SOILS AND SOIL EROSION IN THE TRI-CREEKS EXPERIMENTAL WATERSHED, ALBERTA

by:
H.R. Hudson
Civil Engineering Department
and
G.M. Greenlee
R.W. Howitt
Terrain Sciences Department

Civil Engineering Department
ALBERTA RESEARCH COUNCIL
Report No. SWE 85/08
1985

ABSTRACT

A detailed soil survey of the Tri-Creeks experimental watershed was conducted to delineate soils and related properties for the purpose of hydrologic and sediment yield modelling. The 59 km^2 watershed features three major soil associations, two minor associations, and three soil complexes. The soils are classified as moderately to very highly erodible using the Universal Soil Loss Equation (USLE) K factor as an erodibility index. Erosion potential was described in terms of a combination of the soil erodibility index K and the topographic factor LS of the USLE. Most of the upper basin was classified as potentially highly erodible. The lower basin was classified as potentially moderately erodible. Upland erosion was largely limited to disturbed areas, particularly roads, scarified areas and seismic lines. In addition, stream channel erosion occurred throughout the study area in disturbed and undisturbed areas.

ACKNOWLEDGEMENTS

The work reported herein is part of an Alberta Research Council (ARC) study of the consequences of forest harvesting on the hydrologic and sediment regimes of the Tri-Creeks experimental watershed.

The Alberta Forest Service provided field accommodation, supplied maps and aerial photographs, and provided some field assistance. Staff of the Terrain Sciences Department (ARC), Agriculture Canada, and the Civil Engineering Department (ARC) provided field and laboratory support. T. Ridgway prepared the photo-mosaic base map for field use. B. Balakrishna, A. Beerwald, G. Legge, J. Mellon, J. Olic, and W. Wasciliw provided field assistance at various times. J. Beres, W. McKean, A. Schwarzer, and Mrs. D. Storr conducted the laboratory analyses under the direction of S. Abboud who also assisted with interpretation. R. Howitt and R. MacMillan developed the electronic notebook procedures and data analysis used in this study. Mrs. D. Storr and Dr. L. Turchenek helped describe and classify the organic soils. Mrs. J. Dlask drafted the initial soil map and the Graphic Services Department (ARC) produced the final map. Ms. C. Hutton and Ms. T. Slevinski typed the manuscript.

The soil survey was conducted with the guidance of Dr. R.A. Harrington (project manager) and R. MacMillan who also reviewed the report. Dr. R.J. Fessenden also reviewed the report. Thanks are extended to all of the individuals concerned.

TABLE OF CONTENTS

Page

ABSTRACT .... (i)
ACKNOWLEDGEMENTS .... (ii)
TABLE OF CONTENTS .... (iii)
LIST OF FIGURES .... (v)
LIST OF TABLES .... (vi)

INTRODUCTION 1

METHODOLOGY 5

SOIL MAPPING 7

DESCRIPTIONS OF SOIL ASSOCIATIONS 10
    Jarvis Association (JRV) 10
    Marlboro Association (MLB) 10
    Maskuta Association (MSK) 12
    Robb Association (RBB) 13
    Tri-Creek Association (TRC) 15

MISCELLANEOUS SOIL COMPLEXES 16
    Alluvium Complex (AV) 16
    Erith Complex (ETH) 17
    Fickle Complex (FKE) 19

SOIL EROSION FEATURES AND SOIL ERODIBILITY 20
    Observed Erosion Features 20
    Soil Erosion Potential 28

LIST OF FIGURES

Page

Figure 1. Location and hydrologic features of the Tri Creeks study area 2

Figure 2. Thickness, distribution and type of surficial glacial deposits in the study area (based on Curry, 1972) 4

Figure 3. Locations of the 155 soil inspection sites and 70 soil sampling sites in the Tri Creeks study area 6

Figure 4. Location of documented erosion sites 26

Figure 5. Spring melt water and rainfall concentrate at roads and enter small tributary streams in upper Eunice Creek 27

Figure 6. The reclaimed winter haul road parallelling upper Wampus Creek is a major sediment source 27

Figure 7. Seismic lines cut in the late 1950's have developed into gullies in lower Eunice Creek 29

Figure 8. Timber harvesting has resulted in slope instability in shallow glaciolacustrine material on cut block 22 in Deerlick Creek 29

INTRODUCTION

A detailed soil survey of the Tri-Creeks experimental watershed was conducted during 1984 to delineate soils and related properties for the purpose of hydrologic and sediment yield modelling. The 59 km^2 watershed, which is located in the foothills of West Central Alberta (figure 1), is an International Hydrological Decade Experimental Research basin (number 1 W.B.- E.B.- 13), that is under study to evaluate the effects of pulpwood harvesting on the aquatic environment.

The objectives of this study were to:

(1) describe the soils of the Wampus, Deerlick and Eunice Creeks drainage basins which constitute the "Tri Creeks" experimental watershed;

(2) relate the distribution of soil associations to pertinent topographic, hydrometerologic and geologic parameters, and,

(3) describe and discuss the susceptibility of the various soil associations to erosion by running water.

The report is presented in three main sections: **(1)** a description of methodology; **(2)** a description of soil associations (accompanied by a 1:15 000 map and legend), and **(3)** a description of soil erosion features and soil erosion potential. In addition, a summary of the soil chemical and physical properties and descriptive terms are appended.

The reader is referred to Dumanski, Macyk, Veauvy and Lindsay (1972), Currie (1976) and Hillman, Powell and Rothwell (1978) for a detailed discussion of the environment of the Tri Creeks watershed including physiography, geology, climate, vegetation, drainage and hydrology. A brief summary of these features is presented to provide an overview of the setting.

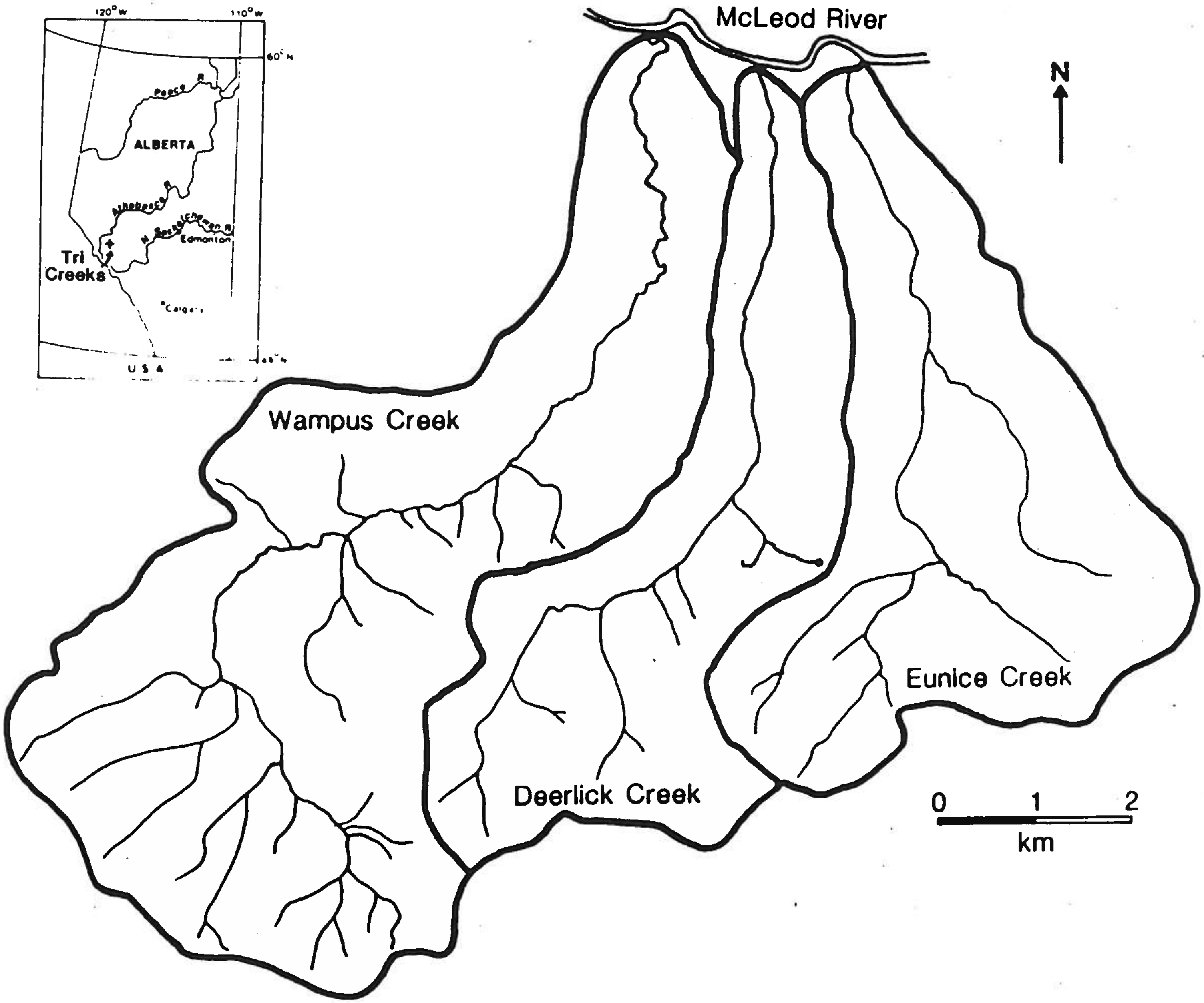

Figure 1. Location and hydrologic features of the Tri Creeks study area

The Tri Creeks streams flow about 10 to 15 km from the high foothills of the Brazeau syncline north-east into the McLeod River. The streams flow through the general topographic form of NNW-SSE trending ridges and valleys which decrease in elevation from around 1 650 m in the headwaters to about 1 280 m at the McLeod River. The imbricated, southwest dipping, folded and faulted thrust sheets which structuraly determine the high relief, ridge and valley topography, consist of thick sequences of clastic rocks mostly of the Brazeau formation of Late Cretaceous age. At higher elevations, the basin is blanketed by till deposits which are generally less than 3 m thick. In the valley bottoms the deposits, which locally exceed 20 m in depth, are predominantly till and glaciolacustrine silts with alluival materials associated with present day drainage channels (figure 2).

The mean annual precipitation ranges with location from an average of 650 to about 670 mm of which approximately one third falls as snow. Bergstrom (1980) estimated that about 40 percent of the precipitation leaves the drainage basin as surface runoff. The mean annual daily temperature at Robb is 1.5°C. The mean summer temperature (May to September) is 11°C and the mean winter temperature is -5°C.

Lodgepole pine is the predominant tree species on well drained upland sites, but white spruce and black spruce are also well represented. Wet areas are covered with black spruce or muskegs. About 44 percent of Wampus Creek basin was clear cut in several cutblocks and scarified mainly in the period 1977 to 1981. About 42 percent of Deerlick Creek was clear cut and scarified in 1984. Eunice Creek is the control basin and has minor clear cuts (2 percent) made in 1959 which are largely re-vegetated. Seismic lines, which were cut mainly in the late 1950's, cross each of the basins.

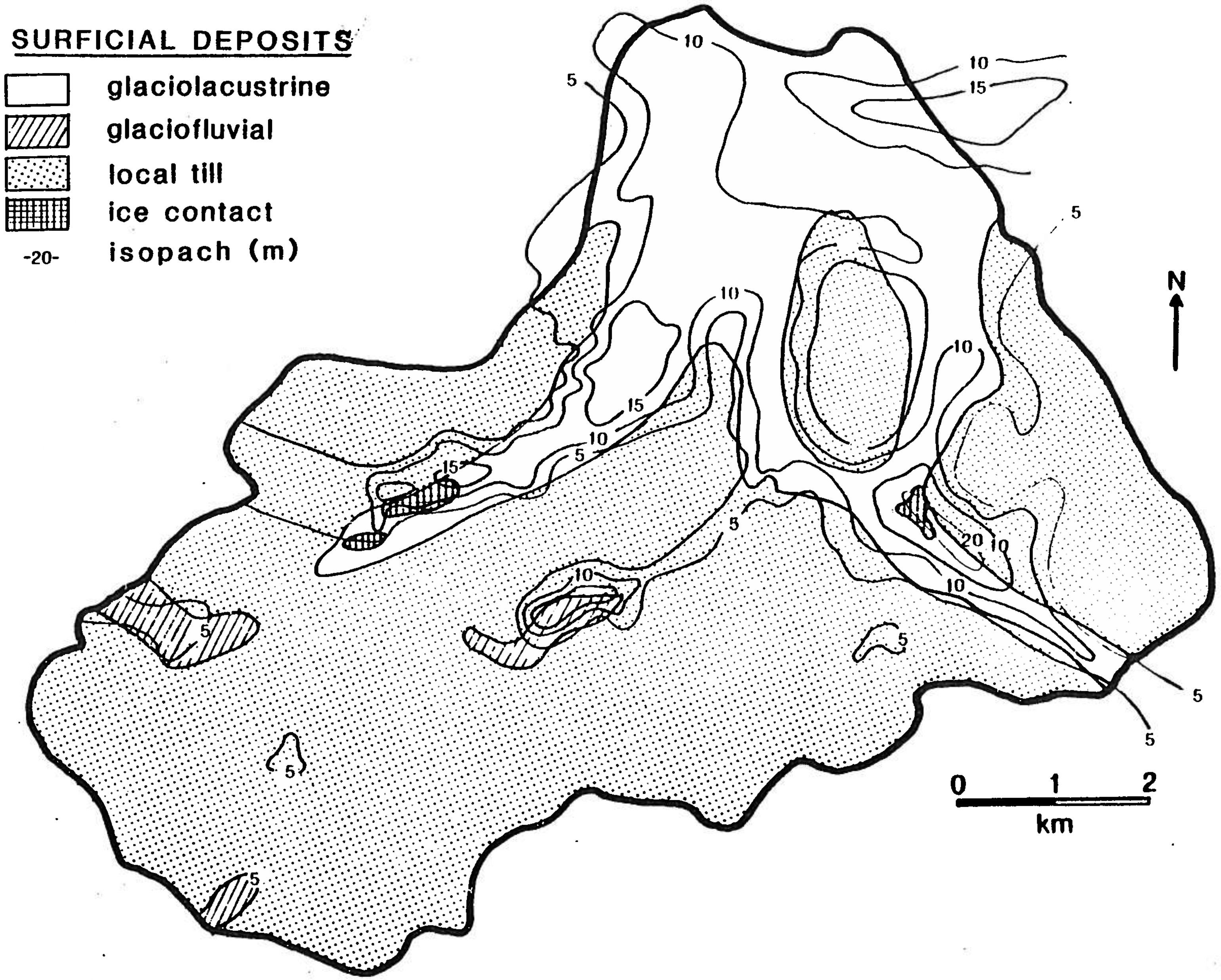

Figure 2. Thickness, distribution and type of surficial glacial deposits in the study area (based on Curry, 1972).

METHODOLOGY

As previously stated, the purpose of the soil survey is to identify and delineate different soil patterns in the landscape. These different soil patterns are then used to make predictions about soil properties and soil behaviour throughout the study area for the purpose of determining the susceptibility of the various soils to erosion.

The soil survey of the Tri Creeks study area was undertaken using standard soil survey practice (Canada Soil Survey Committee, 1978) at various survey intensity levels (SIL) throughout the area. The survey intensity level refers to the detail with which the soils are described and mapped. Five survey intensity levels have been defined by the Mapping Systems Working Group (1981). Level one is the highest intensity, with the most detailed procedures, resulting in the most accurate map. Level five is the lowest intensity, with the least detailed procedures, giving a generalized map. Ground truth inspection levels in the Tri Creeks study varied from relatively detailed (SIL2) in the northern portion of the area, to considerably less detailed (SIL4) in the less accessible southern portion (figure 3).

Soil pits were dug throughout the watershed (figure 3) to examine and describe soil horizons and site characteristics according to the criteria outlined in the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). The soil profile descriptions consisted of naming and describing the surface organic horizon and the master mineral horizons, with the descriptions including thickness, texture, structure, permeability and percentage coarse fragments. The site descriptions included naming the soil mapping unit, identifying the soil parent material, type, texture and percentage coarse fragments, depth to non-conforming layers, texture and percentage coarse fragments of non-conforming layers, indicating the surface expression and slope position, measuring the percentage slope, naming the soil subgroup, indicating the soil phase if present, measuring the depth to carbonate if found, and determining the degree of carbonate effervescence if carbonate was found. This data was entered on site into a Omnidata

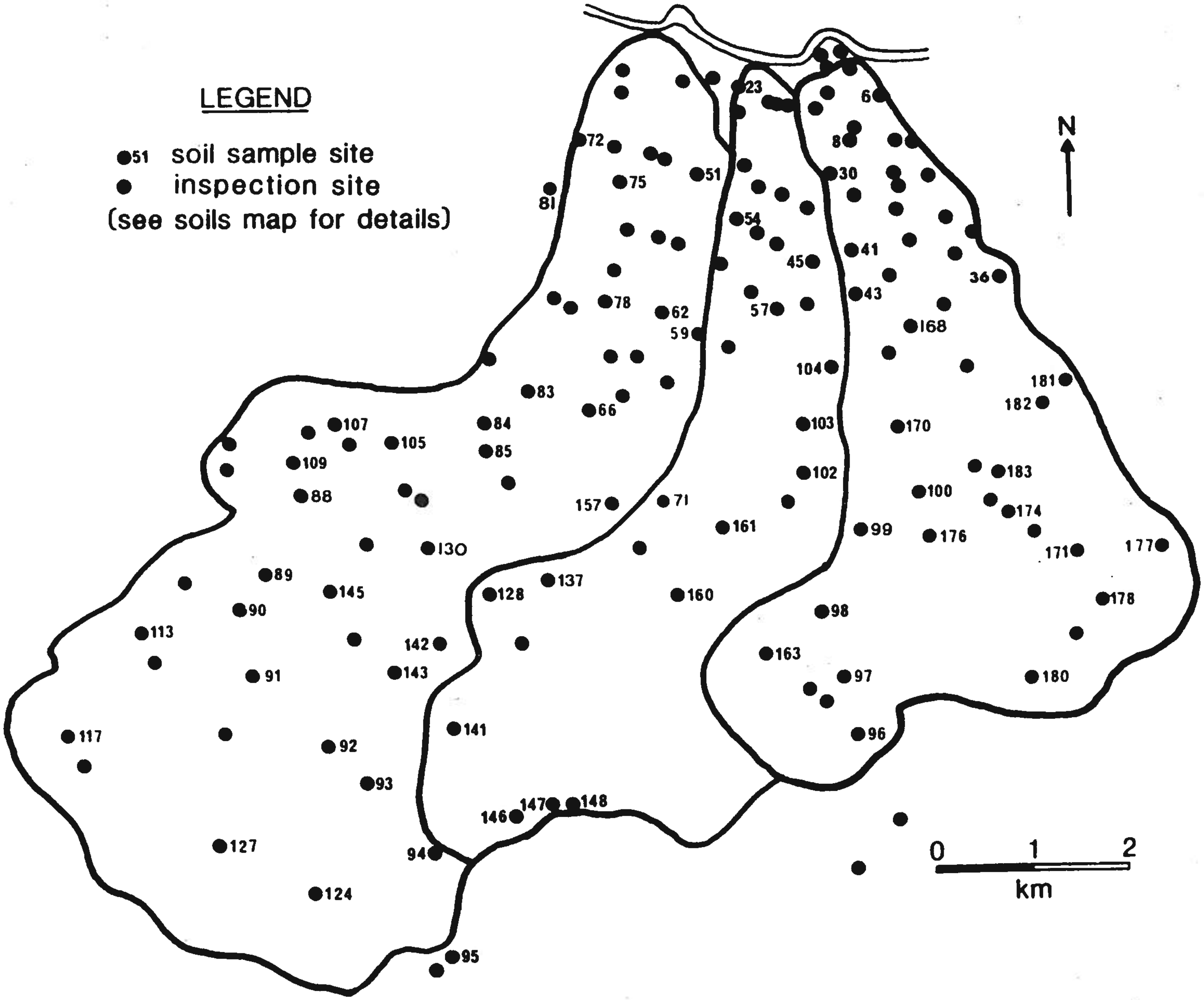

Figure 3. Locations of the 155 soil inspection sites and the 70 soil sampling sites in the Tri Creeks study area.

Polycorder model 516 electronic notebook.

Soil boundaries were determined along lines of traverse, then extrapolated on black and white aerial photographs of 1:60 000 scale with the aid of a pocket stereoscope. The field and final mapping is appended as a photo-mosaic at a scale of 1:15 000.

Soil samples from the master mineral horizons were collected for chemical and physical analyses at approximately half of the soil inspection sites throughout the watershed (figure 3). Generally, sub-horizons within master mineral horizons were not sampled separately unless a marked textural change occurred within the horizon. Rather, sub-horizons were sampled as one and combined as a composite sample, representing the overall master horizon.

Drainage characteristics were qualitatively described using the definitions in Appendix 3. Singh (1983) measured the infiltration rates of the major soil associations in the study area and vicinity using double ring infiltrometers.

SOIL MAPPING

The soil associations used in this survey are named according to the scheme established by Dumanski, Macyk, Veauvy and Lindsay (1972). Mapping units are subdivisions of the soil associations based on the relative proportion of dominant and significant soils. A soil is considered to be dominant if it occupies more than 40 percent of the unit whereas soils which occupy 15 to 40 percent of the map unit are considered to be significant. Soils which occupy less than 15 percent of a map unit are inclusions and do not influence map unit designation. It is the map unit designation which identifies the soil association and the relative proportions of the soils in each delineation on the map.

Map unit designations may be further modified with a phase identifier. The phase identifier is a mapping convention that allows identification of pertinent features of the landscape not reflected in soil taxonomy. Three phases have been identified in this study:

Lithic Phase:	Consolidated bedrock occurs within 100 cm of the soil surface.
Peaty Phase:	15 to 60 cm of fibric moss peat or 15 to 40 cm of other kinds of peat is found above the mineral soil surface.
Shallow Phase:	A second parent material occurs within 100 cm of the soil surface (mineral soils only).

Each delineation on the map is identified with a symbol which incorporates the soil association name, map unit designation, topographic class and phase identifier. For example, $\frac{\text{MLB 6/L}}{\text{F}}$ indicates Marlboro association map unit 6 (MLB6), lithic phase (L), on a 15 to 30 percent slope (F).

Table 1. Topographic Classes

Simple Topography (single slopes) (regular surface)	Complex Topography (multiple slopes) (irregular surface)	Slope %
A depressional to level	a nearly level	0 to 0.5
B very gently sloping	b gently undulating	>0.5 to 2
C gently sloping	c undulating	>2 to 5
D moderate sloping	d gently rolling	>5 to 9
E strongly sloping	e moderately rolling	>9 to 15
F steeply sloping	f strongly rolling	>15 to 30
G very steeply sloping	g hilly	>30 to 60
H extremely sloping	h very hilly	>60

(Source: National Soil Survey Committee of Canada, 1974).

Two further mapping conventions were used in this study. Miscellaneous land units are areas of undifferentiated soils but with distinct identifiable features. Three were identified in the study area:

/\/\/ - outcropping bedrock

GV - Gravel Bars

RB - rough broken steeply sloping river stream banks

Miscellaneous soil complexes are soil units in which soil distribution and characteristics are not differentiated in detail. These include very young soils developed on alluvial materials, Gleysic soils, and organic soils. Three soil complexes were identified in this study and are described in the following section.

DESCRIPTIONS OF SOIL ASSOCIATIONS

Three major soil associations, two minor associations, and three soil complexes were recognized in the Tri Creeks study area. Each association was described in terms of the parent material, landform and topography, internal and surface drainage and soil texture. Each soil map unit was described and their properties were related to other units and topography. Pertinent features of the soil associations and soil complexes and their distribution are appended.

JARVIS ASSOCIATION (JRV)

The Jarvis association consists mainly of Luvisolic and Brunisolic soils, developed on cobbly outwash gravel (Dumanski et al., 1972). One small pocket of Jarvis soils was mapped in the Tri-Creeks watershed, in the south-central Wampus Creek basin. Thickness of these deposits varies from a few meters to a few tens of meters, and they overlie bedrock or till. The topography is very steeply sloping, surface drainage and internal drainage are excessive. One Jarvis association soil pit was examined in the study area. The A-horizon texture was sandy loam, the B-horizon texture was loam, and the parent material texture was gravel with pockets of loamy sand. At the site examined, thickness of the A-horizon was 22 cm, and thickness of the B-horizon was 16 cm. The depth to the lime accumulation horizon was more than a meter.

One map unit was identified in the study area:

JRV3 - Dominantly Podzolic Gray Luvisol, in combination with significant amounts of Brunisolic Gray Luvisol and Orthic Gray Luvisol.

MARLBORO ASSOCIATION (MLB)

The Marlboro association consists chiefly of Luvisolic soils developed on medium to fine textured cordilleran till (Dumanski et al., 1972). The till is friable and moderately stony. It is generally silty clay loam or clay loam in texture but loam textures are also common.

Although the till is generally more than a meter thick in the study area, bedrock was sometimes found within about 70 cm of the surface on ridge or hill crests and in upper slope positions. The bedrock is commonly sandstone, but shale also occurs. Marlboro soils cover about half of the study area and are dominant in the upper basin where till is predominant.

Marlboro soils commonly occur on bedrock controlled inclined landforms. Occasional hummocky and rolling till landforms also occur. Topography ranges from gently to very steeply sloping, but is commonly steeply sloping.

Marlboro soils are generally well drained except in lower slope positions, where the soil may be imperfectly drained. A-horizon textures are predominantly silt loam. B-horizon textures range from loam and silt loam, to clay loam and silty clay loam.

Three Marlboro map units were identified in the study area:

MLB5 - Dominantly "bleached" Orthic Gray Luvisol, in combination with significant amounts of Brunisolic Gray Luvisol and Eluviated Dystric Brunisol; possible inclusions of weakly gleyed and shallow soils; commonly occurring on steeply sloping topography covering about 7 percent of the study area.

MLB6 - Dominantly Brunisolic Gray Luvisol, in combination with significant amounts of Podzolic Gray Luvisol and Eluviated Dystric Brunisol; possible inclusions of weakly gleyed and shallow soils; commonly occuring on steeply sloping topography, covering about 42 percent of the study area.

MLB7 - Dominantly Orthic Gray Luvisol, in combination with significant amounts of Podzolic Gray Luvisol and Eluviated Dystric Brunisol; possible inclusions of "bleached" Orthic Gray Luvisol and shallow soils; occurring on very steeply sloping topography and covers less than one percent of the study area.

Dumanski et al. (1972) identified several other Marlboro soils in the vicinity of the study area. The lithic phase of Marlboro soils was mapped in the study area.

The thickness of Marlboro A-horizons ranged from about 15 cm on ridge and hill crests, to 22 cm on mid slopes. The thickness of B-horizons ranged from 26 cm on crests, to 36 cm on lower slopes. The depth to the lime accumulation horizon commonly exceeded a meter. The carbonate content of BC horizons ranged from 0.04 to 0.15 percent (Appendix 2).

MASKUTA ASSOCATION (MSK)

The Maskuta association consists of Brunisolic and Luvisolic soils developed on weathered bedrock (Dumanski et al., 1972). The bedrock is dominantly sandstone and shale in the study area and the soils reflect the nature of the bedrock. Weathering depth is commonly less than 30 cm. Occurences of these soils are limited to about five percent of the study area located mainly in upper Deerlick Creek and the central Eunice Creek basins on steeply to very steeply sloping landforms.

Maskuta soils are well drained. A-horizon textures range from silt loam to sandy loam. B-horizon textures range from sandy loam to clay loam.

One Maskuta map unit was identified in the study area:

MSK4 - Dominantly Eluviated Dystric Brunisol lithic phase, in combination with Orthic Dystric Brunisol, lithic phase; possible inclusions of Orthic Gray Luvisol, lithic phase, and Brunisolic Gray Luvisol, lithic phase.

Maskuta A-horizon thicknesses range from 8 cm on upper and mid slopes, to 15 cm on lower slopes. The thickness of B-horizons range from 22 cm on upper slopes, to 40 cm on lower slopes. The depth to the lime accumulation horizon commonly exceeded a meter. The carbonate content in one BC horizon sample was 0.08% (Appendix 2).

ROBB ASSOCIATION (RBB)

The Robb association consists of Brunisolic and Luvisolic soils developed on mixtures of till and colluvium parent materials overlying bedrock on steep slopes (Dumanski et al., 1972). The parent material is primarily medium textured till of Cordilleran origin. Occasional moderately coarse textured pockets also occur. The till is friable, and moderately to very stony. In the study area the thickness generally exceeds a meter, but bedrock often occurs within 60 cm on upper slopes and crests. The bedrock is usually sandstone, but sometimes shale. Robb soils occupy about 18 percent of the study area.

Robb soils are generally well drained but may be imperfectly to poorly drained on lower slopes and in depressions. The A-horizon texture of Robb soils is usually silt loam, but may be loam. B-horizon textures are generally silt loam to loam.

Five Robb map unit soils were described in the study area:

RBB1 - Dominantly Eluviated Dystric Brunisol, in combination with significant amounts of "bleached" Orthic Gray Luvisol and Brunisolic Gray Luvisol; possible minor inclusions of Eluviated Eutric Brunisol, weakly gleyed, and very shallow soils; occurring predominantly on steeply to very steeply sloping topography over less than one percent of the study area.

RBB2 - Dominantly Eluviated Dystric Brunisol, in combination with significant amounts of Brunisolic Gray Luvisol and Podzolic Gray Luvisol; possible inclusions of Eluviated Eutric Brunisol, weakly gleyed, and very shallow soils; occurring predominantly on steeply to very steeply sloping topography, but occasionally on gently sloping topography over about nine percent of the study area primarily in mid and upper Eunice and mid Deerlick Creek basins.

RBB4 - Dominantly Eluviated Dystric Brunisol and "bleached" Orthic Gray Luvisol, in combination with significant amounts of Brunisolic Gray Luvisol and Podzolic Gray Luvisol; possible inclusions of Orthic Dystric Brunisol, weakly gleyed, and very shallow soils; occurring on steeply to very steeply sloping topography on about five percent of the study area.

RBB5 - Dominantly Eluviated Eutric Brunisol, in combination with significant amounts of "bleached" Orthic Gray Luvisol; possible inclusions of Orthic Eutric Brunisol, weakly gleyed, and very shallow soils; restricted to areas of very steeply sloping topography over less than one percent of the study area.

RBB6 - Dominantly Eluviated Dystric Brunisol, in combination with significant amounts of "bleached" Orthic Gray Luvisol and Brunisolic Gray Luvisol; possible inclusions of Orthic Dystric Brunisol, weakly gleyed, and very shallow soils; occurring primarily on very steeply sloping topography, and occasionally on steeply sloping topography over about two percent of the study area.

Lithic and peaty phases of Robb soils were mapped in the study area.

The thickness of Robb A-horizons ranges from 15 cm on ridge and hill crests and upper slopes, to 30 cm on lower slopes. The thickness of B-horizons ranges from about 25 to 45 cm. The depth to the lime accumulation horizon consistently exceeded a meter. The carbonate content of BC horizons ranged from 0.04 to 0.13% (Appendix 2).

TRI-CREEK ASSOCIATION (TRC)

The Tri Creek association consists of Luvisolic soils developed on heterogeneous fine to medium textured glaciolacustrine sediments. Low concentrations of pebbles and cobbles are sometimes found and interbedded sand lenses often occur. The thickness of the deposit is usually more than 1 m but varies from several centimeters to more than 3 m, and commonly overlies till in the study area. Tri Creek soils are dominant throughout the lower basin on gently to very steeply sloping topography and cover about 15 percent of the study area. The steeply to very steeply sloping portions occur on stream valley walls.

Tri Creek soils are generally well drained except in finer textured soils on lower landscape positions where drainage is poor. Gleysolic soils often occur in depressions. The A-horizon texture of Tri Creek soils is usually silt loam, and occasionally silty clay loam. B-horizon textures range from silty clay loam to clay.

Three Tri Creeks map units were identified in the study area:

TRC1 - Dominantly "bleached" Orthic Gray Luvisol, in combination with significant amounts of Orthic Gray Luvisol and Brunisolic Gray Luvisol; possible inclusions of weakly gleyed soils. Parent materials of this map unit have silty clay to clay textures, and are relatively thick. The topography is commonly moderately sloping. TRC1 units cover about nine percent of the study area.

TRC2 - Dominantly "bleached" Orthic Gray Luvisol, in combination with significant amounts of Orthic Gray Luvisol and Gleyed Gray Luvisol; possible inclusions of Gleysolic soils; occuring on silty clay to clay textured parent materials on gently sloping topography with slightly impeded internal drainage. TRC2 units occupy about three percent of the study area.

TRC3 - Dominantly "bleached" Othic Gray Luvisol, in combination with significant amounts of Brunisolic Gray Luvisol and Podzolic Gray Luvisol; possible inclusions of weakly gleyed soils. This unit occurs where the glaciolacustrine deposits are relatively thin and the parent material texture is commonly silty clay loam. TRC3 units occupy about three percent of the study area.

The thickness of Tri Creek A-horizons ranges from about 12 cm on knoll crests, to about 20 cm on lower slopes. The thickness of B-horizons ranges from about 20 to 50 cm. The shallow soil phase class occurs with the Tri-Creek soils where the glaciolacustrine thickness is less than a meter and overlying till. The thickness ranges from 40 to 90 cm.

Lime accumulation commonly exceeds one meter and was occasionally detected to 130 cm. The carbonate content of BC horizons ranges from 0.04 to 0.17 percent (Appendix 2).

MISCELLANEOUS SOIL COMPLEXES

Soil complexes are collections of soils whose distribution is not related to parent material, or whose characteristics are not differentiated in detail.

ALLUVIUM COMPLEX (AV)

The alluvium complex consists of a heterogeneous collection of

Brunisolic, Regosolic, and some Luvisolic soils developed on fluvial deposits along drainage channels in the floodplains of the McLeod River and Wampus, Deerlick and Eunice Creeks (Dumanski et al., 1972). These soils vary greatly in chemical and physical characteristics. They are usually developed on sand or gravel and occur on gently sloping topography over about five percent of the study area. Drainage varies from rapid to moderately good.

Three alluvium map units were identified in the study area:

AV - Undifferentiated fluvial deposits.

AVI - Dominantly Orthic Regosol and Cumulic Regosol, in combination with significant amounts of Orthic Eutric Brunisol and Eluviated Eutric Brunisol; possible inclusions of weakly gleyed soils. This mapping unit denotes areas of fluvial deposits in the McLeod River floodplain.

AV2 - Dominantly Orthic Eutric Brunisol, in combination with significant amounts of Eluviated Eutric Brunisol and "bleached" Orthic Gray Luvisol; possible inclusions of Brunisolic Gray Luvisol and weakly gleyed soils. This unit denotes areas of fluvial deposits in the floodplains of Wampus, Deerlick, and Eunice creeks.

The peaty phase of the Alluvium complex was mapped.

Lime occurs throughout the Regosolic soil profiles of this complex. The lime accumulation horizon usually exceeds one meter in the Brunisolic and Luvisolic soils.

ERITH COMPLEX (ETH)

The Erith complex consists of Gleysolic soils which occur on all parent materials (Dumanski et al., 1972). These soils have mottled profiles and restricted internal drainage. Erith soils are found on lower slopes, in depressions and small drainage channels. They have developed and are maintained because of groundwater discharge on slopes and high groundwater tables in depressions. Erith soils are often saturated, or nearly so, throughout the growing season. They are commonly associated with springs, seepages, hummocky ground, and swamps which are all features of groundwater discharge (Dumanski et al., 1972). Vegetation includes black spruce and white spruce, with an undergrowth of Labrador tea and feathermoss. Patches of Erith soils occur throughout the study area.

Erith soils have accumulations of unconsolidated, semi-decomposed peat on the mineral soil surface, which range from 10 to 60 cm thick. The peat is derived primarily from the growth and decomposition of feather mosses and residue from higher order plants. Below the peat a mottled mineral zone occurs.

Two Erith map units were identified in the study area:

ETH2 - Dominantly Orthic Gleysol, in combination with significant amounts of Orthic Luvic Gleysol; possible inclusions of Rego Gleysol, peaty phases and organic soils. This map unit denotes Gleysolic soils developed on fine texture glaciolacustrine sediments and is restricted to less than one percent of the study area.

ETH3 - Dominantly Orthic Gleysol, in combination with significant amounts of Orthic Luvic Gleysol; possible inclusions of Rego Gleysol, peaty phases and Organic soils. This map unit denotes Gleysolic soils developed on till of Cordilleran origin, or from glaciofluvial sands and gravels and covers about eight percent of the study area primarily in upper Deerlick basin and along drainage channels in upper Eunice and Wampus basins.

The peaty phase of Erith soils was mapped in the study area.

FICKLE COMPLEX (FKE)

The Fickle complex consists of organic soils in concave or level topographic positions or on lower slopes, where they have developed and are maintained by permanent groundwater discharge manifest by seepages, springs, hummocky ground, and swamps (Dumanski et al., 1972). These soils are commonly saturated, and are typically associated with muskeg vegetation, including black spruce and tamarack with an undergrowth of feather mosses, sphagnum moss, horsetails, sedges, and Labrador tea. The Fickle complex occurs in the lower basin on gentle to moderate slopes and each unit covers less than one percent of the study area.

Soils of the Fickle complex are characterized by an accumulation of more than 60 cm of unconsolidated fibric moss peat, or more than 40 cm of unconsolidated peat. The peat, derived chiefly from the growth and decomposition of feather mosses and sphagnum mosses, is raw and undecomposed near the surface, but is largely semi-decomposed below. Usually, this state of intermediate decomposition continues to the contact with the underlying mineral material, except for individual strata which may be raw or highly humified. Remains of higher plants commonly occur in the peat.

Three Fickle map units were identified in the study area:

O - Undifferentiated Organic soils.

FKE1 - Dominantly Mesisols, in combination with significant amounts of Humisols and terric subgroups; possible inclusions of Fibrisols and Gleysolic soils.

FKE2 - Dominantly Humisols, in combination with significant amounts of Mesisols and terric subgroups; possible inclusions of Gleysolic soils.

SOIL EROSION FEATURES AND SOIL ERODIBILITY

OBSERVED EROSION FEATURES

Two types of erosion were identified in the study area - channel erosion and upland erosion. Channel erosion is a focus of a broader study of hydrology and sediment yield in the Tri Creeks basin. Suffice it to note here that minor channel erosion, manifest by undercut banks and reaches of aggradation and degradation, is a general phenomenon in the study area. In addition, there are several areas where erosion of the valley walls (eg. lower and mid Wampus Creek) and incision into glaciolucustrine material (eg. mid Deerlick Creek) provides significant point sources of sediment. The remainder of the discussion focuses on upland erosion.

In the course of undertaking the soil survey, observations of active upland erosion were made. Information collected included the type of erosion (rill, gully or mass movements), extent and severity of erosion, potential delivery of sediment to the stream network and type of area affected. This information is summarized in table 2 and the locations of the soil erosion sites are shown in figure 4. The documentation of soil erosion features is not exhaustive.

Surface water erosion (such as rilling, interrill erosion and gullying) is limited to areas where the vegetation cover has been disturbed, usually by road construction or by scarification of logged areas (figures 5 and 6). In otherwise undisturbed areas, road cuts appear to concentrate runoff onto the road by intercepting throughflow, and overland flow may also occur with rainfall or snowmelt.

Scarification of logged areas exposes mineral soil which may be subject to rainsplash, rilling, or in more advanced cases, gullying. Rainsplash erosion, expressed as soil pedestals, root exposure, profile truncation, soil pore clogging, surface lag developments and soil splash on vegetation, is ubiquitous where mineral soil is exposed. Rilling

Table 2. Summary of observed erosion phenomena.

Site[1]	Process	Extent & Severity	Delivery[2]	Comments[3]
14	Gully	14 m long, 1.7 m wide, 0.5 m deep in lower reach	drains into Eunice Cr., moderate rate of delivery	lower slope position (8%), TRC1 soil area, seismic line 1958, fans through ETH2/P area (5% slope) enroute to creek.
15	Gully	125 m long, 1.8 wide, 0.6 m deep in lower reach	drains into Eunice Cr., low rate of delivery	upper slope position (8%), TRC1 soil area, seismic line 1958, fans into TRC1 soil area above site 14
16	Gully	15 m long, 2 m wide, 0.4 m deep in lower reach	drains into Eunice Cr., high rate of delivery	mid slope position (4%), AV2 soil area, seismic line 1958, fans enroute to creek
17	Gully	20 m long, 5 m wide, 1.5 m deep in lower reach	drains into Eunice Cr., moderate rate of delivery	mid slope position (15%), TRC2 soil area, seismic line 1958, cut block 7 (1959), fans enroute to creek
25	Gully	4 m long, 1 m wide, 0.4 m deep in lower reach	drains into Deerlick Cr., low rate of delivery	several short gullies in ditch bank, mid slope position (25%), TRC1 soil area, cut block 4 (1959), sediment deposited in road ditch
26	Gully	70 m long, 10 m wide, 1.5 m deep in lower reach	drains into Deerlick Cr., high rate of delivery	mid and lower slope positions (25%), TRC1 soil area, seismic line 1958, cut block 4 (1959), slumping and branched in lower reach
28	Gully	60 m long, 4 m wide, 0.7 m deep in lower reach	drains into Deerlick Cr., low rate of delivery	mid slope position (28%), TRC1/T soil area, seismic line 1958, cut block 36 (1981), fans enroute to creek
39	Gully	70 m long, 4 m wide, 1.5 m deep in lower reach	drains into Eunice Cr., high rate of delivery	upper to lower slope position (8%), TRC3 soil area, seismic line 1958, fans through AV2 soil area (3%) enroute to creek

Table 2. (Continued)
Summary of observed erosion phenomena.

Site[1]	Process	Extent & Severity	Delivery[2]	Comments[3]
41	Gully	50 m long, 1 m wide, 0.4 m deep in lower reach	drains into Eunice Cr., low rate of delivery	lower slope position (21%), MLB6 soil area, seismic line 1958, cut block 7 (1959), fans enroute to creek
52	Gully	80 m long, 8 m wide, 2 m deep in lower reach	drains into Wampus Cr., high rate of delivery	lower slope position (35%), TRC1 soil area, seismic line 1958, fans through AV2 soil area (2%) enroute to creek
69	Slump	slump block is 50 m wide, 20 m long	drainage is toward Wampus Cr., low rate of delivery	mid slope position (20%), TRC1 soil area, cut block 22 (1977), slump block situated on ditch bank, has slid toward road
73	Gully	50 m long, 4 m wide, 1.5 m deep in lower reach	drains into Wampus Cr., high rate of delivery	upper to lower slope positions (41%), TRC1 soil area, cut block 23 (1978), gully has cut into one bank of a natural drainage channel perpendicular to it, slumping in lower reach
74	Gully	100 m long, 0.4 m wide, 0.2 m deep in lower reach	drains into Wampus Cr., high rate of delivery	lower slope position (4%), MLB6 soil area, cut block 23 (1978), gully outlets into a natural drainage channel
94	Rill	several rills over a 20 m width, 600 m long, 0.2 m deep in lower reaches	drains into Wampus Cr., high rate of delivery	mid to lower slope position (20%), MLB5 soil area, cut block 15 (1981)
118	Gully	150 m long, 0.5 m wide 0.2 m deep in lower reach	drains into Wampus Cr., low rate of delivery	mid to lower slope position (8%), MLB6 soil area, haul road in cut block 9 (1981), fans enroute to creek
119	Gully	100 m long, 0.5 m wide, 0.4 m deep in lower reach	drains into Wampus Cr., high rate of delivery	lower slope position (8%), MLB6 soil area, haul road in cut block 9 (1981), fans enroute to a natural drainage channel

Table 2. (Continued)
Summary of observed erosion phenomena.

Site[1]	Process	Extent & Severity	Delivery[2]	Comments[3]
120	Gully	30 m long, 0.6 m wide, 0.4 m deep in lower reach	drains into Wampus Cr., high rate of delivery	lower slope position (25%), MLB6 soil area, haul road 1981, fans enroute to natural drainage channel
121	Rill	several rills, 40 m long, 0.2 m wide, 0.1 m deep in lower reaches	drains into Wampus Cr., high rate of delivery	lower slope position (25%), MLB6 soil area, haul road 1981, rills drain into a natural drainage channel that the haul road crosses
122	Rill	several rills, 15 m long, 0.1 m wide, 0.03 m deep in lower reaches	drains into Wampus Cr., moderate rate of delivery	lower slope position (33%), MLB6 soil area, haul road 1981, rills in ditch bank perpendicular to it, sediment deposited in road ditch
125	Gully	50 m long, 0.5 m wide, 0.3 m deep in lower reach	drains into Wampus Cr., high rate of delivery	lower slope position (15%), MLB6 soil area, haul road in cut block 12 (1981), drains into a natural drainage channel that the haul road crosses
126	Gully	80 m long, 0.3 m wide, 0.2 m deep in lower reach	drains into Wampus Cr., high rate of delivery	lower slope position (25%), MLB6 soil area, haul road in cut block 12 (1981), drains into a natural drainage channel that the haul road crosses
131	Gully	150 m long, 0.2 m wide, 0.2 m deep in lower	drains into Wampus Cr., moderate rate of delivery	mid slope position (25%), MLB6/L soil area, haul road in cut block 18 (1979), fans enroute to creek
133	Rill	several rills, 10 m long, 0.3 m wide, 0.05 m deep in lower reach	drains into Wampus Cr., low rate of delivery	mid slope position (25%), MLB6 soil area, cut block 17 (1979), rills above and perpendicular to haul road, fan above haul road
134	Rill	100 m long, 0.2 m wide, 0.1 m deep in lower reach	drains into Wampus Cr., moderate rate of delivery	depressional slope position (2%), MSK4/L soil area, haul road 1983, drains into a natural drainage channel that the haul road crosses

Table 2. (Continued)
Summary of observed erosion phenomena.

Site[1]	Process	Extent & Severity	Delivery[2]	Comments[3]
135	Rill	50 m long, 0.1 m wide, 0.02 m deep in lower reach	drains into Deerlick Cr., low rate of delivery	depressional slope position (2%), MLB6/L soil area, haul road 1983, rill branches at lower reach, and fans into an Organic soil area (1% slope)
138	Gully	50 m long, 0.4 m wide, 0.3 m deep in lower reach	drains into Deerlick Cr., high rate of delivery	lower slope position (25%), MLB6/L soil area, haul road in cut block 28 (1983), fans through ETH3/P soil area (8% slope) enroute to creek
139	Gully	200 m long, 1 m wide, 0.5 m deep in lower reach	drains into Deerlick Cr., low rate of delivery	begins in mid slope position (150 m and 28% slope), ends in lower slope position (50 m and 50% slope), begins in RBB6 soil area and ends in MSK4/L soil area, seismic line 1958, fans into an Organic soil area (1% slope).
149	Rill	200 m long, 0.4 m wide, 0.1 m deep in lower reach	drains into Deerlick Cr., high rate of delivery	mid to lower slope position (15%), MLB5 soil area, haul road in cut block 26 (1981), fans into ETH3/P soil area (8% slope) enroute to creek
153	Gully	several gullies, 70 m long, 0.7 m wide, 0.3 m deep in lower reach	drains into Wampus Cr., high rate of delivery	lower slope position (25%), MLB6 soil area, cut block 20 (1978), fan into ETH3/P soil area (8% slope) enroute to creek
155	Gully	10 m long, 0.4 m wide, 0.1 m deep in lower reach	drains into Wampus Cr., moderate rate of delivery	mid slope position (11%), TRC2 soil area, haul road in cut block 20 (1978), fans into natural drainage channel that haul road crosses
156	Gully	80 m long, 0.9 m wide, 0.3 m deep in lower reach	drains into Wampus Cr., low rate of delivery	mid slope position (11%), TRC2 soil area, haul road in cut block 20 (1978), fans enroute to creek

Table 2. (Continued)
Summary of observed erosion phenomena.

Site[1]	Process	Extent & Severity	Delivery[2]	Comments[3]
159	Gully	500 m long, 0.1 m wide, 0.1 m deep in lower reach	drains into Deerlick Cr., moderate rate of delivery	mid to lower slope position (40%), RBB2 soil area, cut block 31 (1983), fans enroute to creek
164	Gully	500 m long, 0.7 m wide, 0.3 m deep in lower reach	drains into Deerlick Cr., high rate of delivery	mid to lower slope position (20%), MLB6 soil area, old bush trail, fans into ETH3/P soil area (8% slope) enroute to creek
172	Gully	200 m long, 0.9 m wide, 0.4 m deep in lower reach	drains into Eunice Cr., moderate rate of delivery	upper to mid slope position (60%), MSK4/L soil area, seismic line 1958, slump in upper reach, fans enroute to creek

[1] Location of documented erosion sites are shown in figure 4.

[2] Delivery refers to the destination of the erosion product and to the relative rate of contribution to the stream network from the erosion site.

[3] The slope position, local slope, soil type, type and date of disturbance and additional comments regarding erosion and delivery are given.

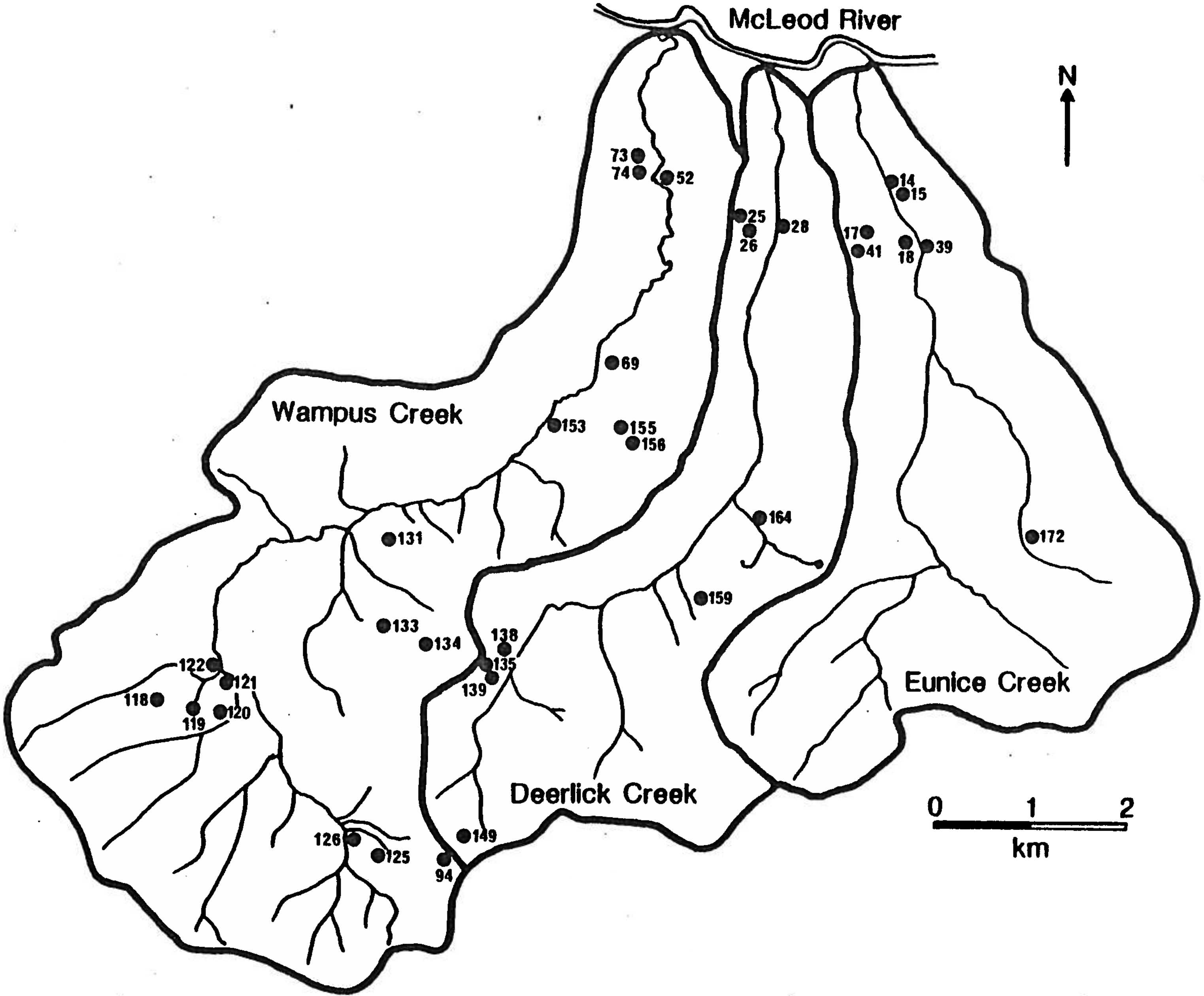

Figure 4. Location of documented erosion sites

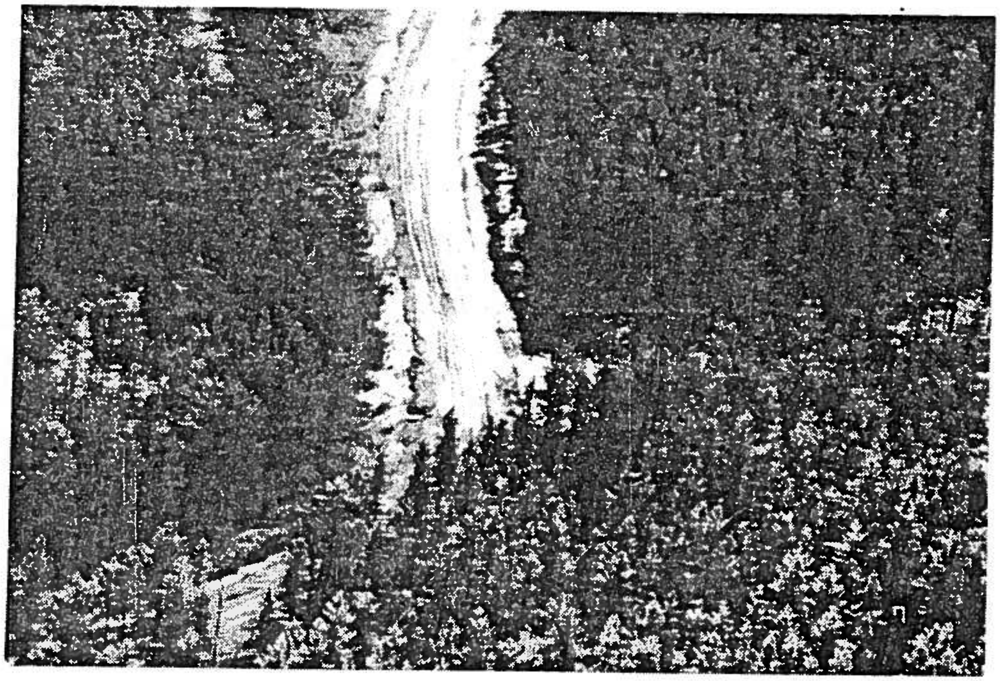

Figure 5. Spring melt water and rainfall concentrate at roads and enter small tributary streams in upper Eunice Creek.

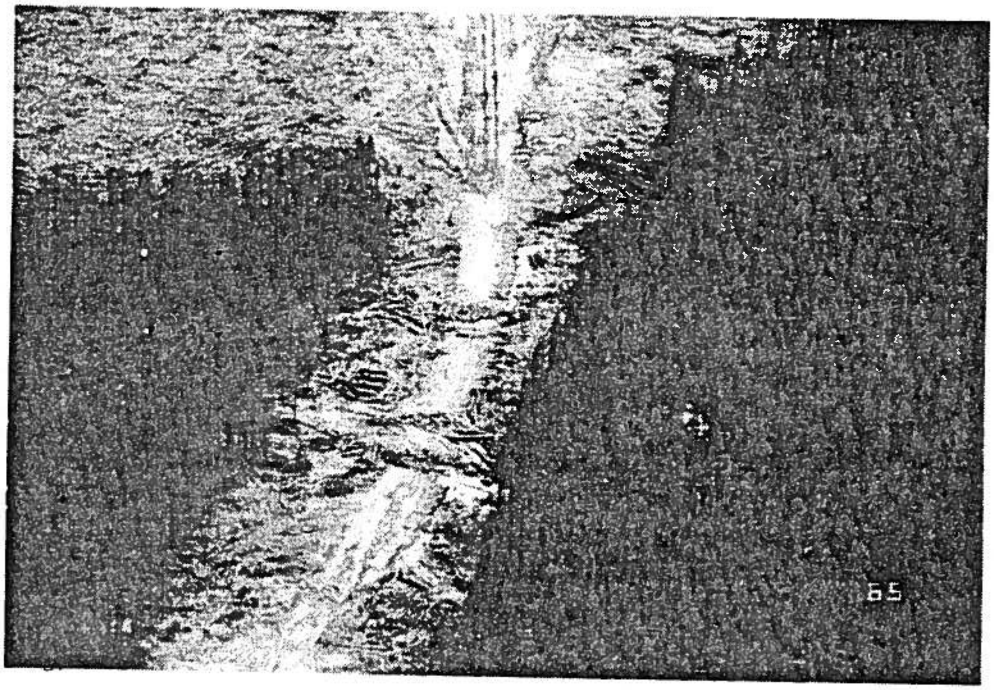

Figure 6. The reclaimed winter haul road parallelling upper Wampus Creek is a significant sediment source.

occurs on relatively short slopes and large rills and gullies tend to occur in mid to lower slope positions on long steep slopes, such as on cutblock 8, in upper Wampus Creek.

In many cases surface erosion of scarified areas is contained within the cut block because deep depressions prevent movement further downslope. In addition, vegetation buffers promote deposition before the material from upland erosion can reach the stream network.

Erosion was also noted along seismic lines which traverse the drainage basin, often running across several stream channels without regard to topography. Some such lines have been revegetated since the cuts were made in the late 1950's, whereas others have developed major rills and gullies, such as in lower Eunice Creek (site 15) (figure 7).

Evidence of slope instability by slumping, flowage or sliding, occur along the stream network, along road cuts and fills and in some logged areas. Generally, mass movements are small scale features. However, slumping may also occur over more extensive areas, such as in mid Deerlick Creek in cut block 22 where harvesting presumably decreased evapotranspiration, resulting in higher soil moisture content and thus, in conjunction with decreasing mechanical stability due to tree root rotting, caused slumping of shallow lacustrine material which overlays tills (figure 8).

Slope instability also occurs, or has occurred, in areas that presently are forested. The mixture of medium textured till and colluvium on steep slopes indicate mass movements have occurred. As well, there is evidence of soil creep elsewhere.

SOIL EROSION POTENTIAL

Soil erosion is determined by rainfall-runoff energy, boundary conditions (eg. type, size and distribution of vegetation and erosion control practices), soil erodibility and topography. These variables are not constant in time or space. The determination of the rainfall-

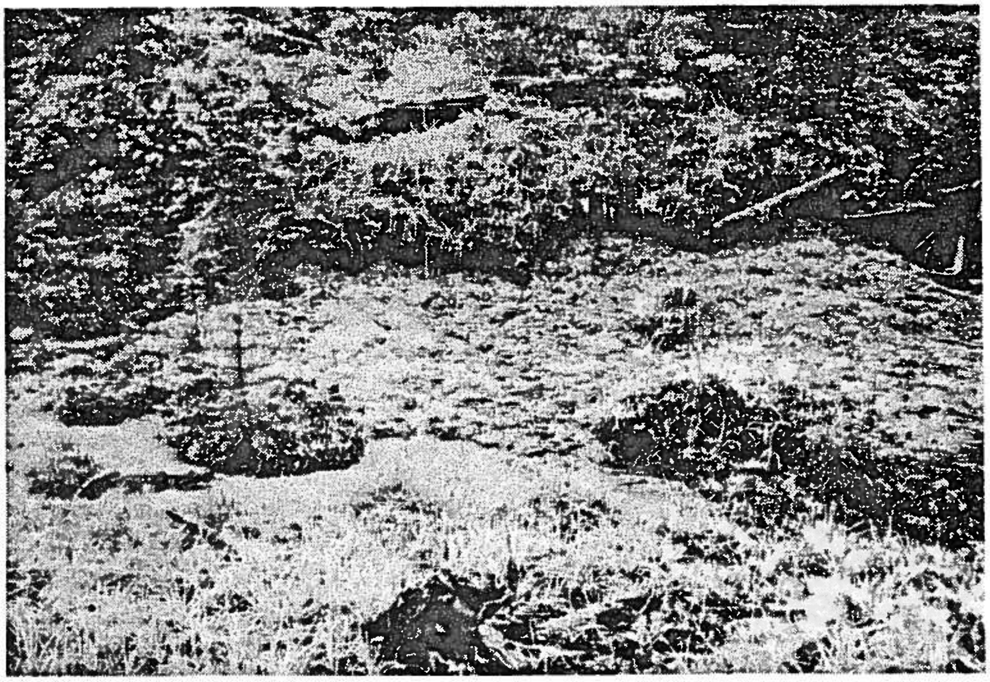

Figure 7. Seismic lines cut in the late 1950's have developed into gullies in lower Eunice Creek.

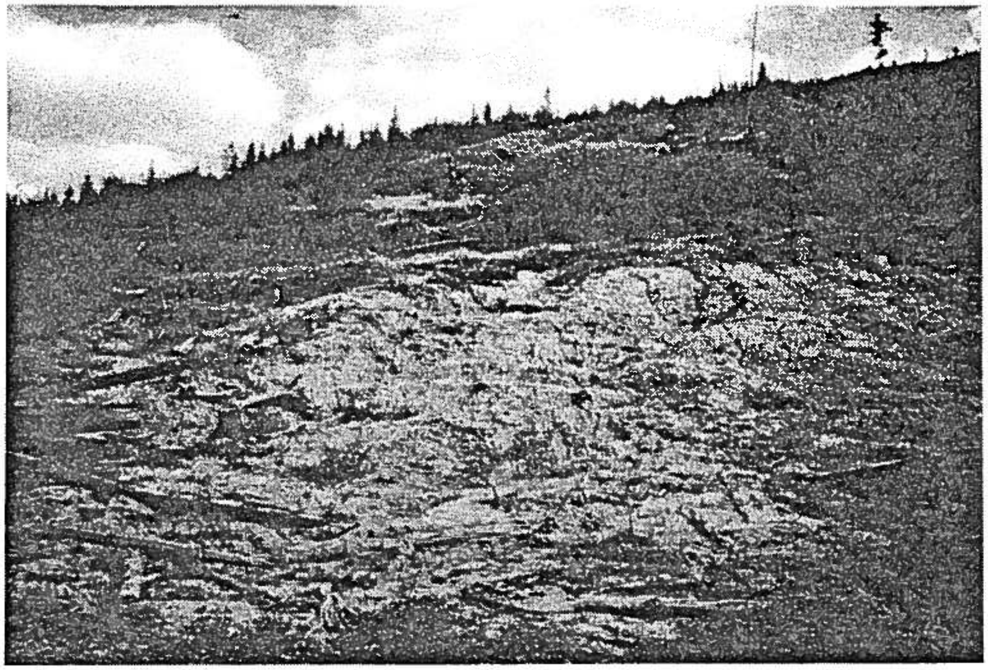

Figure 8. Timber harvesting has resulted in slope instability in shallow glaciolacustrine material on cut block 22 in Deerlick Creek.

runoff factor, particularly the role of snow melt runoff, is beyond the scope of this report. Thus, at this time estimates of erosion are not possible. However, in order to provide an assessment of soil erosion potential, two attributes derived from soil mapping may be used - inherent soil erodibility and topography.

A convenient means of describing soil erodibility is the soil erodibility factor K of the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978). The K factor was chosen as an index of erodibility because it is very widely used, there are no universally acceptable alternative indices of soil erodibility and because the USLE is a possible approach to be taken to model sediment yield as part of a broader study in Tri Creeks.

The K factor is determined from fundamental physical properties of the soil, notably grain size distribution (percent sand, very fine sand, silt and clay), organic matter content, soil structure and permeability. The K factors can be determined from a nomograph or by equation (Wischmeier, and Smith, 1978):

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

where OM = percent organic matter (range 0 to 4)

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

S = structure code (range 1 to 4)

P = permeability class (range 1 to 6)

The values and further descriptions of each of the terms are presented in Appendix 2. Erodibility values derived by the above equation are presented in Appendix 2 and are summarized in table 3.

It is normal practice to include the organic matter content in calculating the soil erodibility factor K, because the organic matter is often intimately incorporated into the soil such that it binds the mineral particles together, thus reducing soil erodibility (Wischmeier, Johnson and Cross, 1971). However, in forest soils in Alberta the 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 rather than less dispersive (Coen and Pettapiece, Agriculture Canada, pers. comm.). The degree to which the lack of intimate incorporation effects soil erodibility is not known. Therefore, it is felt that at the present state of knowldege the most appropriate index value to be used in interpreting soil erodibility is that in which the organic matter content is assumed to have no effect on soil erodibility.

As a result of the lack of intimate incorporation of organic matter, forest soils in the study area are considerably more erodible than they otherwise may be (table 3). The area weighted average K value for the A horizon is 0.48, which is significantly greater than a K value of 0.35 when organic matter is assumed to be intimately incorporated into the soil. Because there is far less organic matter in the B and BC horizons, the disparity between area weighted K values calculated without and with organic matter is smaller (0.42 and 0.38, respectively for the B horizon).

Maps of the spatial distribution of soil erodibility classes were constructed based on the average erodibility of each soil unit. The erodibility of minor units which were not texturally analysed were deduced from the erodibility values of surrounding units. Thus defined, the A horizon of the Tri Creeks study area are almost exclusively classed as highly erodible[1] (K value of 0.42 to 0.56) with the exception of a very highly erodible small pocket of RBB1 soil located in a mid slope position in the middle of Wampus Creek basin and a small area of moderately erodible MRB7 soil parallelling the stream channel alluviums in the lower kilometer of Deerlick and Eunice Creeks.

---

[1] The terms refering to soil erodibility classes as very low to very highly erodible are relative. To formalize the definitions, five equal divisions of the K factor range of 0.0 to about 0.7, were arbitarily used to describe soil erodibility classes as very low, low, moderate, high and very highly erodible. These classes have an incremental K value of 0.14 units (Hudson, in prep.).

TABLE 3 Summary of soil erodibility index values

Map Unit		Soil Erodibility Index K					No. of Samples	Map Unit area (% of basin area)
		A_O	B_O	A	B	BC		
AVI	mean					0.51	2	5
	SD					0.01		
MLB5	mean	0.35	0.38	0.48	0.39	0.38	7	7
	SD	0.02	0.06	0.07	0.07	0.06		
MLB6	mean	0.36	0.39	0.49	0.43	0.43	26-28	42
	SD	0.06	0.08	0.07	0.08	0.09		
MLB7	mean	0.28	0.29	0.34	0.35	0.37	1	<1
	SD	----	----	-----	----	----		
MSK4	mean	0.31	0.35	0.45	0.41	0.59	1-2	5
	SD	----	0.03	----	0.05	----		
RBB1	mean	0.42	0.51	0.59	0.59	----	1	<1
	SD	----	----	----	----	----		
RBB2	mean	0.33	0.40	0.45	0.44	0.46	6-8	9
	SD	0.02	0.08	0.07	0.09	0.11		
RBB4	mean	0.33	0.38	0.46	0.45	0.52	6	5
	SD	0.07	0.14	0.07	0.16	0.12		
RBB6	mean	0.37	0.45	0.49	0.50	0.47	4	2
	SD	0.09	0.05	0.11	0.06	0.09		
TRC1	mean	0.34	0.30	0.49	0.35	0.30	9	9
	SD	0.07	0.08	0.10	0.13	0.07		
TRC3	mean	0.39	0.47	0.56	0.52	0.48	4	3
	SD	0.07	0.02	0.05	0.04	0.05		

A_O and B_O refer to K values for A and B horizon materials where organic matter is included in the K factor analysis.

A, B and BC refer to K values for A, B and BC horizon material respectively, where organic matter is assumed not to be intimately incorporated into the soil and thus is assumed to have no effect on the soil erodibility factor K.

The A horizons in the study area are relatively thin (Appendix 2). Thus, as erosion becomes more advanced with gully development, the erodibility of the B and BC horizons becomes increasingly important. In addition, scarification exposes deeper mineral soils, and road cuts and fills expose B and BC horizons. Hence, the erodibility of these soil horizons are also discussed.

The B horizon of TRC1, TRC2, MSK4, MLB5 and some ETH3 soils in upper Deerlick Creek are classified as moderately erodible. They cover about a quarter of the study area, primary in the lower third of the three basins. In addition, less extensive patches of moderately erodible material occur in the middle to upper portions of each basin (figure 9). Apart from a very small, highly erodible pocket of RBB1 soil in mid Wampus Creek basin, the remainder of the study area is classified as highly erodible.

There are minor differences in the erodibility of the B and BC horizons (area weighted average K values of 0.42 and 0.43 respectively). The BC horizon of the MSK4 unit, which covers about five percent of the study area mainly in upper Deerlick Creek and in central Eunice Creek, is thought to be very highly erodible (there is only one soil sample with a K value of 0.59). Further, the RBB4 unit has a greater BC horizon erodibility (K=0.52) than the B horizon (K=0.45) but is still classified as highly erodible (table 3).

Soil erodibility indices, although typically used to show erosion potential, in fact describe only part of the erosion rubric. Another important attribute is topography. For example, a highly erodible soil on a horizontal surface may have a low erosion potential but a less erodible material on a steep slope may have a high erosion potential. However, the local slope may also only provide part of the story. To develop the dependence between soil erodibiliy, slope gradient and runoff lengths, a topographic factor map was produced by computing the LS factor of the Universal Soil Loss Equation.

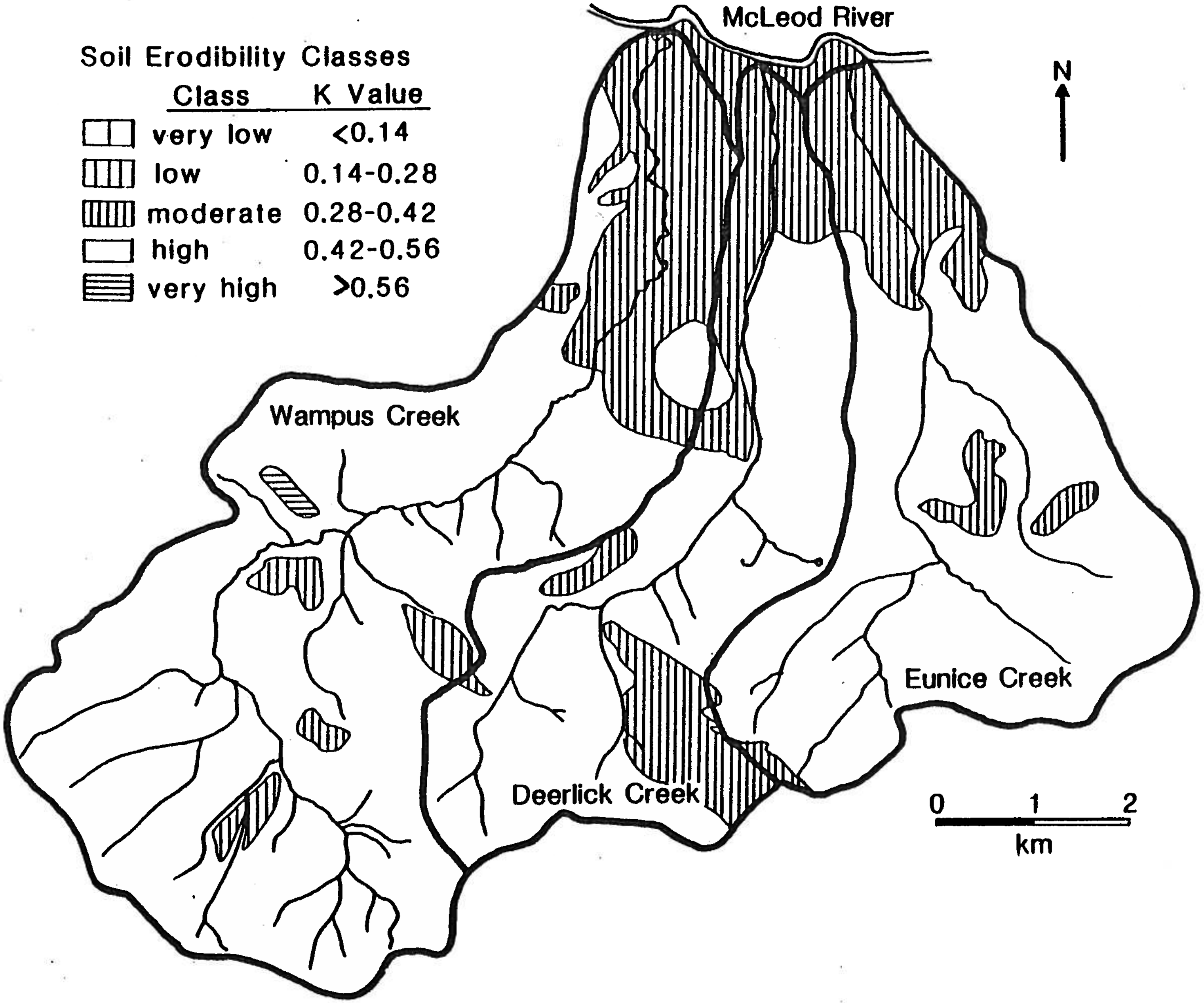

Figure 9. Soil erodibility classes of B horizons with organics excluded.

The LS factor was computed by measuring the cummulative runoff length (L) and slope (S) sequentially downslope from the watershed divide to a point of deposition (such as a depression, or stream channel) for over 350 grid elements of approximately 400 by 400 m (16 to a section) on a 1:15 000 scale map. In some cases a particular grid element was the end point of more than one sequence of grid elements in which case the average of each of the converging interconnecting grids was assigned to the end point grid element. If there was more than one possible runoff path through a downslope sequence of grid elements, an average LS factor was similarly assigned.

The LS factor was computed using the following equation adapted from Wischmeier and Smith (1978):

$$LS = (1/22.13)^m (0.045 S + 0.0065 S^2) + 0.065$$

where l = slope length in meters

m = an exponent 0.5 if slope $>5\%$

0.4 if $3>s<5$

0.3 if $1>s<3$

0.2 if $1>s)$

S = slope gradient factor

$= (0.43 + 0.30s + 0.043s^2)/6.613$

s = gradient in percent

The combination of the topographic factor LS and soil erodibility factor K can be used to delineate erosion potential classes (table 4). The classification is based on the product of the maximum K value of 0.7 and an equal division of the logarithmic ordinate of the LS factor values of 0.03 to 20 into five classes. This division centres the moderate erosion potential class on the value 1.0, which is the standard value of the plot data upon which the factors of the Universal Soil Loss Equation are based (table 4) (Hudson, in prep.).

Table 5. Summary of soil erosion potential for the Tri Creeks Study area.

A Horizon (Percent of area in each class)

Class	Deerlick (15.0km^2)	Eunice (17.2km^2)	Wampus (26.8km^2)	Total (59km^2)
very low	0	0	0	0
low	0	1	0	<1
moderate	9	15	10	11
high	25	27	34	30
very high	48	56	47	50
extreme	17	<1	9	9

B Horizon (Percent of area in each class)

Class	Deerlick (15.0km^2)	Eunice (17.2km^2)	Wampus (26.8km^2)	Total (59km^2)
very low	0	0	0	0
low	0	1	1	<1
moderate	10	15	13	13
high	25	27	33	29
very high	50	56	48	51
extreme	15	<1	5	7

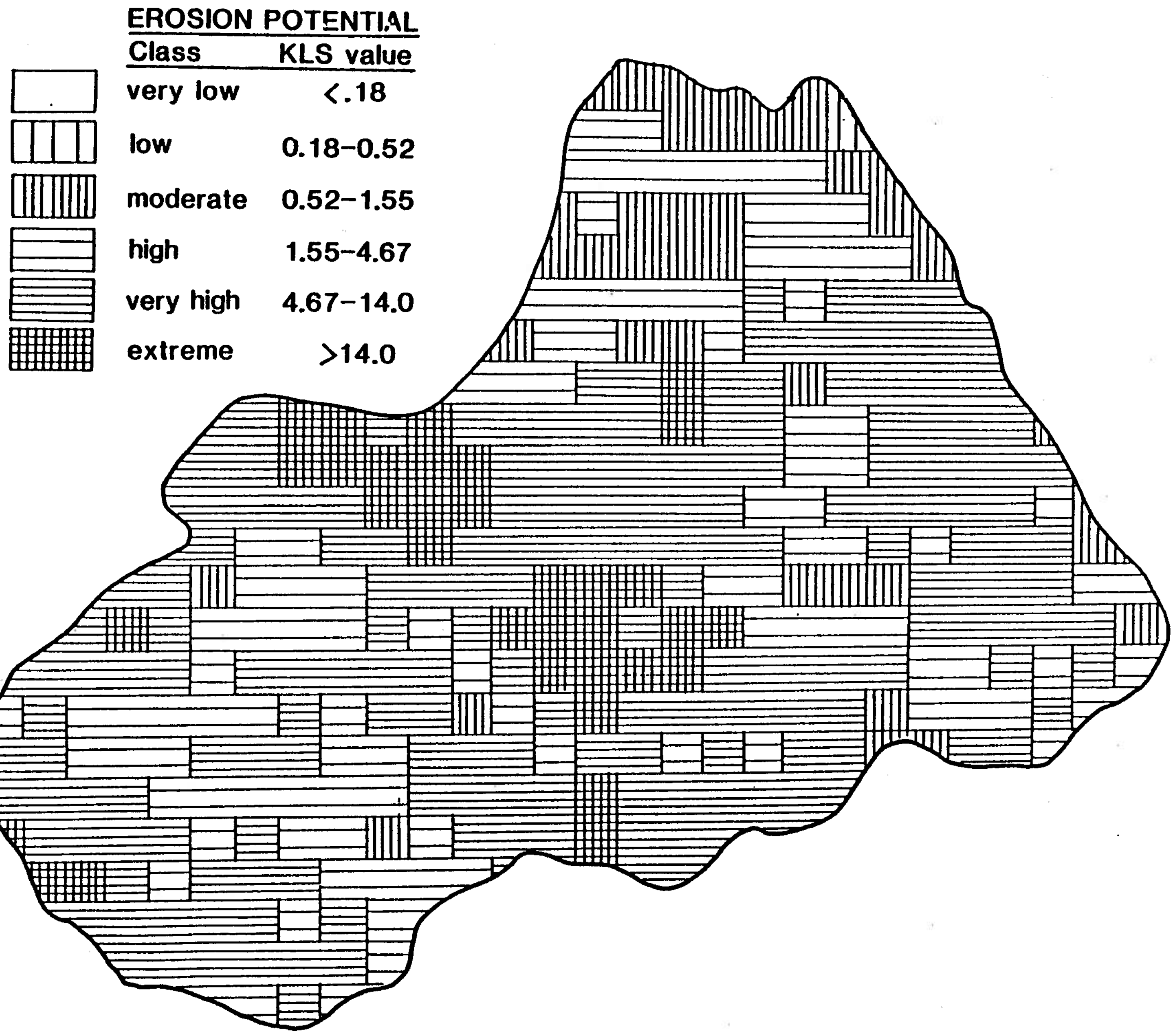

Figure 10. Soil erosion potential (KLS) of A horizons in the Tri Creeks study area.

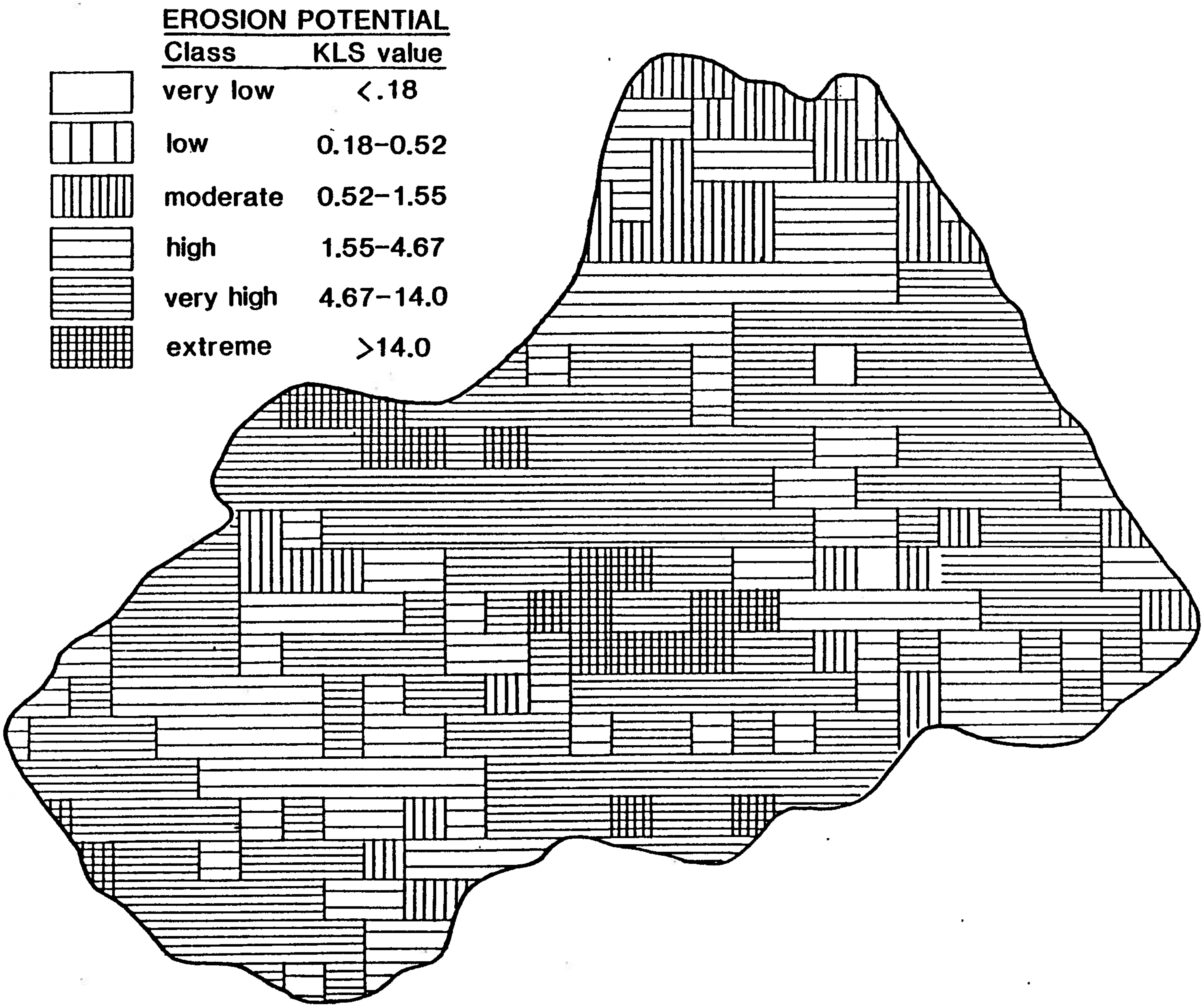

Figure 11. Soil erosion potentials (KLS) of B horizons in the Tri Creeks study area.

SUMMARY AND CONCLUSIONS

A detailed soil survey of the Tri Creeks experimental watershed was conducted to document soil attributes, factors determining soil association distribtuion and the susceptibility of the soil associations to erosion. The 59 km^2 watershed features three major soil associations which cover over 80 percent of the study area, two minor associations, and three soil complexes which are valley bottom alluviums or peaty soils in poorly drained areas. In a general sense, the various soils occupy successive elevation and topographic ranges.

Marlboro soils, the most extensive soil association, are Brunisolic Gray Luvisols which develop on mid to upper slopes in medium to fine textured till blankets and are strongly influenced by the underlying clastic bedrock topography. Tri Creeks soils, which are classified as bleached Orthic Gray Luvisols, develop in heterogeneous, fine to medium textured glaciolacustrine sediment in lower slope positions at lower elevations (less than 1 460 m) in the basin. Robb soils are classified as Eluviated Dystric Brunisols. They develop in parent materials that are a mixture of medium textured till and colluvium. The mixing of till and colluvium is taken as an indication of soil movement on the steep, slopes where these soils generally occur. They are found most frequently along the steep upper portions of subparallel, bedrock controlled, ridges. The two minor soil associations, Jarvis and Maskuta, develop on cobbly outwash gravels and upper slope sandstone and shale bedrock, respectively, and cover a small portion of the study area.

Observations were made on the nature and locations of existing erosion in order to investigate relationships between soil or landscape properties and observed erosion. Most erosion was observed in association with areas where the natural forest cover was in some way disturbed, thus permitting surface water erosion.

Maps of erosion potential were developed based on the soil erodibility (K) and topographic factor (slope length and gradient, LS) of the Universal Soil Loss Equation. There was little variability in the erodibility of A horizon materials throughout the basin. With the exception of two small soil units (RBB1 very highly erodible, and MLB7 moderately erodible) the study area A horizons are classed as highly erodible (K values of 0.42 to 0.56). Moderately erodible B and BC horizons materials are the dominant class in the lower third of each creek. As well, patches of moderately erodible material occur in the middle and upper portions of each basin. The remaining two thirds of the basin is classified as highly erodible.

The soil erodibility assessment is based on the observation that in Alberta forest soils the organic matter content is not intimately incorporated into the mineral soil. Thus, the organic matter is assumed (for want of knowledge) to have no effect on soil erodibility.

The combination of the topographic factor (LS) and the soil erodibility factor (K) can be used to delineate erosion potential. The highest erosion potentials occur in highly erodible soils, which cover most of the upper bains, in long steep slopes. Moderate or low erosion potentials occur in the lower elevation, less steep, moderately or highly erodible soils of the lower drainage basins.

The very high and extreme erosion potential class areas which have been logged and scarified are significant sediment sources. Thus, it appears as though the erosion potential approach based on the inherent soil erodibility and topographic characteristics provides a good indicator of the erosion hazard following timber harvesting and scarification.

REFERENCES

Agriculture Canada, 1976. Glossary of terms in soil science. Canada Department of Agriculture. Publ. 1459. Supply and Services Canada, Ottawa, Ontario. 44 pp.

Bascomb, C.L., 1961. A calcimeter for routine use on soil samples. Chemistry and Industry, Part 2 pp. 1826-1827.

Bergstrom, G.D., 1980. Streamflow characteristics and calibration of the Tri Creeks subwatersheds. Report No. 5, Alberta Energy and Natural Resources, Forest Land use Branch, Watershed Management, Edmonton, Alberta, 24 pp.

Canada Soil Survey Committee, subcommittee on Soil Classification, 1978. The Canadian system of soil classification. Canada Department of Agriculture, Publication 1646. Supply and Services Canada, Ottawa, Ontario, 164 pp.

Currie, D.V., 1976. Hydrogeology of the Tri-Creek basin, Alberta. Alberta Research Council Bulletin 33. Edmonton, Canada. 67 pp.

Dumanski, J., Macyk,T.M., Veauvy, C.F., and Lindsay, J.D., 1972. Soil survey and land evaluation of the Hinton-Edson area, Alberta. Alberta Soil Survey, Rep. No. 31. Department of Extension, University of Alberta, Edmonton, Canada. 119 pp.

Hillman, G.R., Powell, J.M., and Rothwell, R.L., 1978. Hydrometeorology of the Hinton-Edson area, Alberta. 1972-1975. Information Report NOR-X-202, Northern Forest Research Centre, Canadian Forestry Service, Edmonton, Canada, 171 pp.

Hudson, H.R. in prep. Soil erodibility rating classes and estimated erosion potential classes. Open file report, Civil Engineering Department, Alberta Research Council, Edmonton, Canada.

Leco Corporation, 1979. Leco CR-12 carbon system. St. Joseph, Mich., U.S.A.

Mapping System Working Group, 1981. A soil mapping system for Canada: revised. Land Resource Research Institute, Contribution No. 142, Agriculture Canada, Ottawa, Ontario, 94 pp.

National Soil Survey Committee of Canada, 1974. The system of soil classification for Canada. Canada Department of Agriculture, Publication 1455. Supply and Services Canada, Ottawa, Ontario. 255 pp.

Peech, M., 1965. Hydrogen-Ion activity. In: Methods of soil analysis, Part 2. Chemical and Microbiological Properties. Black, C.A. ed-in-chief. A.S.A. Monograph 9. American Society of Agronomy, Madison, Wisconsin. pp. 914-926.

Singh, T., 1983. A proposed method for preliminary assessment of erosion hazards in west-central Alberta. Environment Canada, Canadian Forest Service, Northern Forest Research Centres, Edmonton, Information Report NOR-X-251.

Toogood, J.A., and Peters, T.W., 1953. Comparison of methods of mechanical analysis of soils. Journal of Agricultural Science 33:159-171.

United States Department of Agriculture (undated). Procedure guide, Section 400 - Applications of soil survey information. Section 403 - Rating soils for selected uses. Soil Conservation Service. Unpublished guide for Interim Use.

Wischmeier, W.H., Johnson, C.B. and Cross, B.U., 1971. A soil erodibility nomograph for farmland and construction sites. Journal of Soil and Water Conservation, 26:189-193.

Wischmeier, W.H., and Smith, D.D. 1978. Predicting rainfall erosion losses - a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537. 58 pp.

Appendix 1. Features of the soils of Tri Creeks.

Soil Association	Map Unit	Dominant Soils	Significant Soils	Possible Minor Soil Inclusions	Soil Parent Material	Topography (% Slope)	Drainage
Alluvium (Soil Complex)	AV	undifferentiated fluvial deposits			recent fluvial deposits (usually sand or gravel)	gently sloping (2 to 5%)	rapid to moderately good
	AV1	Orthic Regosol, Cumulic Regosol	Orthic Eutric Brunisol, Eluviated Eutric Brunisol	weakly gleyed soils			
	AV2	Orthic Eutric Brunisol	Eluviated Eutric Brunisol, "bleached" Orthic Gray Luvisol	Brunisolic Gray Luvisol, weakly gleyed soils			
Erith (Soil Complex)	ETH2	Orthic Gleysol	Orthic Luvic Gleysol	Rego Gleysol, peaty phases, organic soils	fine textured glaciolacustrine sediments	undulating to steeply sloping (2 to 30%)	poor
	EHT3	Orthic Gleysol	Orthic Luvic Gleysol	Rego Gleysol, peaty phases, organic soils	Cordilleran till, or sand and gravel therefrom		
Fickle (Soil Complex)	O	undifferentiated organic soils			organic materials	gently to moderately sloping (2 to 9%)	very poor
	FKE1	Mesisols	Humisols, terric subgroups	Fibrisols, Gleysolic soils			
	FKE2	Humisols	Mesisols, terric subgroups	Gleysolic soils			

Soil Association	Map Unit	Dominant Soils	Significant Soils	Possible Minor Soil Inclusions	Soil Parent Material	Topography (% Slope)	Drainage
Jarvis	JRV3	Podzolic Gray Luvisol	Brunisolic Gray Luvisol, Orthic Gray Luvisol		cobbly gravels: outwash terraces, kame and esker complexes, well expressed cross bedding; overlie bedrock or till	very steeply sloping (30 to 60%)	surface: good, internal: rapid
Marlboro	MLB5	"bleached" Orthic Gray Luvisol	Podzolic Gray Luvisol, Brunisolic Gray Luvisol	weakly gleyed, and shallow soils	medium to fine textured cordilleran till (sandy loam texture also observed), coal flecks common; moderately stony	gently to very steeply sloping (2 to 60%)	good
	MLB6	Brunisolic Gray Luvisol	Podzolic Gray Luivsol, "bleached" Orthic Gray Luvisol	weakly gleyed, and shallow soils			
	MLB7	Orthic Gray Luvisol	Podzolic Gray Luvisol, Eluviated Eutric Brunisol	"bleached" Orthic Gray Luvisol, shallow soils			
Maskuta	MSK4	Eluviated Dystric Brunisol, lithic phase	Orthic Dystric Brunisol, Lithic phase	Orthic Gray Luvisol, lithic phase;Brunisolic Gray Luvisol, lithic phase	weathered bedrock: sandstone, shale conglomerate	moderatley to extremely sloping (5 to 60%)	good

Soil Association	Map Unit	Dominant Soils	Significant Soils	Possible Minor Soil Inclusions	Soil Parent Material	Topography (% Slope)	Drainage
Robb	RBB1	Eluviated Dystric Brunisol	"bleached" Orthic Gray Luvisol, Brunsolic Gray Luvisol	Eluviated Eutric Brunisol, weakly gleyed, and very shallow soils	cordilleran till plus colluvium; the till is medium to moderately coarse textured, and moderately to very stony	gently to very steeply sloping (2 to 60%)	surface: good to rapid, internal: good
	RBB2	Eluviated Dystric Brunisol	Brunisolic Gray, Luvisol, Podzolic Gray Luvisol	Eluviated Eutric Brunisol, weakly gleyed, and very shallow soils			
	RBB4	Eluviated Dystric Brunisol, "bleached" Orthic Gray Luvisol	Brunisolic Gray Luvisol, Podzolic Gray Luvisol	Orthic Dystric Brunisol, weakly gleyed, and very shallow soils			
	RBB5	Eluviated Eutric Brunisol	"bleached" Orthic Gray Luvisol	Orthic Eutric Brunisol, weakly gleyed and very shallow soils			
	RBB6	Eluviated Dystric Brunisol	"bleached" Orthic Gray Luvisol, Brunisolic Gray Luvisol	Orthic Dystric Brunisol, weakly gleyed, and very shallow soils			

Soil Association	Map Unit	Dominant Soils	Significant Soils	Possible Minor Soil Inclusions	Soil Parent Material	Topography (% Slope)	Drainage
Tri-Creek	TRC1 (parent material textures silty clay to clay)	"bleached" Orthic Gray Luvisol	Orthic Gray Luvisol, Brunisolic Gray Luvisol	weakly gleyed soils	heterogeneous fine (usually) to medium textured glacio-lacustrine sediments; contain variable but low contents of cobbles and pebbles; thin interbedded sand lenses sometimes occur; thickness varies from a few cm to >3m; overlies til, bedrock or outwash; can be overlain by sand or organic soil	gently to very steeply sloping (2 to 60%)	good
	TRC2 (parent material textures silty clay to clay)	"bleached" Orthic Gray Luvisol	Orthic Gray Luvisol, Gleyed Gray Luvisol	Gleysolic soils			
	TRC3 (parent material textures clay loam to silty clay loam)	"bleached" Orthic Gray	Brunisolic Gray Luvisol, Podzolic Gray Luvisol	weakly gleyed soils			

APPENDIX 2

SUMMARY OF CHEMICAL AND PHYSICAL CHARACTERISTICS OF SOILS IN THE TRI CREEKS STUDY AREA.

Chemical and physical data for selected soils are given in the following table. The pH was determined with a pH meter equipped with a glass and calomel electrode. The pH in $CaCl_2$ was determined using a 2:1 0.01 M $CaCl_2$ solution to soil ratio (Peech, 1965). Total carbon was determined by dry combustion using a resistance furnace with a gasometric detection of evolved CO_2 in an infrared detector (Leco Coporation, 1979). In samples containing calcium carbonate, organic carbon was determined by subtracting inorganic carbon, as calculated from the calcium carbonate equivalent determination. If calcium carbonate was not present, organic carbon was assumed to equal total carbon. The calcium carbonate equivalent was determined by the inorganic carbon manometric method of Bascomb (1961). The mechanical analysis was carried out by the pipette method of Kilmer and Alexander, as modified by Toogood and Peters (1953).

Appendix 2. Summary of chemical and physical characteristics of soils in the Tri Creeks study area.

Site No.	Map Unit	Horizon	Depth (cm)	$CaCl_2$ pH	Organic		$CaCO_3$ equiv. (%)	<2mm fraction (%)			VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index	
					carbon (%)	matter (%)		sand	silt	clay						K_1	K_2
5	AV1	C1	0-48	7.2	2.7	4.6	9.4	47	44	9	22	1	3	2	L	0.35	0.52
		C2	48-64	7.2		(4.6)	8.6	38	47	15	24	1	3	1	L	0.33	0.50
36	MLB5	A	0-26	4.5	1.8	3.1		16	56	28	7	1	3	3	SiCL	0.31	0.40
		B	26-71	4.6		(1.4)		15	57	28	(7)	1	3	5	SiCL	0.42	0.46
		BC2	71+	4.8		(1.4)		58	32	10	21	2	3	3	FSL	0.38	0.43
45	MLB5	A	0-23	4.1	4.1	2.0		22	68	10	12	1	3	3	SiL	0.36	0.61
		B	23-39	4.4		(2.4)		41	41	18	5	2	3	4	L	0.30	0.36
		BC2	57-100	4.9		20	49	31	(2)	1	3	5	CL		0.36		
89	MLB5	A	0-20	3.9	2.3	3.9		13	64	23	7	1	3	4	SiL	0.37	0.52
		B	20-45	4.2	1.2	2.0		9	59	32	(5)	2	3	6	SiCL	0.40	0.46
		BC	45-100	5.2		(2.0)	0.11	12	49	39	(7)	1	3	5	SiCL	0.33	0.38
93	MLB5	A	0-17	4.0	1.4	2.4		16	57	27	6	1	3	4	SiL	0.36	0.43
		B	17-37	4.2	0.66	1.1		10	45	45	(4)	2	3	5	SiC	0.27	0.29
		BC	37-80	4.9		(1.1)	0.08	13	41	46	(5)	2	3	5	SiC	0.25	0.27
94	MLB5	A	0-10	3.6	1.8	3.1		28	55	17	10	2	3	3	SiL	0.37	0.49
		B	10-40	4.4	0.95	1.6		24	50	26	9	2	3	5	SiL	0.39	0.44
		BC	40-100	5.5		(1.6)	0.11	21	52	27	9	2	3	5	CL	0.40	0.45
95	MLB5	A	0-18	4.2	1.7	2.9		32	49	19	10	2	3	3	L	0.33	0.43
		B	18-60	4.4	0.72	1.2		30	33	37	10	2	3	5	CL	0.27	0.29
		BC	60-80	4.8		1.2		52	31	17	(17)	2	3	5/2	L	0.37	0.40
146	MLB5	A	0-30	4.6	2.9	4.9		24	57	19	12	1	3	3	SiL	0.35	0.50
		B	30-50	5.4	1.2	2.0		31	47	22	9	2	3	4	L	0.35	0.41
		BC	50-100	6.4		2.0	0.13	36	40	24	(8)	2	3	5	L	0.32	0.37

Site No.	Map Unit	Horizon	Depth (cm)	$CaCl_2$ pH	Organic carbon (%)	Organic matter (%)	$CaCO_3$ equiv. (%)	<2mm fraction (%) sand	silt	clay	VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index K_1	K_2
41	MLB6	A	0-13	4.2	2.4	4.1		15	59	26	5	1	3	5	SiL	0.34	0.47
		B	23-46	4.4		(1.9)		17	48	35	(6)	1	3	5	SiCL	0.32	0.36
		BC	46+	4.6		(1.9)		20	50	30	(7)	2	3	5	CL	0.35	0.40
43	MLB6	A	0-24	4.4	2.4	4.1		31	52	17	9	1	3	3	SiL	0.32	0.45
		B	24-59	4.5		(1.9)		33	57	10	27	2	3	4	SiL	0.62	0.72
		BC	59-100	5.0		(1.9)		51	44	5	37	1	3	3	FSL	0.61	0.71
66	MLB6	Ael		4.0	3.7	6.3		11	68	21	6	1	3	3	SiL	0.31	0.52
		Bf	0-25	4.4	3.6	6.1		14	63	23	6	1	3	3	SiL	0.33	0.48
		Ae2		4.4	0.86	1.5		9	74	17	4	1	3	3	SiL	0.46	0.53
		Bt	25-90	4.6		12	57	31		2	3	5	SiCL				
		BC	90+	4.9		(1.5)		8	56	36	(3)	1	3	5	SiCL	0.35	0.38
71	MLB6	A	0-34	4.3	3.1	28	54	18	9	1	3	3	SiL	0.32	0.46		
		B	34-64	4.3	0.52	(.88)		27	45	28	9	1	3	5	CL	0.37	0.39
		BC	64-100	4.4		(.88)		29	42	29	(9)	1	3	5	CL	0.35	0.37
72	MLB6	A	0-25	4.1	2.1	3.6		24	51	25	6	2	3	3	SiL	0.28	0.38
		B	25-55	4.4	1.6	2.7		16	55	29	7	2	3	5	SiCL	0.36	0.44
		BC	55-100	4.5		(2.7)	0.04	24	60	16	20	1	3	3	SiL	0.48	0.61
75	MLB6	A.	0-16	4.5	2.9	4.9		15	68	17	8	1	3	3	SiL	0.32	0.39
		B	16-53	4.6	0.64	1.1		11	36	53	(3)	1	3	6	C	0.23	0.24
		BC1	53-80	4.9		(1.1)	0.13	13	53	34	(4)	1	3	5	SiCL	0.36	0.38
81	MLB6	A	0-22	4.7	1.7	2.9		18	60	22	7	1	3	3	SiL	0.36	0.47
		B	22-42	5.3	0.87	1.5		13	56	31	(5)	1	3	5	SiCL	0.38	0.42
		BC	42-100	5.1		(1.5)	0.13	8	62	30	(4)	1	3	5	SiCL	0.41	0.46
83	MLB6	A	0-25	4.2	1.6	2.7		12	71	17	6	1	3	3	SiL	0.46	0.58
		B	25-55	4.4	0.69	1.2		29	51	20	7	1	3	4	SiL	0.40	0.44
		BC	55-100	4.7		(1.2)		23	40	37	(6)	1	3	5	CL	0.28	0.31

Site No.	Map Unit	Horizon	Depth (cm)	$CaCl_2$ pH	Organic carbon (%)	Organic matter (%)	$CaCO_3$ equiv. (%)	<2mm fraction sand (%)	<2mm fraction silt (%)	<2mm fraction clay (%)	VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index K_1	Soil erodibility index K_2
91	MLB6	A	0-18	4.0	2.0	3.4		25	52	23	6	1	3	4	SiL	0.32	0.42
		B	18-60	4.2	0.72	1.2		33	46	21	9	2	3	5	L	0.40	0.44
		BC	60-100	4.5		(1.2)	0.13	39	38	23	(11)	2	3	5	L	0.35	0.38
96	MLB6	A	0-23	3.9	1.9	3.2		14	70	16	8	2	3	3	SiL	0.37	0.56
		B	23-55	4.2	1.2	2.0		41	41	18	8	2	3	5	L	0.35	0.41
		BC	55-100	4.6		(2.0)	0.13	36	43	21	(7)	2	3	5	L	0.35	0.40
97	LMB6	A	0-30	4.1	2.0	3.4		28	54	18	7	2	3	3	C	0.33	0.45
		B	30-65	4.1	1.1	1.9		36	44	20	7	2	3	4	L	0.34	0.39
		BC	65-100	4.3		(1.9)	0.13	43	36	21	10	2	3	4	L	0.30	0.35
98	MLB6	A	0-18	4.2	1.2	2.0		29	58	13	10	1	3	3	SiL	0.45	0.54
		B	18-60	4.3	0.46	.8		27	47	26	9	2	3	5	L	0.40	0.42
		BC	60-100	4.8		(.8)	0.15	32	45	23	(11)	2	3	5	L	0.41	0.43
109	MLB6	A	0-12	4.2	1.9	3.2		27	53	20	10	2	3	3	SiL	0.34	0.45
		B	12-44	4.4	0.56	0.9		29	52	19	11	2	3	5	SiL	0.47	0.51
		BC	44-100	4.8		(.9)	0.13	31	43	26	10	2	3	5	L	0.37	0.40
113	MLB6/L	A	0-20	4.3	1.6	2.7		16	64	20	7	1	3	3	SiL	0.40	0.51
		B	20-55	4.4	0.46	0.8		28	47	25	(12)	2	3	5	L	0.42	0.44
117	MLB6	A	0-20	4.4	2.0	3.4		20	62	18	8	1	3	3	SiL	0.38	0.52
		B	20-55	4.3	0.52	(.9)		33	39	28	13	2	3	5	CL	0.36	0.38
		BC	55-100	4.6		(.9)		10	57	33	(4)	1	3	5	SiCL	0.39	0.41
124	MLB6	A	0-18	4.2	2.1	20	56	24	7	2	3	3	SiL	0.31	0.43		
		B	18-50	4.3	0.51	(.9)		33	45	22	(12)	2	3	5	L	0.42	0.45
		BC	50-100	4.5		37	37	26	(13)	2	3	5	L	0.36	0.38		
128	MLB6/L	A	0-12	4.0	1.7	2.9		24	62	14	8	1	3	3	SiL	0.42	0.55
		B	12-40	4.1	1.2	2.0		20	41	39	(7)	2	3	5	CL	0.27	0.31
		BC	40-60	4.2		(2.0)		29	61	10	(10)	2	3	5	SiL	0.54	0.63

Site No.	Map Unit	Horizon	Depth (cm)	CaCl$_2$ pH	Organic		CaCO$_3$ equiv. (%)	<2mm fraction (%)			VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index	
					carbon (%)	matter (%)		sand	silt	clay						K$_1$	K$_2$
130	MLB6/L	A	0-20	3.8	2.3	3.9		8	66	26	6	1	3	4	SiL	0.35	0.50
		B	20-45	4.0	0.92	1.6		4	66	30	(3)	1	3	5	SiCL	0.43	0.48
157	MLB6	A	0-15	4.3	2.8	4.8		20	55	25	8	1	3	3	SiL	0.29	0.42
		B	15-50	4.2	0.57	1.0		26	53	21	9	2	3	5	SiL	0.46	0.49
		BC	50-100	4.5		(1.0)	0.11	23	48	29	8	2	3	5	CL	0.38	0.40
161	MLB6	A	0-20	3.8	1.6	2.7		11	67	22	5	1	3	3	SiL	0.40	0.51
		B	20-50	4.1	0.78	1.3		13	56	31	(4)	2	3	5	SiCL	0.38	0.42
		BC	50-100	4.4		(1.3)	0.11	8	57	35	(4)	2	3	5	SiCL	0.37	0.40
163	MLB6	A	0-15	4.5	1.6	2.7		25	40	35	9	2	3	3	CL	0.22	0.28
		B	15-55	4.7	0.65	1.1		28	56	16	(10)	2	3	5	SiL	0.51	0.55
		BC2	75-100	5.1		(1.1)	0.11	33	49	18	(12)	2	3	5	L	0.46	0.50
171	MLB6	A	0-20	4.2	0.91	1.6		27	58	15	11	1	3	3	SiL	0.47	0.53
		B	20-55	4.7	0.38	.7		34	36	30	14	2	3	5	CL	0.34	0.36
		BC	55-100	5.3		(.7)	0.11	26	44	30	8	2	3	5	CL	0.36	0.37
174	MLB6	A	0-22	4.2	1.7	2.9		30	55	15	13	1	3	3	SiL	0.40	0.52
		B	22-70	4.5	0.60	1.0		35	44	21	11	2	3	4	L	0.38	0.41
		BC	70-100	5.1		(1.0)	0.11	38	40	22	(10)	2	3	4	L	0.37	0.40
177	MLB6	A	0-20	4.1	1.7	2.9		22	57	21	9	2	3	3	SiL	0.36	0.47
		B		4.1	0.93	1.6		27	45	28	(7)	2	3	5	CL	0.34	0.38
		BC	50-100	4.2		(1.6)	0.08	51	31	18	(21)	2	3	5	L	0.38	0.43
178	MLB6	A	0-18	4.3	2.4	4.1		19	70	11	3	1	3	3	SiL	0.35	0.59
		B	18-45	4.3	0.51	0.9		22	56	22	(3)	2	3	5	SiL	0.43	0.46
		BC1	45-80	4.5		(0.9)		35	49	16	(6)	2	3	4	L	0.41	0.44
180	MLB6	A	0-15	4.0	1.8	3.1		8	66	26	5	1	3	3	SiL	0.36	0.47
		B	15-50	4.2	0.54	0.9		3	70	27	(2)	1	3	5	SiCL	0.49	0.52
		BC	50-90	4.3		(0.9)	0.04	13	58	29	(8)	1	3	5	SiCL	0.44	0.47

Site No.	Map Unit	Horizon	Depth (cm)	$CaCl_2$ pH	Organic carbon (%)	Organic matter (%)	$CaCO_3$ equiv. (%)	<2mm fraction sand (%)	silt	clay	VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index K_1	K_2
181	MLB6	A	0-15	4.3	1.8	3.1		27	52	21	9	1	3	3	SiL	0.33	0.43
		B	15-40	4.4	0.59	1.0		32	44	24	11	2	3	5	L	0.39	0.42
		BC	40-100	4.7		(1.0)	0.04	41	39	20	10	2	3	4	L	0.35	0.37
183	MLB6	A	0-30	4.1	1.7	2.9		22	66	12	14	1	3	3	SiL	0.40	0.61
		B	30-60	4.3	0.59	1.0		42	39	19	12	2	3	4	L	0.36	0.39
		BC	60-100	4.6		(1.0)	0.06	42	38	20	(12)	2	3	5	L	0.38	0.40
8	MLB7	A	0-20	4.5	1.4	2.4		12	54	34	4	1	3	3	SiCL	0.28	0.34
		B	20-50	4.7		(2.4)		23	46	31	7	2	3	4	CL	0.29	0.35
		C	50-100	5.2		(2.4)	0.10	35	39	26	14	2	3	4	L	0.31	0.37
142	MSK4/L	B	0-25	4.0	1.4	2.4		6	62	32	2	2	3	5	SiCL	0.37	0.44
147	MSK4	A	0-7	4.4	3.2	5.4		38	48	14	10	2	3	3	L	0.31	0.45
		B	7-47	4.4	0.95	1.62		17	49	34	6	1	3	5	SiCL	0.33	0.37
		BC	47-100	4.8		(1.62)	0.08	34	55	11	18	1	3	3	SiL	0.52	0.59
88	RBB1/L	A	0-16	3.9	2.1	3.6		22	64	14	11	2	3	3	SiL	0.42	0.59
		B	16-46	3.9	1.1	1.9		16	65	19	8	2	3	5	SiL	0.51	0.59
84	RBB2/L	A	0-20	5.1	0.94	1.6		46	39	15	8	1	3	3	L	0.31	0.35
		B	20-55	4.8	0.70	1.2		40	46	14	8	2	3	4	L	0.40	0.44
		BC	55-85	4.0		(1.2)	0.08	26	54	20	8	2	3	3/6	SiL	0.40	0.44
90	RBB2	A	0-20	4.0	3.1	5.3		18	61	21	7	2	3	3	SiL	0.33	0.48
		B	20-45	4.2	1.1	1.9		30	51	19	14	2	3	4	SiL	0.43	0.50
		BC	45-100	4.3		(1.9)	8	70	22	3	2	3	3	3	SiL	0.44	0.51
100	RBB2/L	A	0-20	4.2	2.5	4.3		27	56	17	16	1	3	3	SiL	0.32	0.54
		B	20-65	4.5	1.2	2.0		17	41	42	(10)	1	3	5	SiC	0.27	0.31
104	RBB2/L	A	0-18	4.3	2.4	4.1		24	56	20	9	2	3	3	SiL	0.32	0.47
		B	18-48	4.6	0.72	1.2		30	41	29	(11)	2	3	5	CL	0.35	0.38

Site No.	Map Unit	Horizon	Depth (cm)	$CaCl_2$ pH	Organic		$CaCO_3$ equiv. (%)	<2mm fraction			VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index	
					carbon (%)	matter (%)		sand	silt (%)	clay						K_1	K_2
137	RBB2/L	A	0-15	4.2	1.3	2.2		36	44	20	10	1	3	3	L	0.32	0.38
		B	15-65	4.6	0.52	0.9		25	48	27	9	1	3	5	CL	0.39	0.42
		BC	65-80	5.2		(.9)		61	30	9	9	1	3	3	SL	0.29	0.31
160	RBB2	A	0-22	4.3	1.8	3.1		25	56	19	10	1	3	3	SiL	0.37	0.48
		B	22-60	5.3	0.63	1.1		19	64	17	10	2	3	5	SiL	0.56	0.61
		BC	60-100	5.8		(1.1)		39	49	12	25	2	3	4	L	0.57	0.63
176	RBB2/L	B1	0-25	4.8	1.3	2.2		42	38	20	14	2	3	3	L	0.31	0.37
		B2	25-50	4.7	0.40	0.7		50	35	15	26	2	3	2	L	0.42	0.44
		BC	50-90	5.0		(0.7)	0.08	45	42	13	14	2	3	3	L	0.41	0.44
182	RBB2	A	0-35	4.0	3.2	5.4		31	53	16	15	1	3	3	SiL	0.35	0.52
		B	35-70	4.3	0.54	0.9		38	46	16	14	1	3	3	L	0.42	0.45
		BC	70-100	4.6		(0.9)		52	36	12	15	1	3	3	L	0.37	0.40
59	RBB4	A	0-22	4.3	4.7	8.0		20	62	18	10	1	3	3	SiL	0.32	0.53
		B	22-67	4.5		(3.1)		35	49	16	10	2	3	5	L	0.39	0.49
		BC	67-100	4.8		(3.1)		37	52	11	22	2	3	3	SiL	0.46	0.60
102	RBB4	A	0-18	4.3	2.2	3.7		28	53	19	10	1	3	3	SiL	0.32	0.46
		B	18-58	4.6	0.71	1.2		18	54	28	7	2	3	5	SiCL	0.40	0.44
		BC	58-100	4.9		(1.2)	0.11	25	53	22	11	2	3	4	SiL	0.43	0.47
103	RBB4	A	0-12	4.0	3.1	5.3		53	34	13	9	2	3	2	SL	0.21	0.31
		B	12-25	4.5	2.0	3.4		42	17	41	10	2	3	3	C	0.11	0.15
141	RBB4	A	0-15	4.6	0.81	1.4		32	46	22	20	1	3	3	L	0.41	0.46
		B	15-45	4.3	0.94	1.6		32	26	22	15	1	3	4	L	0.40	0.45
		BC	45-100	4.2		(1.6)	0.11	21	62	17	14	1	3	5	SiL	0.55	0.62
143	RBB4/P	A	0-12	4.0	1.3	2.2		18	62	20	6	1	3	3	SiL	0.41	0.49
		B	12-50	3.3	1.3	13	73	14	10	2	3	4	SiL	0.48	0.61		
		BC	50-100	3.6		0.09	13	67	20	9	2	3	4	SiL	0.50	0.57	

Site No.	Map Unit	Horizon	Depth (cm)	$CaCl_2$ pH	Organic carbon (%)	Organic matter (%)	$CaCO_3$ equiv. (%)	<2mm fraction (%) sand	silt	clay	VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index K_1	K_2
148	RBB4	A	0-15	3.9	2.9	4.9		23	58	19	9	2	3	3	SiL	0.34	0.49
		B	15-50	4.0	1.0	1.7		28	55	17	14	2	3	4	SiL	0.47	0.54
		BC	50-90	4.3		(1.7)	0.08	45	36	19	6	2	3	4/1	L	0.29	0.33
57	RBB6	A	0-15	4.3	2.5	4.3		26	45	29	10	1	3	3	CL	0.24	0.35
		B	15-55	4.6		(1.7)		20	57	23	8	1	3	5	SiL	0.44	0.50
		BC	55-90	5.0		(1.7)		25	48	27	10	1	3	4	L	0.35	0.40
85	RBB6	A	0-20	4.4	1.7	2.9		31	53	16	10	2	3	3	SiL	0.37	0.48
		B	20-65	4.7	0.41	.7		24	51	25	(8)	2	3	5	SiL	0.42	0.44
		BC	65-100	4.5		(.7)		15	61	24	(5)	1	3	5	SiL	0.47	0.50
105	RBB5	A	0-12	3.7	2.0	3.4		20	64	16	16	1	3	3	SiL	0.45	0.61
		B	12-42	4.0	0.87	1.5		21	60	19	16	2	3	4	SiL	0.52	0.58
		BC	42-100	4.4		(1.5)	0.13	11	53	36	9	2	3	5	SiCL	0.36	0.40
107	RBB5	A	0-12	4.1	1.5	2.6		33	53	14	10	2	3	4	SiL	0.42	0.51
		B	12-57	4.3	0.88	1.5		41	45	14	11	2	3	4	L	0.41	0.46
		BC	57-100	4.7		(1.5)	0.08	21	57	22	16	2	3	5	SiL	0.50	0.58
6	TRC1	A	0-15	4.6	1.8	3.1		11	64	25	(6)	1	3	3	SiL	0.36	0.47
		B	15-40	4.2		(1.2)		2	43	55	(2)	1	3	6	SiC	0.24	0.26
		C	40-96	5.4		(1.2)	0.17	0	55	45	(0)	1	3	6	SiC	0.32	0.34
23	TRC1	A	0-29	4.3	1.2	2.0		17	65	18	9	1	1/3	3	SiL	0.46	0.55
		B	29-59	4.7		(0.9)		3	44	53	(3)	1	3	(6)	SiC	0.26	0.27
		BC	59-100	5.4		(0.9)		2	47	51	(2)	1	3	6	SiC	0.27	0.29
30	TRC1	A	0-18	4.3	2.4	4.1		8	48	44	4	1	3	3	SiC	0.18	0.26
		B	18-36	4.5		(1.7)		5	35	60	(5)	1	3	6	C	0.20	0.22
		BC	36-100	5.2		(1.7)		2	38	60	(2)	1	3	6	C	0.20	0.22

Site No.	Map Unit	Horizon	Depth (cm)	CaCl$_2$ pH	Organic carbon (%)	Organic matter (%)	CaCO$_3$ equiv. (%)	<2mm fraction sand (%)	silt (%)	clay (%)	VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index K$_1$	K$_2$
51	TRC1	A	0-16	4.1	3.2	5.4		21	64	15	11	1	3	3	SiL	0.35	0.59
		B	16-42	4.5		(1.7)		22	40	38	(11)	2	3	6	CL	0.32	0.35
		BC1	42-100	5.3		(1.7)		2	47	51	(1)	1	3	6	SiC	0.26	0.28
62	TRC1	Ae1		4.3	3.3	5.6		17	66	17	11	1	3	3	SiL	0.32	0.56
		Bfj	0-24	4.4	2.2	3.7		21	61	18	14	1	3	6	SiL	0.40	0.62
		Ae2		4.5	0.71	1.2		24	64	12	18	1	3	6	SiL	0.62	0.67
		Bt	24-70	4.6		20	45	35		1			CL				
		BC	70+	5.2		(3.7)		14	27	39	(9)	1	3	6	SiCL	0.22	0.27
78	TRC1	A	0-14	4.3	3.1	5.3		15	59	26	10	1	3	3	SiL	0.32	0.46
		B	14-44	4.5	0.96	1.6		6	33	61	(6)	1	3	6	HC	0.20	0.21
		BC	44-100	4.9		(1.6)	0.11	3	36	61	(3)	1	3	6	HC	0.20	0.21
92	TRC1	A	0-10	4.0	2.5	4.3		7	68	25	3	1	3	3	SiL	0.33	0.48
		B	10-32	4.2	1.0	1.7		3	51	46	(3)	1	3	6	SiC	0.30	0.33
		BC	32-90	4.5		1.7		16	38	46	(16)	1	3	6	C	0.30	0.3
127	TRC1/T	A	0-12	4.0	1.8	3.1		6	72	22	4	1	3	3	SiL	0.34	0.51
		B	12-37	4.2	1.0	1.7		1	66	33	1	1	3	6	SiCL	0.42	0.47
		BC	37-65	4.4		(1.7)		3	53	44	1	1	3	6	SiC	0.31	0.34
145	TRC1	A	0-14	3.9	2.1	3.6		3	68	29	3	1	3	6	SiCL	0.40	0.53
		B	14-44	4.3	1.3	2.2		2	61	37	(2)	1	3	6	SiCL	0.37	0.43
		BC	44-100	5.0		2.2	0.09	2	64	34	(2)	1	3	6	SiCL	0.40	0.46
54	TRC3	A	0-16	4.3	1.6	2.7		23	59	18	15	1	3	3	SiL	0.40	0.54
		B	16-46	4.3		(0.9)		6	61	33	(4)	2	3	6	SiCL	0.44	0.46
		BC	46-100	4.6		(0.9)		2	67	31	(1)	1	3	6	SiCL	0.47	0.49
99	TRC3	A	0-8	3.7	4.0	6.8		8	69	23	6	1	3	3	SiL	0.34	0.51
		B	8-60	4.3	0.68	1.2		1	72	27	(0)	1	3	5	SiCL	0.48	0.53
		BC	60-100	4.8		(1.2)	0.15	3	71	26	2	1	3	5	SiL	0.48	0.54

Site No.	Map Unit	Horizon	Depth (cm)	CaCl$_2$ pH	Organic carbon (%)	Organic matter (%)	CaCO$_3$ equiv. (%)	<2mm fraction sand (%)	silt	clay	VFS (%)	CF class	S class	P class	Texture class	Soil erodibility index K$_1$	K$_2$
168	TRC3	A	0-30	4.1	1.2	2.0		22	63	15	14	1	3	5	SiL	0.49	0.62
		B	30-50	4.4	0.60	1.0		13	61	26	(8)	1	3	5	SiL	0.47	0.51
		BC	50-70	4.7		(1.0)	0.08	10	60	30	(6)	1	3	5	SiCL	0.43	0.46
170	TRC3	A	0-18	4.0	2.4	12	71	17	8	1	3	3	SiL	0.33	0.55		
		B	18-50	4.3	0.64	1.1		9	66	25	(6)	1	3	5	SiL	0.50	0.56
		BC	50-100	4.8		(1.1)	0.15	8	57	35	(6)	1	3	5	SiCL	0.38	0.41

OC - organic carbon

OM - organic matter (1.7 X OC); brackated values estimated from average ratio of A to B horizon OM content of the same map unit soils.

VFS - very fine sand (0.0625 to 0.10 mm)

CF - coarse fragments >2 mm diameter, visually estimated classes (1 $\leq$20% CF; 2 >20% CF)

S - soil structure class from the Universal Soil Loss Equation (USLE) (1-very fine granular; 2 fine granular, 3 medium or coarse granular; 4 blocky, platy, or massive).

P - permeability class from the USLE (1 rapid, 2 moderate to rapid, 3 moderate, 4 slow to moderate, 5 slow, 6 very slow) (see Appendix 3 for qualitative descriptions)

K$_1$,K$_2$ - soil erodibility index K from the USLE. K$_1$ organic matter included and K$_2$ organic matter excluded (see text for details).

APPENDIX 3

QUALITATIVE DESCRIPTIONS OF SOIL DRAINAGE AND SOIL PERMEABILITY

Soil Drainage

Soil drainage refers to the rapidity and extent of removal of water from soils in relation to additions. It is affected by a number of factors acting separately or in combination, including texture, structure, organic matter content, slope gradient, length of slope, position in landscape, water holding capacity, and evapotranspiration. Seven soil drainage classes are recognized. These are defined in terms of available water storage capacity (AWSC) and source of water, as follows.

> **Very Rapid or Excessive Drainage.** Water is removed from the soil very rapidly in relation to supply. Excess water flows downward very rapidly if underlying material is pervious. There may be very rapid subsurface flow during heavy rainfall if there is a steep gradient. Soils have very low AWSC (usually <2.5 cm) within the control section and are usually coarse textured, shallow, or both. Water source is precipitation.
>
> **Rapid Drainage.** Water is removed from the soil rapidly in relation to supply. Excess water flows downward if underlying material is pervious. Subsurface flow may occur on steep gradients during heavy rainfall. Soils have low AWSC (2.5 to 4 cm) within the control section, and are usually coarse textured, or shallow, or both. Water source is precipitation.
>
> **Well Drained or Good Drainage.** Water is removed from the soil readily but not rapidly. Excess water flows downward

readily into underlying pervious material or laterally as subsurface flow. Soils have intermediate AWSC (4 to 5 cm) within the control section, and are generally intermediate in texture and depth. Water source is precipitation. On slopes, subsurface flow may occur for short durations but additions are equalled by losses.

Moderately Well Drained. Water is removed from the soil somewhat slowly in relation to supply. Excess water is removed somewhat slowly due to low perviousness, shallow water table, lack of gradient, or some combination of these. Soils have intermediate to high AWSC (5 to 6 cm) within the control section and are usually medium to fine textured. Precipitation is the common water source in medium-to-fine textured soils; precipitation and significant additions by subsurface flow are necessary in coarse-textured soils.

Imperfect or Poor Drainage. Water is removed from the soil sufficiently slowly in relation to supply to keep the soil wet for a significant part of the growing season. Excess water moves slowly downward if precipitation is the major supply. If subsurface water or groundwater, or both, are the main sources, flow rate may vary but the soil remains wet for a significant part of the growing season. Precipitation is the main souce if AWSC is high; contribution by subsruface flow or groundwater flow, or both, increases as AWSC decreases. Soils have a wide range in available water supply, texture, and depth, and are gleyed phases of well-drained subgroups.

Poorly Drained. Water is removed so slowly in relation to supply that the soil remains wet, for a comparatively large part of the time the soil is not frozen. Excess water is evident in the soil for a large part of the time. Subsurface flow or groundwater flow, or both, in addition to precipitation are the main water sources; there may also be perched water tables with precipitation exceeding evapotranspiration. Soils have a wide range in AWSC, textures and depths, and are gleyed subgroups, Gleysols and Organic soils.

Very Poorly Drained. Water is removed from the soil so slowly that the water table remains at or on the surface, for the greater part of the time the soil is not frozen. Excess water is present in the soil for the greater part of the time. Groundwater flow and subsurface flow are the major water sources. Precipitation is less important except where there is a perched water table with precipitation exceeding evapotranspiration. Soils have a wide range in AWSC, texture, and depth, and are either Gleysolic or Organic.

Soil Permeability

Permeability is that quality of a soil that enables it to transmit water or air. Accepted as a measure of this quality is the rate at which soil will transmit water under saturated conditions. The classes of soil permeability are as follow:

Permeability Class	Rate of Permeability
Very slow	<0.15 cm/hr
Slow	0.15 - 0.5 cm/hr
Moderately Slow	0.5 - 1.5 cm/hr
Moderate	1.5 - 5.0 cm/hr
Moderately Rapid	5.0 - 15.0 cm/hr
Very rapid	15.0 - 50.0 cm/hr

SOIL ASSOCIATION	MAP UNITS	DOMINANT SOILS	SIGNIFICANT SOILS	POSSIBLE MINOR SOIL INCLUSIONS	SOIL PARENT MATERIAL
Alluvium (Soil Complex)	AV	undifferentiated fluvial deposits			recent and subrecent fluvial deposits (usually sand or gravel)
	AV1	Orthic Regosol, Cumulic Regosol	Orthic Eutric Brunisol, Eluviated Eutric Brunisol	weakly gleyed soils	
	AV2	Orthic Eutric Brunisol	Eluviated Eutric Brunisol, "bleached" Orthic Gray Luvisol	Brunisolic Gray Luvisol, weakly gleyed soils	
Erith (Soil Complex)	ETH2	Orthic Gleysol	Orthic Luvic Gleysol	Rego Gleysol, peaty phases, organic soils	fine-textured glaciolacustrine sediments
	ETH3	Orthic Gleysol	Orthic Luvic Gleysol	Rego Gleysol, peaty phases, organic soils	Cordilleran till, or sand and gravel therefrom
Fickle (Soil Complex)	O	Undifferentiated organic soils			organic materials
	FKE1	Mesisols	Humisols, Terric subgroups	Fibrisols, Gleysolic soils	
	FKE2	Humisols	Mesisols, Terric subgroups	Gleysolic soils	
Jarvis	JRV3	Podzolic Gray Luvisol	Brunisolic Gray Luvisol, Orthic Gray Luvisol		cobbly gravels: outwash terraces, kame and esker complexes; well expressed cross-bedding; overlie bedrock or till
Marlboro	MLB5	"bleached" Orthic Gray Luvisol	Podzolic Gray Luvisol, Brunisolic Gray Luvisol	weakly gleyed, and shallow soils	medium to fine-textured Cordilleran till (sandy loam textures also observed), coal flecks common; moderately stony.
	MLB6	Brunisolic Gray Luvisol	Podzolic Gray Luvisol, "bleached" Orthic Gray Luvisol	weakly gleyed, and shallow soils	
	MLB7	Orthic Gray Luvisol	Podzolic Gray Luvisol, Eluviated Eutric Brunisol	"bleached" Orthic Gray Luvisol, shallow soils.	
Maskuta	MSK4	Eluviated Dystric Brunisol, lithic phase	Orthic Dystric Brunisol lithic phase	Orthic Gray Luvisol lithic phase, Brunisolic Gray Luvisol lithic phase	weathered bedrock: sandstone, shale, conglomerate
Robb	RBB1	Eluviated Dystric Brunisol	"bleached" Orthic Gray Luvisol, Brunisolic Gray Luvisol	Eluviated Eutric Brunisol, weakly gleyed, and very shallow soils.	Cordilleran till plus colluvium; the till is medium to moderately coarse textured and moderately to very stony.
	RBB2	Eluviated dystric Brunisol	Brunisolic Gray Luvisol, Podzolic Gray Luvisol.	Eluviated Eutric Brunisol, weakly gleyed, and very shallow soils.	
Robb	RBB4	Eluviated Dystric Brunisol, "bleached" Orthic Gray Luvisol	Brunisolic Gray Luvisol, Podzolic Gray Luvisol	Orthic Dystric Brunisol, weakly gleyed, and very shallow soils.	Cordilleran till plus colluvium; the till is medium to moderately coarse textured and moderately to very stony.
	RBB5	Eluviated Eutric Brunisol	"bleached" Orthic Gray Luvisol	Orthic Eutric Brunisol, weakly gleyed, and very shallow soils.	
	RBB6	Eluviated Dystric Brunisol	"bleached" Orthic Gray Luvisol, Brunisolic Gray Luvisol	Orthic Dystric Brunisol, weakly gleyed, and very shallow soils.	
Tri-Creek	TRC1 (parent material textures silty clay to clay)	"bleached" Orthic Gray Luvisol	Orthic Gray Luvisol, Brunsolic Gray Luvisol	weakly gleyed soils	heterogeneous fine (usually) to medium textured glaciolcustrine sediments; contain variable but low contents of cobbles and pebbles; thin interbedded sand lenses sometimes found; thickness varies from a few cm to >3m, usually >1m; overlies till, bedrock, or outwash. can be overlain by sand, or organic soil.
	TRC2 (parent material textures silty clay to clay)	"bleached" Orthic Gray Luvisol	Orthic Gray Luvisol, Gleyed Gray Luvisol	Gleysolic soils	
	TRC3 (parent material textures clay loam to silty clay loam)	"bleached" Orthic Gray Luvisol	Brunsolic Gray Luvisol, Podzolic Gray Luvisol	weakly gleyed soils	

Scale 1 : 15,000 (approx.)

MISCELLANEOUS LAND UNITS

VVV -bedrock outcrop-sandstone (usually), or conglomerate.
GV(Gravel) -gravel bar in river bed.
RB(River Bank) -strongly eroded continuous landform, formed by recent or historical river erosion.

PHASE SYMBOLS

/L -lithic phase-used in areas where bedrock occurs within the control section (100cm) of the soil profile, below a depth of 10cm.
/P -peaty phase-used in areas where the mineral soil has a surface horizon of 15 to 60 cm of fibric moss peat, or 15 to 40 cm of other kinds of peat
/T -shallow phase-used in areas where depth to non-conforming material is less than 100 cm (reserved for mineral soils).

EXPLANATION OF MAP SYMBOL STRUCTURE

TOPOGRAPHY CLASSES

Simple topography (Single slopes) (regular surface)		Complex topography (Multiple slopes) (irregular surface)		Slope %
A	depressional to level	a	nearly level	0 to 0.5
B	very gently sloping	b	gently undulating	>0.5 to 2
C	gently sloping	c	undulating	>2 to 5
D	moderately sloping	d	gently rolling	>5 to 9
E	strongly sloping	e	moderately rolling	>9 to 15
F	steeply sloping	f	strongly rolling	>15 to 30
G	very steeply sloping	g	hilly	>30 to 60
H	extremely sloping	h	very hilly	>60

← direction of slope
● 63 example of a field observation site

Soil Map, Tri-Creeks Experimental Watershed

Tp47-48, R22-23, W5M

H.R. Hudson , G.M. Greenlee and R.W. Howitt

Civil Engineering Department Report No. SWE 85/08

Air photo mosaic provided by Alberta Energy and Natural Resources, Edmonton.
Cartography by Alberta Research Council, Graphics Services, J. Dlask.

ALBERTA RESEARCH COUNCIL
Natural Resources Division