout an individual watershed (Brown et al., 1981a, 1981b; De Jong et al., 1982, 1983; Arnalds, 1984).

Cesium-137 can be used to quantify soil erosion and deposition rates because its half-life (30.2 years) and known period of existence (dispersion since 1954) allow estimates of average annual erosion and deposition rates to be made (Brown et al., 1981a). Once these rates are known, additional variables such as intensity of areal concentration, topographic position, and maximum depth of ^{137}Cs activity in the soil profile facilitate the delineation of erosional and depositional zones in watersheds because the ^{137}Cs moves only with sediment that is transported

(De Jong et al., 1982, 1983).

A conceptual model of ^{137}Cs input, activity and transport in a drainage basin is reproduced in Figure 1. Most studies use this type of model to quantify erosion and deposition rates. The bar diagrams of typical ^{137}Cs areal concentrations for various landscape units in Figure 1 illustrate the variable nature of ^{137}Cs activity at different locations in a watershed.

Several studies have examined ^{137}Cs in test plots and watersheds to determine regional concentrations (e.g., Rogowski and Tamura, 1970; Lance et al., 1986; Kachanoski, 1987; Dibb, 1989). Arnalds (1984) measured average ^{137}Cs areal concentrations between 3.6 and 20.2 picocuries per square cm (pCi cm^{-2}) at 12 sites throughout Montana. These concentrations were strongly related to precipitation (R^2 = 0.92), indicating that local precipitation totals will provide a good first estimate of expected ^{137}Cs levels (Arnalds, 1984; Arnalds et al., 1989). Given the previously mentioned regional sources and controls and the assumptions noted above, several researchers have constructed ^{137}Cs mass balances to infer soil erosion and deposition rates (De Jong et al., 1983; Arnalds, 1984; Pennock and De Jong, 1987).

Cesium-137 has been applied to erosion and sedimentation studies in a variety of contexts. Several studies have shown that concentrations have increased in areas of sediment accumulation such as valley floors, lakes, reservoirs and salt marshes (e.g., McHenry et al., 1973; Ritchie et al., 1974, 1975; Pennington et al., 1976; Delaune et al., 1978; McCallan et al., 1980; Brown et al., 1981a, 1981b; Campbell et al., 1982; De Jong et al., 1983; Arnalds, 1984; Pennock and De Jong, 1987). Cesium-137 has been used to determine erosion of natural and clearcut

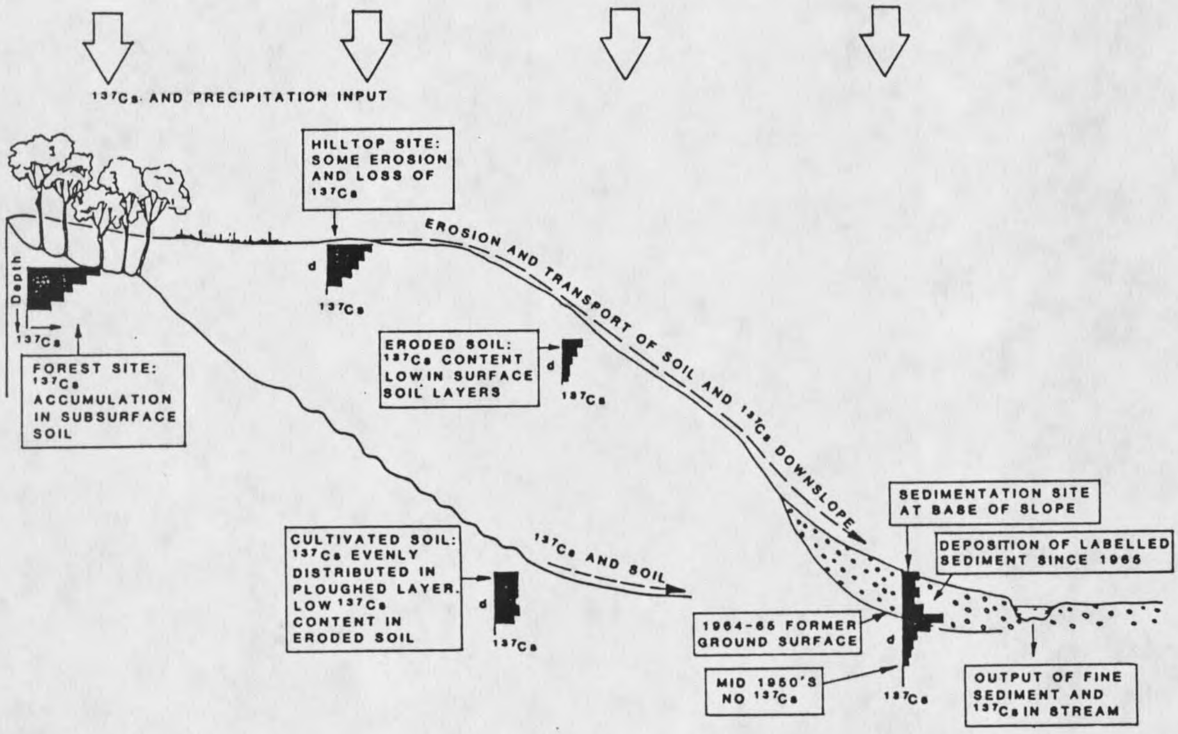

Figure 1. Cesium-137 in a drainage basin (from Campbell et al., 1982).

forests and forest/field systems at a variety of spatial scales (Brown et al., 1981a, 1981b; Campbell et al., 1982; Lowrance et al., 1988). Other studies have used ^{137}Cs to evaluate soil erosion and deposition on agricultural soils (Brown et al., 1981b; Campbell et al., 1982; De Jong et al., 1983; Arnalds, 1984; Pennock and De Jong, 1987).

Recent studies have quantified erosion and deposition rates for entire watersheds by using weighted average areal concentrations for different landscape units (Brown et al., 1981b; De Jong et al., 1983; Arnalds, 1984; Pennock and De Jong, 1987). Several methods have been developed to distinguish landscape units. For example, Brown et al. (1981b) divided their watershed into erosional and depositional zones, with hilltops and midslopes representing erosional zones and footslopes and an alluvial fan representing depositional zones. De Jong et al. (1983), on the other hand, distinguished three landscape units - upper, middle, and lower slopes - determined in the field by pacing. Arnalds (1984) added two further units to this classification, shoulder slopes between hilltops and midslopes, and toeslopes beneath lower slopes (footslopes) but defined his transects by selecting soil samples for ^{137}Cs analysis 50 m apart. Pennock and De Jong (1987) used a similar approach to De Jong et al. (1983) in an attempt to decipher the influence of profile and plan curvature on soil redistribution processes. A digital terrain model was created from an existing digitized topographic survey and used to distinguish convergent and divergent backslopes, convergent and divergent shoulders, convergent and divergent footslopes, and level areas (Pennock and De Jong, 1987). Care must be exercised when using this terminology because the landscape units are defined and labeled using different methods and definitions in different studies. However, the general approach of extrapolating average ^{137}Cs areal concentrations to landscape units is now widely used to estimate average annual erosion and deposition rates.

Most recent studies have undertaken ^{137}Cs detection with laboratory analysis using a lithium-drifted germanium semi-conductor gamma ray detector coupled to a nuclear data multi-channel analyzer (Cutshall and Larsen, 1980; Larsen and Cutshall, 1981; Brown et al., 1981a, 1981b; De Jong et al., 1983; Arnalds, 1984). Cesium-137 concentrations are calculated by multiplying the ^{137}Cs activity in core samples (pCi g^{-1}) by the soil mineral bulk density (g cm^{-3}) and depth of the soil sample (cm).

Results are expressed as radioactivity per unit surface area of soil surface or the "areal concentration" (e.g., Brown et al., 1981b; De Jong et al., 1983; Arnalds, 1984; Pennock and De Jong, 1987).

Campbell et al. (1982) used a different approach to determine ^{137}Cs areal concentrations. Their approach relies on the fact that ^{137}Cs adheres to fine soil fractions, so that the areal concentrations are calculated using only the silt and clay fractions. Silt and clay fractions were estimated using the hydrometer method and their bulk densities were used instead of that of the total sample. This study used an experimental watershed in New South Wales, Australia, which was found to have ^{137}Cs distributed evenly in upper soil layers due to plowing. Areal concentrations were quantified for a variety of topographic positions in upland and lowland areas although no erosion or deposition rates were estimated (Campbell et al., 1982).

In contrast, many North American studies have tried to estimate erosion and deposition zones and rates from ^{137}Cs analysis. Brown and associates (1981b) computed erosion estimates ranging from 3 to 27 t ha^{-1} yr^{-1} for erosional zones based upon detected ^{137}Cs ranging from 3.5 to 15.2 pCi cm^{-2} in two Willamette Valley, OR watersheds. Six out of eight footslopes tested were found to be eroding (Brown et al., 1981b). In another study, De Jong et al. (1983) found upper slopes to have lost 200 to 600 t ha^{-1} of soil while lower slopes were found to have gained 250 to 800 t ha^{-1}. However, middle slopes were found to be both depositional and erosional over 20 to 25 years in eight small Saskatchewan, Canada basins with glacial soils (De Jong et al., 1982; 1983).

Arnalds (1984) examined erosion in a small watershed near Power, MT in which he detected ^{137}Cs areal concentrations ranging from 2.4 to 24.6 pCi cm^{-2}. Hilltops and footslopes both were found to be eroding at 16.5 Mg ha^{-1} yr^{-1}, while shoulders and midslopes were eroding at 20.9 and 45.1 Mg ha^{-1} yr^{-1}, respectively. Toeslopes were found to have deposition occurring at a rate of 9.9 Mg ha^{-1} yr^{-1}. The estimates for the shoulders, midslopes and footslopes compared favorably with USDA SCS soil loss estimates produced with the USLE and WEE models.

Lance et al. (1986) collected data on ^{137}Cs activities in the southwestern United States as well as in adjacent cultivated and grassed watersheds in Oklahoma. A major conclusion of this study based upon the results of a soil mass balance was that ^{137}Cs activity might be a more sensitive indicator of soil productivity losses than measurements of total mass of soil removed from a field caused by highly localized erosion and deposition. McIntyre et al. (1987) found a clearcut forest to be eroding at only 0.2 t ha^{-1} yr^{-1} and attributed the erosion to soil compaction by livestock grazing of native grasses. In a related study Lowrance et al. (1988) estimated erosion and deposition rates of 63 and 256 Mg ha^{-1} yr^{-1}, respectively, for a riparian forest/field system watershed on the southern Georgia coastal plain. The unusually high deposition was attributed to sediment that was transported from upstream locations and deposited during flood events. Three different calculation methods produced nearly identical results.

Pennock and De Jong (1987) examined more landform elements than the other studies and found four of seven to be erosive, from most to least erosive: convergent shoulders, divergent backslopes, convergent backslopes and divergent shoulders. The depositional units were, in order from least depositional to most: divergent footslopes, level areas and convergent footslopes. Soil loss predictions for these same areas using the USLE were two to nine times lower than those indicated by the ^{137}Cs method (Pennock and De Jong, 1987).

Description of Study Area

The study watershed covers approximately 61 ha and is located in Choteau County near Carter, Montana at 47° 53′30" N and 110° 52′00" W (Figure 2). It is located on the U.S.G.S. Carter N.E. 7.5 minute quadrangle in the SW and SE 1/4′s of section 30, Township 25 North, Range 7 East. The watershed is located within a mapped unit of the Colorado Shale and is located approximately 40 km north of the southernmost extent of the Laurentide ice sheet.

The watershed consists of hummocky terrain of glacial origin. Local relief is 22 m, with the highest elevations along the western boundary approaching 922 m. The watershed is drained by an unnamed tributary of the Frank Gilbert Coulee, which drains to the Teton River and eventually to the Missouri River. The area is a mixture of gentle slopes in the west and steeper slopes along the eastern boundary. A well defined ephemeral channel system drains into an incised channel and a 0.25 ha pond situated behind an earth dam constructed in 1973.

The annual average precipitation measured in nearby Great Falls is 390 mm yr^{-1}, with a May-June maximum. Average annual rainfall varied from 186 to 475 mm yr^{-1} between 1954 and 1986. Analysis of wind data for Great Falls between 1950 and 1955 indicates a predominant annual wind direction

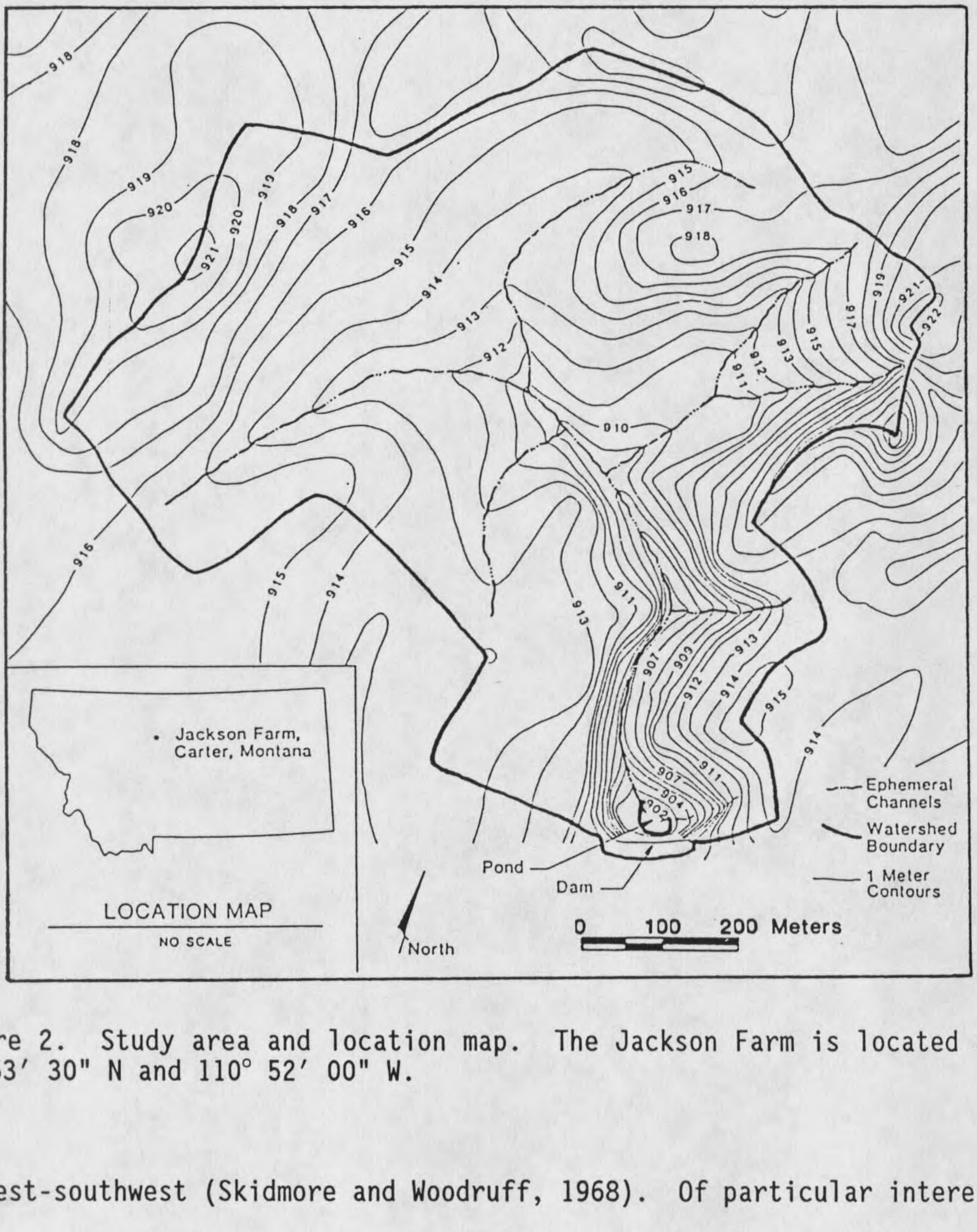

Figure 2. Study area and location map. The Jackson Farm is located at 47° 53′ 30" N and 110° 52′ 00" W.

of west-southwest (Skidmore and Woodruff, 1968). Of particular interest to this study is the percent of cumulative erosive wind energy (EWE) that occurs by a particular month (see Table 1). According to the data, the critical period for erosive wind is between October and April, during which 83 % of the erosive wind occurs.

The soils of the study area are fine, montmorillonitic Aridic Argiborolls (Ethridge series, a silty clay loam) and fine, montmorillonitic frigid, Typic Albaqualfs (Nishon series, a silty clay) (unpublished soil survey maps, Mr. Raymond McPhail, SCS District Conservationist, Choteau County, MT, 1987) (Figure 3). The watershed is part of the Mr. Norman W. Jackson farm which is used mostly for the cultivation of winter wheat. The farm is managed in a winter wheat/summer fallow system. The watershed is almost completely tilled with the exception of the incised channel and pond areas and their margins.

The watershed has undergone considerable change in the last half-century. The middle portion of the study area was formerly a small, seasonal lake. In the 1940's, a channel was incised from the lake to the coulee bottom to drain the lake to allow tillage. The incised channel remains an active component of the fluvial system, channeling overland flow from the upland areas of the watershed. An earth dam was constructed across the mouth of the coulee to create a pond in 1973. The landowner had planned to stock this pond with fish but the pond has always emptied after precipitation events and spring runoff because of a slow leak (Norman Jackson, Carter, MT, personal communication, 1987). This has prevented permanent filling of the reservoir, but it drains slowly enough (a period of months) to be an efficient sediment trap. The ephemeral nature of the pond was beneficial to the present study because it provided access to reservoir bottom sediments.