TECHNICAL REPORT M-77-4

ENVIRONMENTAL BASELINE DESCRIPTIONS FOR USE IN THE MANAGEMENT OF FORT CARSON NATURAL RESOURCES

Report 4

ANALYSIS AND ASSESSMENT OF SOIL EROSION IN SELECTED WATERSHEDS

by

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February 1978

Report 4 of a Series

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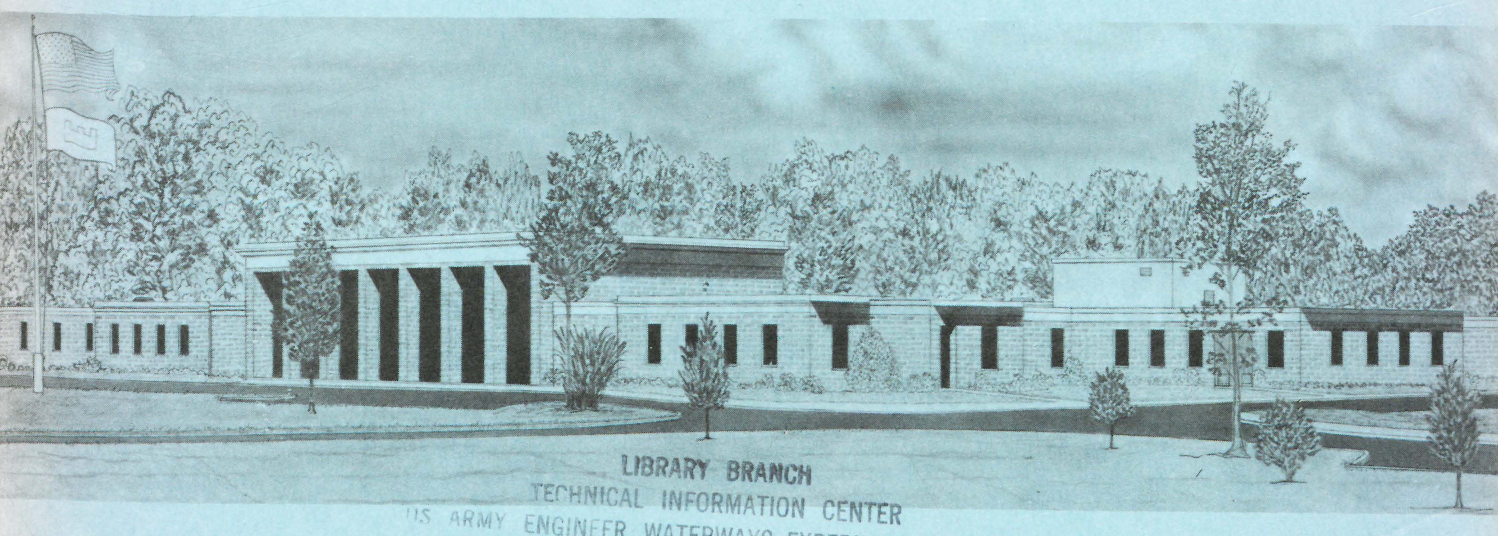

Prepared for Directorate of Facilities and Engineering
Fort Carson, Colorado 80913
and
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Project 4A162121A896, Task 01, Work Unit 006

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Report M-77-4

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
ENVIRONMENTAL BASELINE DESCRIPTIONS FOR USE IN THE MANAGEMENT OF FORT CARSON NATURAL RESOURCES; Report 4, ANALYSIS AND ASSESSMENT OF SOIL EROSION IN SELECTED WATERSHEDS

5. TYPE OF REPORT & PERIOD COVERED
Report 4 of a series

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Malcolm P. Keown
Harold W. West

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Mobility and Environmental Systems Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Project 4A162121A896
Task 01, Work Unit 006

11. CONTROLLING OFFICE NAME AND ADDRESS
Directorate of Facilities and Engineering
Fort Carson, Colo. 80913
and
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

12. REPORT DATE
February 1978

13. NUMBER OF PAGES
120

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Environmental impact
Environmental management
Fort Carson, Colo.
Military installations
Natural resources
Soil erosion
Watersheds

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of the Army's continuing effort to maintain and enhance the natural resources of military installations, environmental quality managers must assess the impact of training activities on soil erosion. A methodology for use in assessing this environmental impact has been developed from studies conducted at Fort Carson, Colorado, by the U. S. Army Engineer Waterways Experiment Station.

(Continued)

20. ABSTRACT (Continued).

Six watershed study areas were selected at Fort Carson, each having an existing sediment catchment basin. These watersheds were considered to be representative of the soil types, vegetation cover, topography, and land use in the Fort Carson region. Borings were made in the catchment basins to determine the accumulated sediment volume. These data were used with the age and area of the basin to estimate the average annual sediment yield for each watershed. A watershed erosion index reflecting the collective influence of rainfall, soil erodibility, topography, and land use was derived using the Universal Soil-Loss Equation as a basis for development.

A plot then was constructed relating average annual sediment yield and the watershed erosion index for each of the watershed study areas. The resulting correlation provides an estimate of the remaining life of existing catchment basins and a capability for evaluating soil loss in terms of military training schedules and determining the percent of catchment basin sediment volume attributable to military activity. Although the assessment methodology was developed for Fort Carson, the general procedures for establishing the correlation and using the methodology to assess the impact of military training activities on soil erosion are applicable to any military reservation, where there are existing catchment basins. In addition to its use as an assessment tool, the methodology can be used as an engineering design aid for the development of new sediment retention structure design parameters in terms of physical parameters that can be measured in the watershed above the site of the proposed catchment basin.

THE CONTENTS OF THIS REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES. CITATION OF TRADE NAMES DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS.

PREFACE

The study reported herein was conducted from 1 August 1975 to 15 July 1977 at the U. S. Army Waterways Experiment Station (WES), Vicksburg, Mississippi, by personnel of the Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL).

The work was authorized by LTC E. R. Hall, Directorate of Facilities and Engineering (DFAE), Fort Carson, Colorado, and supports the Fort Carson Long-Range Environmental Program.

The overall Program Managers at Fort Carson were Messrs. D. W. Davis (now retired), Land Management Branch (LMB), DFAE, and M. E. Halla, Environmental Office, DFAE. Mr. G. J. Bober, LMB, DFAE, provided valuable assistance to the WES field teams during the study. Mr. A. D. Elkin, Soil Conservation Service (SCS), Denver, Colorado, was responsible for the measurement of accumulations in the sediment catchment basins and also provided valuable assistance to the WES field teams during the course of this study. Mr. E. C. Dennis, SCS, La Junta, Colorado, was responsible for the identification of plant species in the watershed study areas.

A portion of the methodology used to acquire on-site environmental data on soils, vegetation, surface geology, topography, surface hydrology, and meteorology was developed under a Department of the Army Project entitled "Environmental Quality for Construction and Operation of Military Facilities," Task 01, "Environmental Quality Management for Military Facilities," Work Unit 006, "Methodology for Characterization of Military Installations Environmental Baseline," sponsored by the Directorate of Military Construction, Office, Chief of Engineers (OCE), U. S. Army. That portion of the Fort Carson work that pertained to on-site environmental data collection was assumed under the auspices of the OCE program as research necessary to assess the adequacy of the procedures used to support environmental baseline development at military installations.

This is one of a series of six reports entitled "Environmental Baseline Descriptions for Use in the Management of Fort Carson Natural

Resources." The individual reports are as follows:

- Report 1. Development and Use of Wildlife and Wildlife Habitat Data
- Report 2. Water-Quality, Meteorologic, and Hydrologic Data Collected with Automated Field Stations
- Report 3. Inventory and Assessment of Current Methods for Rangeland Conservation and Restoration
- Report 4. Analysis and Assessment of Soil Erosion in Selected Watersheds
- Report 5. General Geology and Seismicity
- Report 6. Description and Use of a Computer Information System for Environmental Baseline Data

The work was conducted under the direct supervision of Messrs. H. W. West, Project Engineer, and J. K. Stoll, Chief, Environmental Simulation Branch (ESB), ESD, and under the general supervision of Messrs. B. O. Benn, Chief, ESD, and W. G. Shockley, Chief, MESL.

Messrs. E. A. Dardeau, Jr., A. M. B. Rekas, and C. E. Stevens, all of ESB, were responsible for the field data collection and preparation of soil and vegetation maps. Mr. M. P. Keown, ESB, was responsible for the analysis and erosion assessment of the watershed study areas. This report was prepared by Messrs. Keown and West. Appendix D was prepared by Messrs. Dardeau and Stevens.

COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were Directors of the WES during the study and report preparation. Mr. F. R. Brown was Technical Director.

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CONTENTS

CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	Metric (SI) to U. S. Customary	
centimetres	0.3937007	inches
cubic metres	35.31466	cubic feet
kilometres	0.6213711	miles (U. S. statute)
metres	3.280839	feet
metric tons	1.1	tons
square kilometres	0.3861021	square miles (U. S. statute)
square metres	10.76391	square feet
square metres	2.47105×10^{-4}	acres
	U. S. Customary to Metric (SI)	
acres	4046.856	square metres
cubic feet	0.0283685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
square feet	0.09290304	square metres
tons	0.907	tons (metric)

ENVIRONMENTAL BASELINE DESCRIPTIONS FOR USE IN THE MANAGEMENT OF FORT CARSON NATURAL RESOURCES

ANALYSIS AND ASSESSMENT OF SOIL EROSION IN SELECTED WATERSHEDS

PART I: INTRODUCTION

Background

1. Army Regulation (AR) 200-1 entitled "Environmental Protection and Enhancement," dated 7 December 1973, implements Department of Defense Directive 5100.50 and provides direction regarding Department of the Army policy on environmental protection and enhancement of the natural resources of Army installations. The long-term planning and management goal outlined in this AR requires that design, construction, operation, and maintenance activities on an installation must be conducted with minimum environmental impact on the natural resources of the installation. Inherent in this goal is the objective to minimize soil erosion and attendant pollution caused by rapid and uncontrolled runoff into streams and rivers. To meet this objective, measures must be implemented on military installations to prevent the transport of excessive quantities of soil material and erosional debris from the installation onto lands and into stream channels adjacent to the installation.

2. The broad objectives of the Fort Carson Environmental Program and the Land Use Management Plan that pertain to training area land management are as follows:

- a. To conserve, maintain, restore, and enhance the downrange environment at Fort Carson in terms of its visual attractiveness and productivity, without impairing the Army mission.
- b. To minimize the transport of sediment from watershed areas into stream channels that drain the installation.
- c. To develop and implement an environmental education program for Fort Carson personnel that will describe the installation's cultural relationship to the environment and outline current efforts to monitor and maintain environmental quality.

d. To develop improved methods and techniques for assessing the impacts of military training activities on the environment.

e. To determine and maintain those downrange training areas that should be placed off limits at certain designated time periods to allow for the reestablishment of acceptable landscape conditions, specifically vegetal cover.

f. To manage and control all land and vegetal resources needed for (1) military training programs; (2) use as a facility, road, tank trail, firebreak, dam, or other control structure; and (3) wildlife habitats.

3. The southern two thirds of the Fort Carson Reservation is used intensively for field training of the U. S. Army 4th Infantry Division (Mechanized). These training activities result in damage to both the woody and open grassland vegetation, which are slow to regenerate in the relatively dry climate existing in the Fort Carson area. In addition to the vegetation damage noted above, surface soil disturbance, soil compaction, and the development of roads and trails collectively result in a significant environmental impact that is incurred from military vehicle traffic. The direct result of this impact is the escalation of soil-loss rates. Emphasized in this report is the development of a technique for evaluating soil loss on the Fort Carson Reservation. This basic technique is needed for assessing (and devising mitigation techniques for) the impact of military training activities on the environment.

Purpose and Scope

4. The purpose of this report is to describe a method (a modification of the Universal Soil-Loss Equation (USLE)[1]) developed to assess soil loss as a function of watershed characteristics and land use on the Fort Carson Reservation. The methodology was derived from measurements of sediment accumulated in six catchment basins and the land use history and terrain characteristics of the associated watersheds. The watersheds were selected to be representative of vegetation, soil, and topographic relief occurring in the areas used for training purposes. Although this report is limited to assessment of soil erosion at Fort

Carson, the method of assessment should apply to any military reservation where there are existing sediment catchment basins.

5. Borings were made in the six sediment catchment basins by the Soil Conservation Service (SCS) to determine the accumulated sediment volume in each. Estimates of the average annual sediment yield were calculated for the six basins using the SCS boring data. Environmental data collected by the U. S. Army Engineer Waterways Experiment Station (WES) and the land use history of the watersheds furnished by the Directorate of Facilities and Engineering (DFAE), Fort Carson, were then correlated with the average annual sediment yield to provide the predictive methodology based on measurable watershed parameters. This methodology was used to (a) estimate the average annual sediment yield in the selected watersheds, (b) estimate the remaining design life of the sediment catchment basins in the selected watersheds, (c) demonstrate how the predictive methodology could have been used to develop a more cost-effective design for the existing catchment basins as well as extending the methodology to the design of new sediment retention structures, and (d) estimate the accumulated sediment volume in the selected catchment basins that is directly attributable to military training activities.

Overview of Problem Solution

6. Land management and conservation practices at Fort Carson are directed towards the effective utilization of the downrange environment such that the natural resources (land, water, and wildlife) of the installation are maintained in a state as ecologically viable and as aesthetically pleasing as possible while at the same time providing a suitable area for the primary land use function (military training). The spirit of this effort requires that military training activities be conducted in such a manner that those stresses imposed on the terrain that would result in soil loss should be minimized. In the past environmental resource managers have found it particularly difficult to objectively analyze and assess soil erosion problems at Fort Carson because a technique was not available to estimate soil loss as a function of military land use and terrain conditions.

7. On the Fort Carson Reservation, several well-defined watersheds exist that have been subjected to different levels of erosion due to variations in soil erodibility, topography, and land use. In many of these watersheds, the sediment that was trapped by catchment basins has provided a means for making reliable estimates of the volume and mass of accumulated sediment. These estimates can be obtained by using information derived from surface topographic measurements and borings made in the area where the sediment is deposited. Sediment accumulation data were used in conjunction with terrain data obtainable in selected watershed study areas to refine a technique for estimating soil loss in terms of military training activity and terrain conditions. The technique (USLE) and the approach used in its modification are described herein.

8. Many procedures have been developed for predicting soil loss from sheet and rill erosion in small watersheds. Of these methods, the USLE has been found to be widely applicable and is generally accepted as the best method for estimating areal soil losses.[1] The USLE was originally developed for application to cropland, hayland, and pastures but has recently been extended[2] to terrains including rangeland, woodlands, and idle land. The USLE equation for computing soil loss is expressed as

$$A = RKLSC \tag{1}$$

where

A = annual areal soil loss due to sheet and rill erosion

R = rainfall factor

K = soil erodibility factor

L = slope-length factor

S = slope-gradient factor

C = land use factor

These terms are further described in Part III.

9. Sediment deposition in a catchment basin cannot be directly related to the upland soil loss as estimated by the USLE because of the multiple erosion mechanisms in action. While the USLE predicts soil

losses for sheet and rill erosion, the deposition in a downstream catchment basin may also be attributable in part to gully and channel erosion. A universally accepted method for estimating deposition due to gully and stream channel erosion,[3] that is directly applicable to the Fort Carson Reservation, has not been developed. Thus, for the purposes of this study, the soil loss calculated from the USLE would not account for the total sediment yield as measured in the sediment catchment basins.

10. The approach selected for this analysis was to first develop a procedure, based on the USLE, to calculate a quantitative value reflecting a relative index of erosion for a given watershed, the inputs needed to calculate the index being derivable from land use and environmental baseline data. The next step was to select several watershed study areas (in this case six, as described in Part III) on the Fort Carson Reservation (each having a downstream sediment catchment basin), representing the range of soil erodibility, topography, and land use conditions found on the reservation. Field data were taken in each watershed study area to determine the accumulated sediment volume in the catchment basin (from which a value of the average annual sediment yield was determined) and to acquire data needed to calculate the erosion index. After calculation of the yield and the index for each watershed, the data pairs were plotted and a mathematical correlation was developed. Through the correlation of known yield values with the dimensionless index, the multiple erosion mechanisms active in a given watershed, i.e., sheet and rill erosion as well as soil losses due to gully and stream channel erosion, were accounted for and thus the limitations of the USLE were overcome.

PART II: DEVELOPMENT OF THE WATERSHED EROSION INDEX

11. As stated in paragraph 8, the USLE (Equation 1) is an analytical tool whereby watershed parameters are used to predict the annual areal soil loss resulting from sheet and rill erosion. The numerical values obtained by using the USLE do not reflect soil losses attributable to gully and stream channel erosion and, thus, do not provide a true measure of watershed erosion. To accommodate the multiple erosion mechanisms that collectively determine the sediment yield of a watershed, an erosion index was developed using the USLE as a conceptual basis. The USLE includes five factors that each directly contribute to soil loss: rainfall, soil erodibility, the topographic slope gradient and length, and land use. The factors comprising the index of erosion are identical to the USLE structure except for the land use factor, which has been modified to include the effects of soil losses occurring as a result of military training activities.

12. To account for the variation in erosion rates among the different types of soils present in a given watershed, an erosion index was determined for each area containing a unique soil type. The resulting indices were areally weighed and summed to obtain to an index reflecting the relative soil loss for the entire watershed. This index is hereafter referred to as the Watershed Erosion Index (WEI). The subdivision of watersheds by soil type and the development of the WEI are described below.

Field Mapping Unit Erosion Index

13. Each watershed was subdivided into areas, called field mapping units, according to the SCS soil type. Using the USLE as a basis, the erosion index for each field mapping unit was then calculated from the expression

$$\left(EI\right)_i = R_i K_i \left(LS\right)_i \overline{C}_i \tag{2}$$

where

$(EI)_i$ = field mapping unit erosion index; i is a unique integer value assigned to each unit

R_i = rainfall factor (see paragraphs 14 and 15)

K_i = soil erodibility factor (see paragraphs 16-19)

$(LS)_i$ = slope-length and gradient factor (see paragraphs 20-22)

$\overline{C}_i$ = composite land use factor (see paragraphs 23 and 24)

The various terms in this equation are described below. The acquisition of numerical data for Equation 2 applicable to the Fort Carson area is described in Part III.

Rainfall Factor

14. The rainfall factor (R_i) is the rainfall erosion index developed by Wischmeier.[4] This factor reflects the combined influence of raindrop impact and turbulence of runoff to transport dislodged soil particles, i.e., the factor is a relative measure of rainfall erosive force.

15. The rainfall factor is computed from the records of individual storms and summed over a given time interval to obtain an accumulated value. For many regions of the United States, rainfall factors have been compiled and summarized in the form of "iso-erodent" maps.[5,6]

Soil Erodibility Factor

16. The meaning of the term "soil erodibility" is distinctly different from that of the term "soil erosion." The rate of soil erosion in any given area may be influenced more by land slope, rainstorm characteristics, cover, and management than by properties of the soil itself. However, some soils erode more readily than others even when slope, rainfall, cover, and management are the same. This difference, due to properties of the soil itself, is referred to as soil erodibility.

17. Properties that influence soil erodibility by water are

those that (a) affect the infiltration rate, permeability, and total water capacity, and (b) resist the dispersion, splashing, abrasion, and transporting forces of the rainfall and runoff. A number of attempts have been made to determine criteria for scientific classification of soils according to erodibility. Generally, however, soil classifications used for erosion prediction have been largely subjective, with only relative rankings.

18. The relative erodibility of different soils is difficult to judge from field observation. Even a soil with a relatively low erodibility factor may show signs of serious erosion when the soil occurs on long or steep slopes or in localities having numerous high-intensity rainstorms. A soil with a high natural erodibility factor, on the other hand, may show little evidence of actual erosion under gentle rainfall when it occurs on short and gentle slopes or when the best possible management is practiced.

19. The soil erodibility factor (K_i) is a quantitative value that is experimentally determined by the SCS. For a particular soil, it is the rate of erosion from unit plots of that soil. A unit plot is 22.13 m* long, with a uniform lengthwise slope of 9 percent, in continuous fallow, tilled up and down the slope. Continuous fallow, for this purpose, is land that has been tilled and kept free of vegetation for a period of at least 2 years or until prior crop residues have decomposed. During the period of soil-loss measurements, the plot is plowed and placed in conventional corn seedbed condition each spring and is tilled as needed to prevent vegetal growth or serious surface crusting. When all of these conditions are met, each of the factors L, S, and C in Equation 1 are set equal to 1.0, and K equals A/R. The conditions listed above were selected as unit values in the USLE because they represent the predominant slope length and the median gradient on which past erosion measurements in the United States have been made, and the designated management provides the surface condition least influenced by

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* A table of factors for converting metric (SI) units of measurement to U. S. customary units and U. S. customary units to metric (SI units is presented on page 6.

differences in climate and local cropping systems. To evaluate K for soils that do not usually occur on a 9 percent slope, soil-loss data from plots that meet all the other specified conditions are adjusted to the 9 percent slope by means of the slope-gradient factor (see paragraph 21).

Slope-Length and Gradient Factor

20. Slope length is defined as the distance from the point of origin of overland flow to either of the following points, whichever is limiting for the major part of the area under consideration: (a) the point where the slope decreases to the extent that deposition begins; or (b) the point where runoff enters a well-defined channel, which may be part of a drainage network or a constructed channel, such as a terrace or diversion. Studies[2] have shown that the soil loss per unit area is proportional to some power of the length of the topographical slope. The slope-length factor (L) is defined as the ratio of a field slope to that of a slope 22.13 m in length raised to a given power. The value of L may be expressed as

$$L = \left(\frac{\lambda}{22.13}\right)^m \qquad (3)$$

where

λ = measured slope length in metres

m = power of slope length

The magnitude of the exponent in this expression is not the same for all locations or for all conditions at a given location. However, its average value in past investigations under natural rainfall has been about 0.5; thus, this value was used for this study.[1]

21. Based on analyses of the data assembled at the U. S. Department of Agriculture Runoff and Soil-Loss Data Center, Portland, Oregon, Wischmeier[6] developed the following slope-gradient factor (S) equation:

$$S = \frac{0.43 + 0.30s + 0.043s^2}{6.613} \qquad (4)$$

where s equals the gradient expressed in percent.

22. The collective effects of L and S have been evaluated separately;[1] however, it has been convenient to consider the two as a single topographic factor, LS_i. By multiplying Equations 3 and 4, the following equation represents the slope-length and gradient factor:

$$LS_i = \sqrt{\lambda}\left(0.0076 + 0.00535s + 0.00076s^2\right) \tag{5}$$

Composite Land Use Factor

23. The composite land use factor ($\overline{C}_i$) is a proportional multiplier that accounts for the degree of protection against erosion afforded the in situ soil by plant cover and for the changes in the erosion rate due to the effects of military training activities. After consultation with the SCS South Technical Information Center (STIC), Fort Worth, Texas, it was determined that the influence of military training activities on watershed soil loss has not been quantitatively defined. Thus, it was necessary that an equivalent factor be used to represent these effects. The STIC personnel suggested that a factor developed for cross-slope plowing[2] might be considered as an equivalent factor to account for the results of military training activities on soil-loss rates.

24. Since within any field mapping unit it may be possible that only a part of the actual area is subjected to military training operations, $\overline{C}_i$ was weighted as follows:

$$\overline{C}_i = A_m\left(C_{csp} - C_{nc}\right) + C_{nc} \tag{6}$$

where

A_m = percent of field mapping unit damaged by military training activities

C_{csp} = SCS cover factor for cross-slope plowing

C_{nc} = factor representing the protection provided by natural plant cover against soil erosion

A time-weighted composite land use factor $\left(\overline{C}_{it}\right)$ can be used in Equation 2 instead of $\overline{C}_i$ to account for the fact that both unused land with natural vegetation cover and land with natural vegetation cover used for military training activities may exist for various time intervals during the life of a catchment basin. The equation for $\overline{C}_{it}$ can be expressed as

$$\overline{C}_{it} = C_{nc}\left(\frac{T_v}{T_s}\right) + \overline{C}_i\left(\frac{T_m}{T_s}\right) \tag{7}$$

where

T_v = number of years that the watershed has been used for nonmilitary purposes

T_s = age of sediment catchment basin, years

T_m = number of years that the watershed has been used for troop training activities

Computation of Watershed Erosion Index

25. By areally weighting and summing the erosion indices for each field mapping unit within the watershed study area, the WEI can be calculated from the expression:

$$\text{WEI} = \sum_{i=1}^{i=\alpha} A_{f_i}\left(\text{EI}\right)_i \tag{8}$$

where

α = number of field mapping units within the watershed study area

A_{f_i} = percent of watershed study area occupied by field mapping unit (see paragraph 26)

$\left(\text{EI}\right)_i$ = erosion index for a specified field mapping unit (determined by Equation 2)

Since $(\text{EI})_i$ is considered as being dimensionless, the WEI is interpreted as being a relative measure or index of the soil loss within the watershed study area.

26. The relative influence of the area covered by each field mapping unit on the WEI was accounted for by determining the percent of the watershed study area that was occupied by the unit (A_{f_i} in Equation 8). This factor is a linear multiplier in Equation 8 that gives the value for the computed unit erosion index (Equation 2) a weighting that is directly proportional to the area covered by the unit.

27. Equation 8 provides the analytical framework for making estimates of the WEI; it is emphasized, however, that although the WEI is interpreted as a relative measure of watershed soil loss, specific input data are required to make computations. The selection of six watershed study areas and the acquisition of the data required for making computations using Equation 8 are discussed in Part III.

PART III: SELECTION AND DESCRIPTION OF WATERSHED STUDY AREAS

Watershed Study Area Selection

28. To serve as the basis for acquiring environmental data needed to develop an analytical expression to predict watershed soil loss (Part II), six watershed study areas with sediment basins (Figure 1) were selected by personnel of the WES, DFAE, and SCS. Care was taken to ensure that these watersheds spanned the range of topographic, vegetative, soil, and surface drainage characteristics found on the Fort Carson Reservation, as well as being subject to different land use (military training) pressures.

29. The coordinate position and date of construction for each of the sediment catchment basin retention structures located in the six watershed study areas are as follows:

Watershed	Military Grid Coordinates of Retention Structure	Date of Retention Structure Construction
1	187544	1960
2	046570	1957
3	117526	1947
4	225552	1947
5	087683	1950
6	257697	1950

The date of construction for each structure was obtained from records on file at Fort Carson and by examination of stereo-aerial photography taken over the past 30 years.

General Terrain Descriptions

Watershed 1

30. Watershed 1 is located near the southern edge of the Fort Carson Reservation. The watershed boundary as depicted in Figure 2 has a surface drainage area of 1,355,000 m^2. The locations of the watershed study area boundaries were determined by the SCS from interpretation of drainage divides using topographic maps and from field reconnaissance.

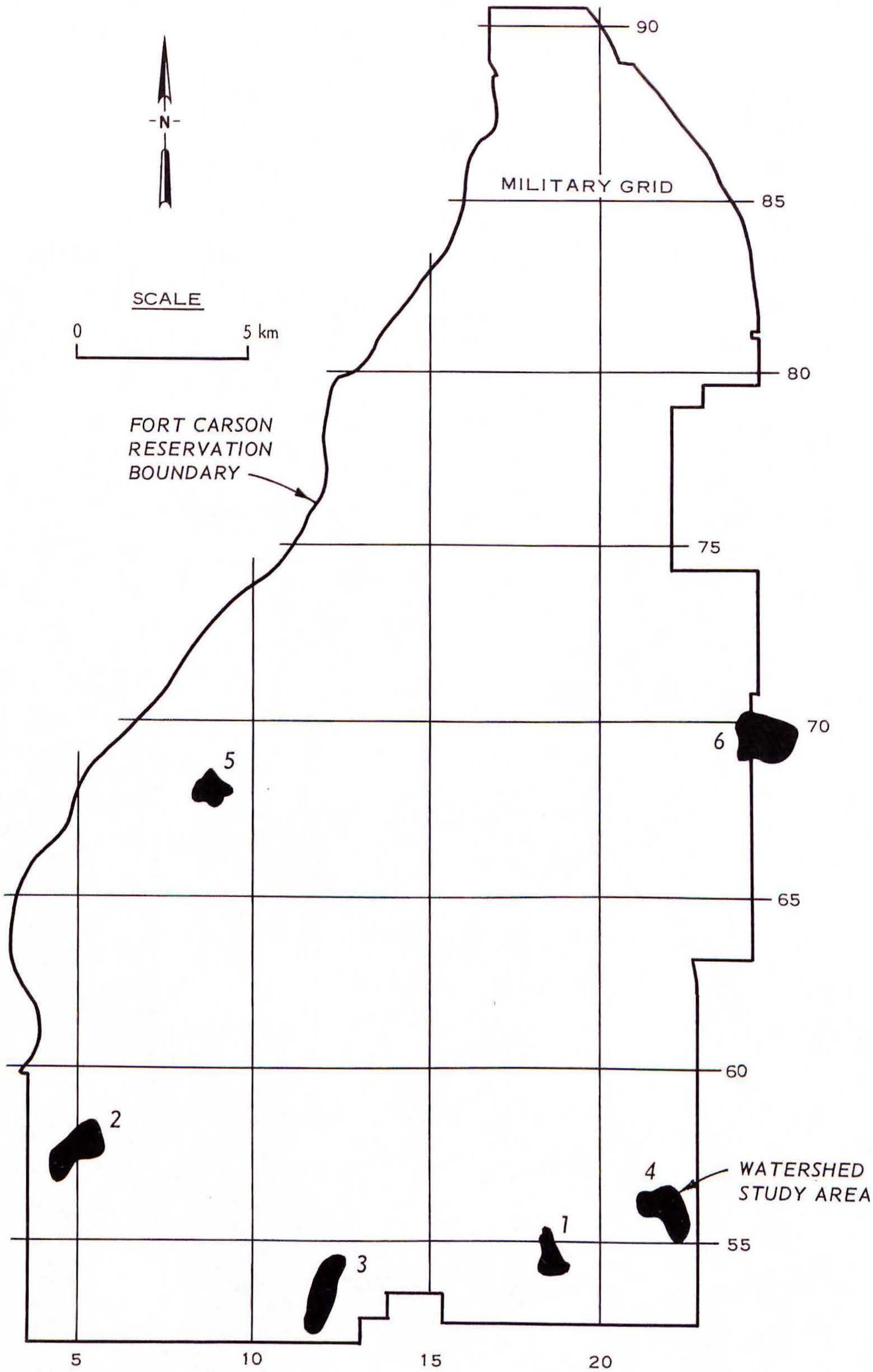

Figure 1. Locations of six watershed study areas, Fort Carson, Colorado

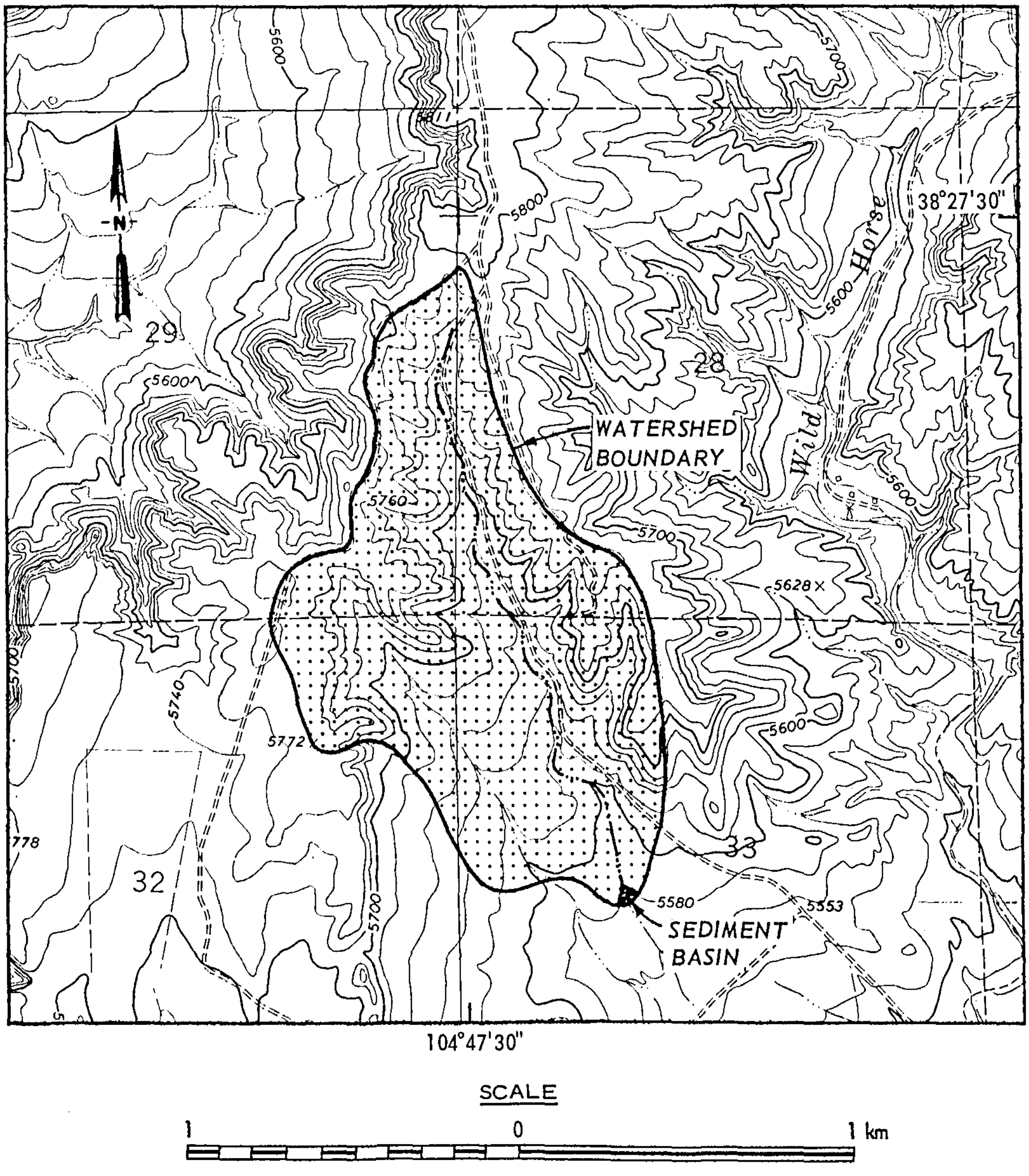

Figure 2. Locations and boundary of watershed 1, Fort Carson, Colorado (Source: USGS 7 1/2' Quadrangle, Stone City, Colorado; AMS 5060 IV NE-Series V877 (1963))

The area within the established boundary was determined using an automated procedure developed by the WES.[7] The relief within the watershed is approximately 220 m, and the soils are primarily loams in the valleys and gravelly sandy loams with scattered rocks on the hills and ridges. The watershed contains a small drainage channel as indicated in Figure 2. Grasses are predominant in the valleys, while one-seed juniper (*Juniperus monosperma*) and pinyon pine (*Pinus edulis*) are predominant on the hills and ridges.

Watershed 2

31. Watershed 2 is located in the southwestern corner of the reservation and has a surface drainage area of 974,000 m^2. Figure 3 shows the boundary of watershed 2. The watershed contains one primary sediment basin (constructed in 1957) and two smaller basins (Figure 3) that were constructed in 1973. At the time this study was conducted, an insignificant amount of deposition had occurred in the small sediment basins. Thus, the historical impact of these two retention structures on the sediment regime of watershed study area 2 was considered to be negligible and did not enter into the analyses described in Part IV. The relief is approximately 350 m; the soils are primarily loams. This watershed contains a large stream channel as indicated in Figure 3. Grasses are predominant in the flat areas, while vegetation in the hills and ridges consists of one-seed junipers and pinyon pines. Many large boulders are found on the hills and ridges.

Watershed 3

32. Watershed 3 is located near the southern boundary of the reservation and has a drainage area of 1,275,000 m^2. Figure 4 shows the boundary of the watershed. The relief within the watershed is 240 m; the soils and vegetation are the same as described for watershed 2. This watershed contains small drainage channels that are not well defined on the topographic map (Figure 4).

Watershed 4

33. Watershed 4 is located near the southeastern corner of the reservation and has a drainage area of 869,000 m^2. Figure 5 shows the boundary of the watershed. No well-defined stream channel has developed

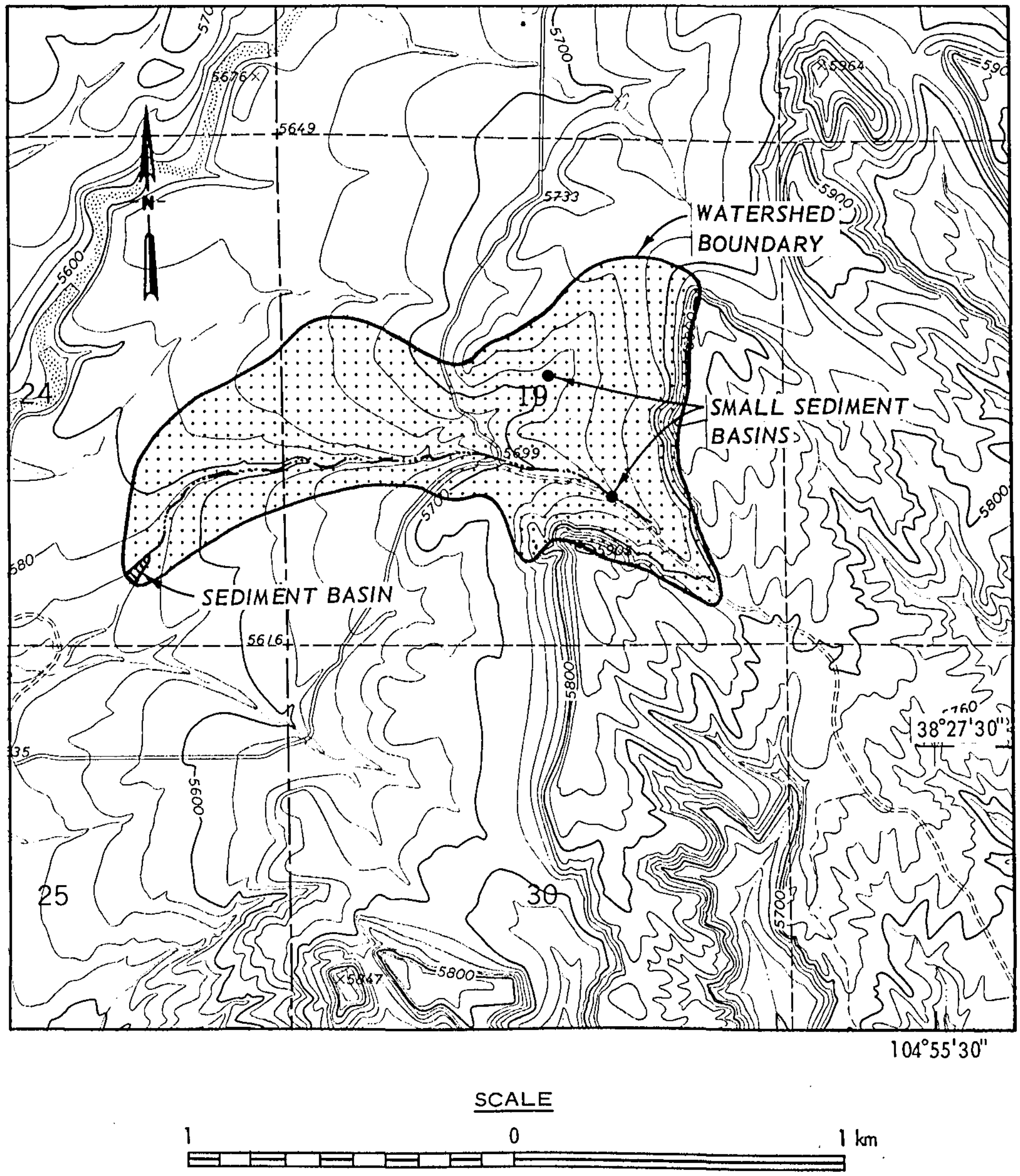

Figure 3. Location and boundary of watershed 2, Fort Carson, Colorado (Source: USGS 7 1/2' Quadrangle, Pierce Gulch, Colorado; AMS 5060 IV NW-Series V877 (1963))

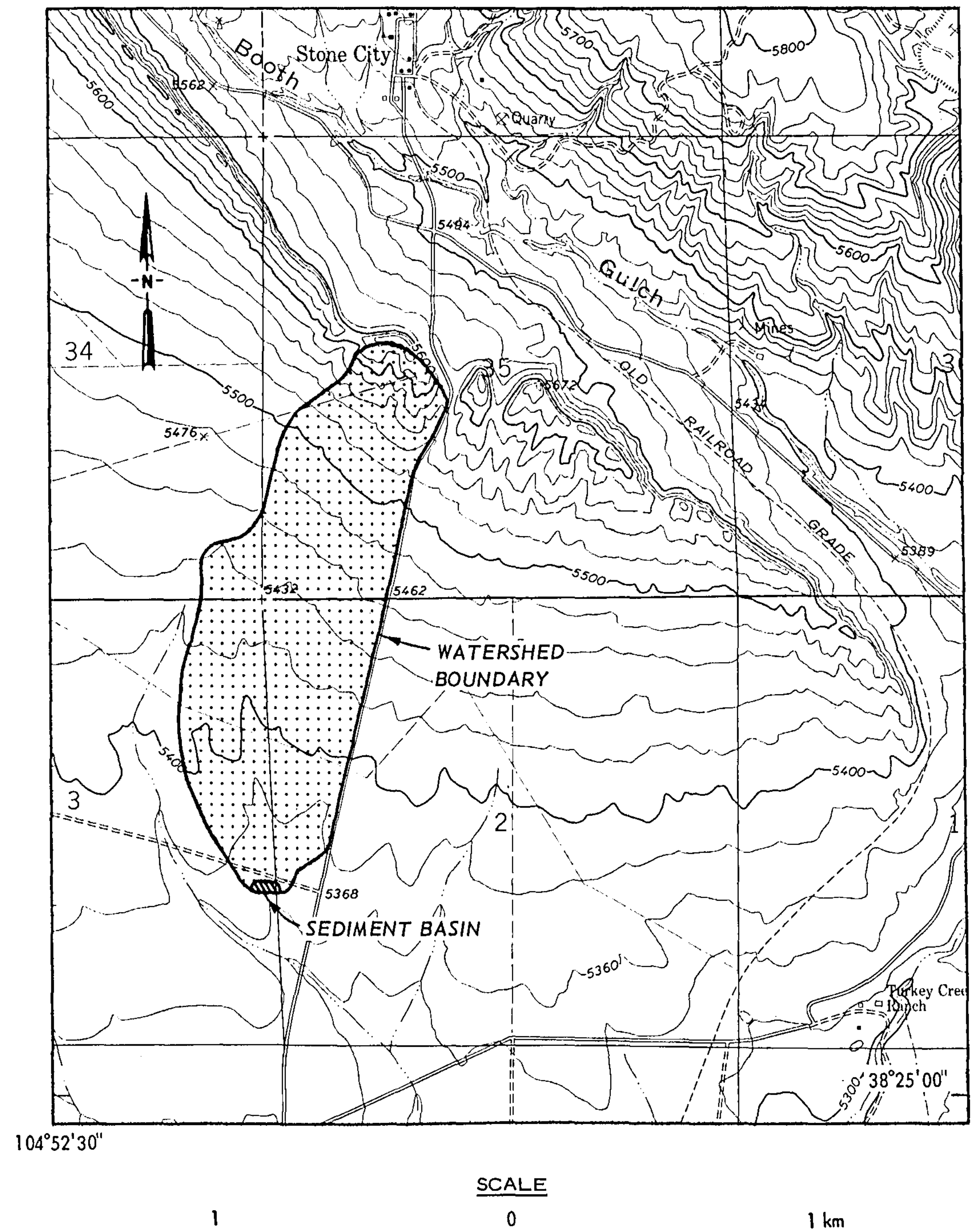

Figure 4. Location and boundary of watershed 3, Fort Carson, Colorado (Source: USGS 7 1/2' Quadrangle, Stone City, Colorado; AMS 5060 IV NE-Series V877 (1963))

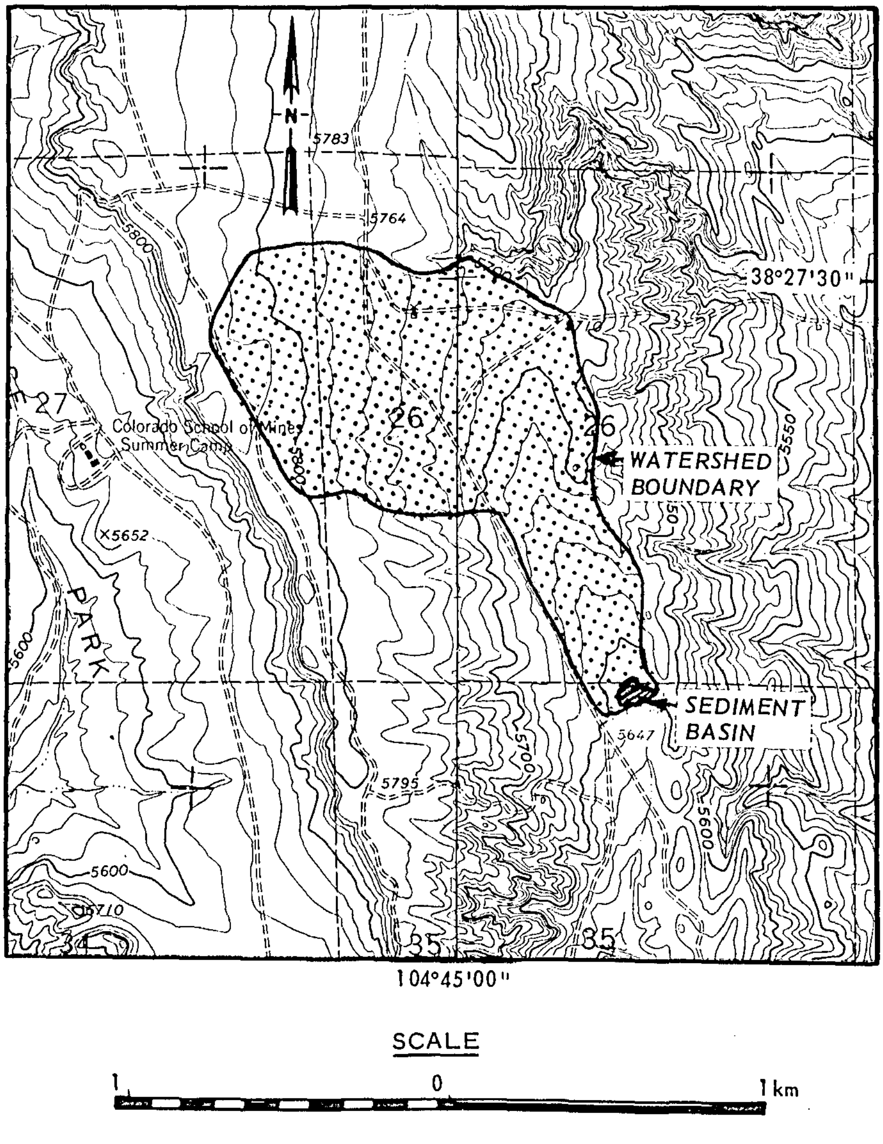

Figure 5. Location and boundary of watershed 4, Fort Carson, Colorado (Source: USGS 7 1/2' Quadrangle, Stone City, Colorado; AMS 5060 IV NE-Series V877 (1963), and USGS 7 1/2' Quadrangle, Steele Hollow, Colorado; AMS 5060 I NW-Series V877 (1961))

in the basin. The relief is approximately 170 m, and the soils are generally loams. The vegetation is primarily grasses in the flat areas and one-seed junipers and pinyon pines in the areas of sloping terrain.

Watershed 5

34. Watershed 5 is located in the west-central portion of the reservation and has a surface drainage area of 504,000 m^2. The boundary of watershed 5 is depicted on the topographic map included as Figure 6. The relief within the watershed is 130 m. The reddish soils are primarily loams, and the vegetation is the same as that for watershed 2.

Watershed 6

35. Watershed 6 is located on the eastern edge of the reservation and lies mostly in privately owned land outside the Fort Carson Reservation. This watershed is subject to very little military activity, and soil loss is not considered to be a problem. Figure 7 shows the boundary of the watershed, which has a drainage area of 1,918,000 m^2. The relief within the area is 100 m. The soils are primarily loam and silt. A good ground cover of grasses occurs over the watershed, but there are no trees . A central drainage channel extends northwest to southeast through the area.

Determination of Accumulated Sediment Volume in Watershed Study Area Catchment Basins

36. Prior to developing an analytical relationship to predict average annual sediment yield as a function of the WEI, the accumulated sediment volume (from which the average annual sediment yield is computed (see paragraph 63)) and WEI must first be determined for each of the watershed study areas.

37. The method used to determine the accumulated sediment volume in the watershed study area catchment basins is explained in the following paragraphs. Then, the acquisition of data needed to calculate the watershed erosion indices is discussed in paragraphs 41-60.

38. During the period July-October 1975, the SCS conducted topographic surveys and drilled holes with a truck-mounted auger in five of the six watershed basins to determine the total volume of sediment (i.e.

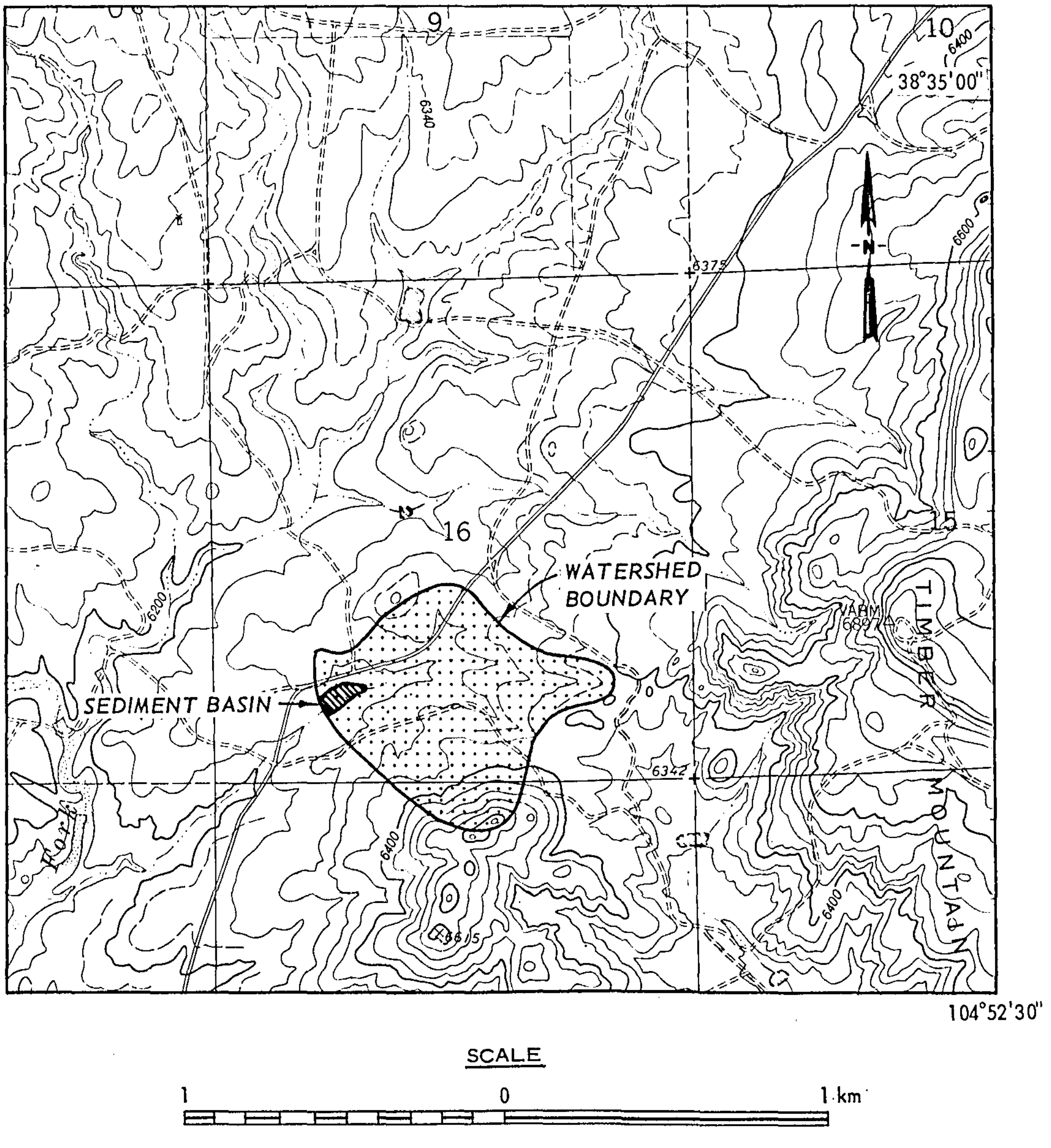

Figure 6. Location and boundary of watershed 5, Fort Carson, Colorado (Source: USGS 7 1/2' Quadrangle, Mount Pittsburg, Colorado; AMS 5061 III SW-Series V877 (1961))

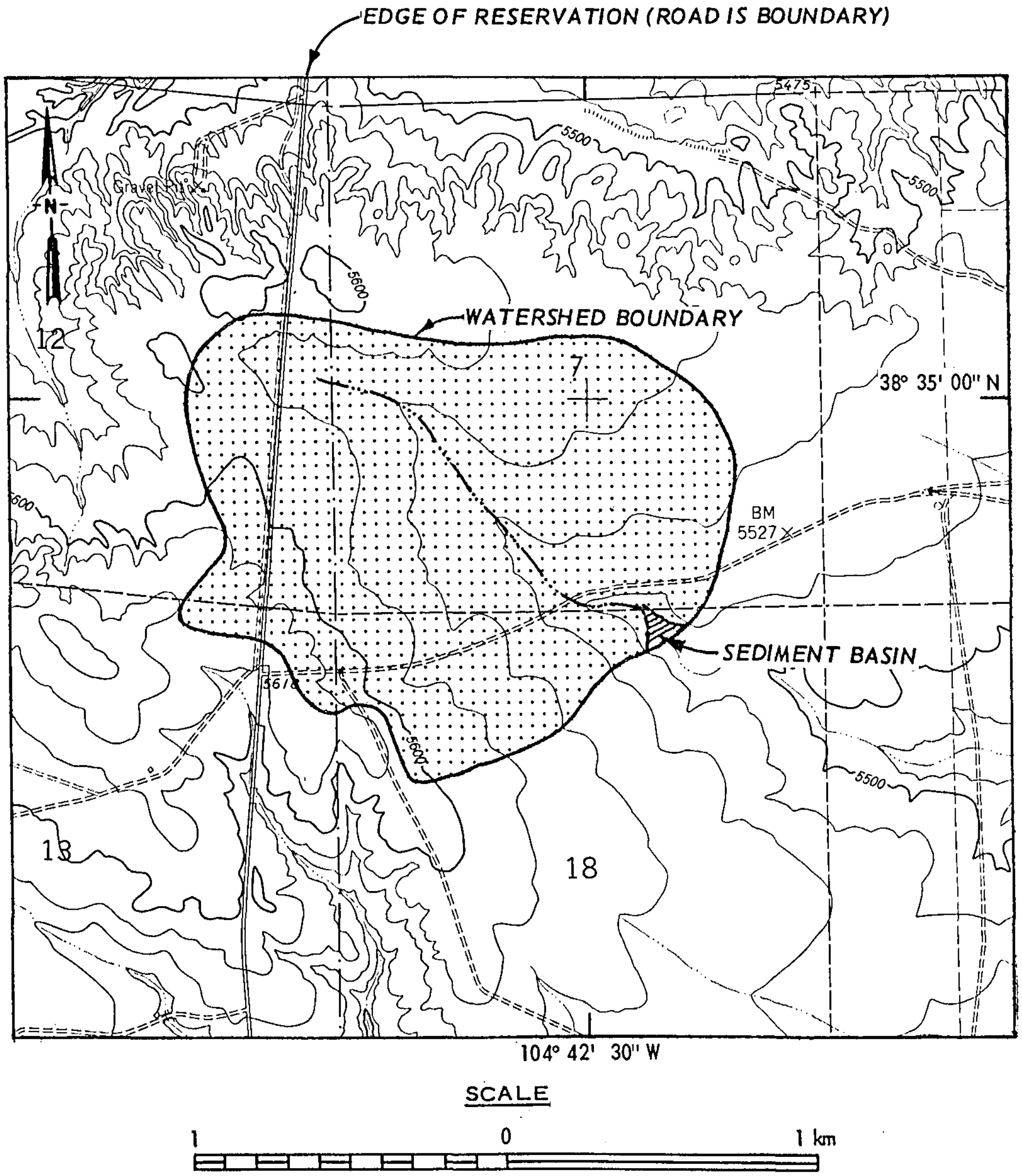

Figure 7. Location and boundary of watershed 6, Fort Carson, Colorado (Source: USGS 7 1/2' Quadrangle Map, Buttes, Colorado; AMS 5061 II SW-Series V877 (1961))

sediment accumulation) that had been deposited in the basins since their construction. The SCS found the sediment accumulation in the basin of watershed study area 6 to be negligible and thus made no borings. The SCS procedure to calculate the thickness of the accumulated sediment consisted of first laying out (i.e. surveying) either a 6.1-m (watershed study areas 1, 2, 3, and 4) or a 12.2-m (watershed study area 5) grid network, each grid point being marked with a wooden stake and numbered according to a row and column format (Figure 8). The boundary of the grid network included the sediment surface as determined by visual inspection. At each grid location within the boundary of the sediment surface, a boring was made using a 10.2-cm-diam auger. The thickness of the sediment accumulation was then determined by noting the depth in the boring where there was a change in the soil type or color of the soil.

39. A two-step procedure was used for calculating accumulated sediment volume in a catchment basin. First, a mean cross-sectional area between sequential pairs of data points along each row was computed according to

$$A_j = \sum_{j=1}^{p+1} D\left(\frac{d_{j-1} + d_j}{2}\right) \tag{9}$$

where

A_j = mean cross-sectional area between grid points $j-1$ and j, m^2

p = number of grid points (stakes) along each row

D = spacing between grid points

d_j = measured thickness of deposited material at each established grid location within the sediment surface. The mean area before the first data point on the row where d_j was not equal to zero was computed by assuming that the thickness of sediment at the hypothetical data point (d_{j-1}) was equal to zero. The same procedure was used to compute the mean area after the last data point on the row where d_j was not equal to zero by assuming that the thickness of sediment at the next grid location was zero.

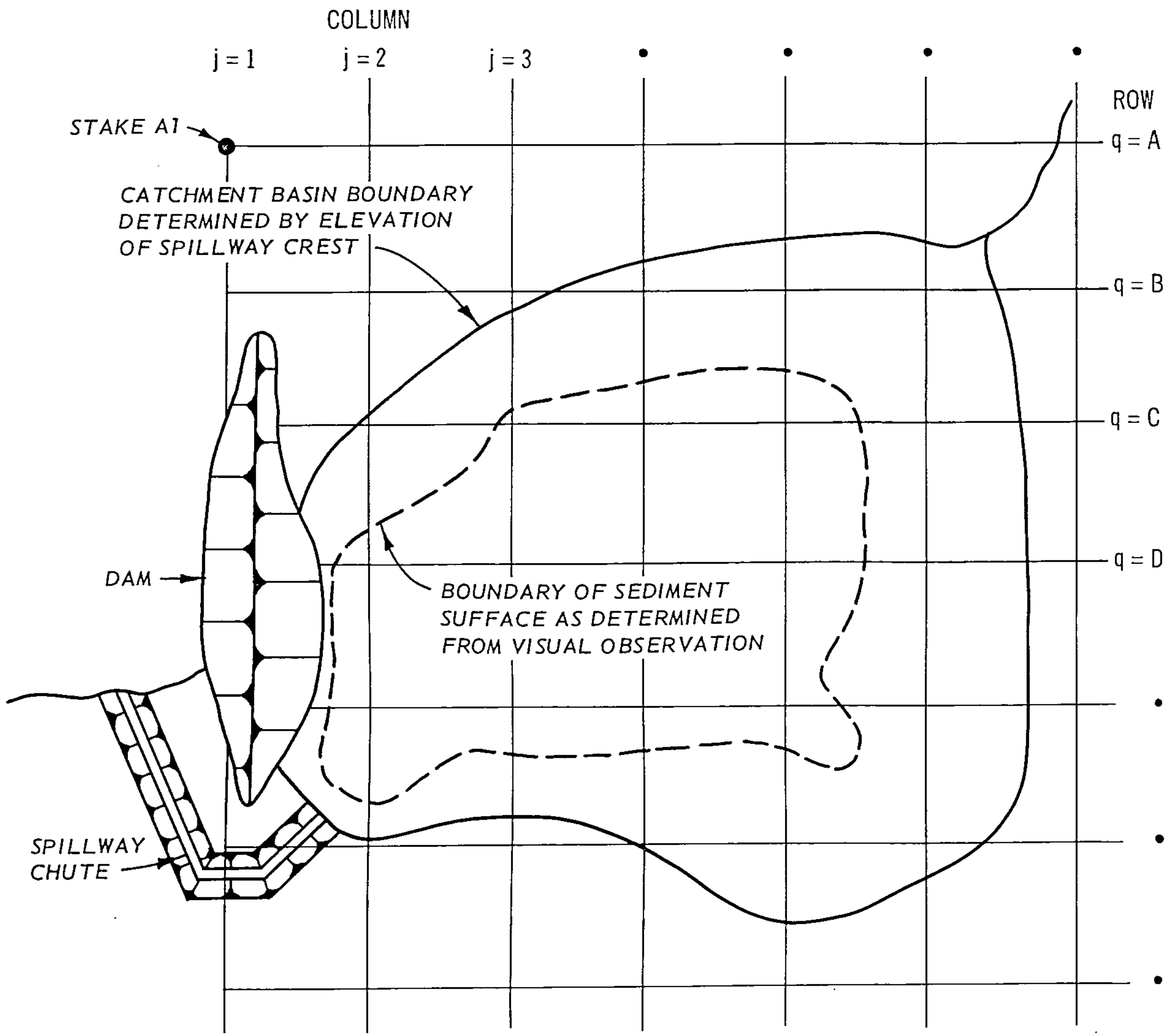

Figure 8. SCS layout for measuring thickness of accumulated sediment in basin

By summing the areas from $j = 1$ to $j = p + 1$, a mean cross-sectional area (A_k) was determined for each row. In the vicinity of the dam, D was adjusted to reflect a distance between the upstream grid point and a point on the embankment above the apparent sediment surface when the traverse between the two grid points crossed the dam. The following equation was used to compute the mean volume of deposited material between sequential rows:*

$$V_k = \sum_{k=1}^{q+1} D\left(\frac{A_{k-1} + A_k}{2}\right) \tag{10}$$

where

V_k = mean volume of sediment material between sequential rows, m^3

q = number of rows across the basin grid

By summing the volumes from $k = 1$ to $k = q + 1$, the accumulated sediment volume of the basin (V_B) was computed.

40. A summary of the SCS calculated values of V_B in each catchment basin is tabulated below:

Watershed Study Area	SCS Calculated Accumulated Sediment Volume (V_B) in 1975, m^3
1	1530
2	2960
3	1060
4	369
5	2825
6	Negligible amount

Since there was no apparent sediment surface and very little military activity indicated, watershed study area 6 was not surveyed.

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* The mean volume before the first cross-sectional area (A_1) was computed by assuming that a hypothetical area (A_0) was equal to zero. The same procedure was used to compute the mean volume after the last row by assuming that a hypothetical area A_{q+1} was equal to zero.

Data Needed To Compute Watershed Erosion Index

41. Determination of the erosion index (Equation 2) for each field mapping unit and the resulting WEI (Equation 8) for the six watershed study areas required that the following data be available: (a) rainfall factor (see paragraph 14), (b) the soil erodibility factor (see paragraph 16), (c) the slope-length and gradient factor (see paragraphs 20-22), (d) the composite land use factor (see paragraphs 23-24), and (e) the percent of the watershed occupied by the field mapping unit (see paragraph 26). The determination of the field mapping unit boundaries and the acquisition of the data needed for Equation 2 are discussed below. Table 1 presents the acquired data.

Determination of field mapping unit boundaries

42. The boundaries of the mapping units in each of the watershed study areas were determined in the following manner. The Colorado Springs and Pueblo District offices of the SCS furnished the WES with mapping unit boundaries drawn on uncontrolled aerial photomosaics at a scale of 1:21,000 for El Paso and Pueblo Counties. WES personnel transferred the boundaries of the units shown on the photomosaics to more recent aerial photographic base maps at a scale of 1:24,000 for each watershed study area. Soil series maps were then constructed for each watershed study area from the base maps and are included as Figures 9-14. Table 2 presents the SCS soil series field mapping units by name, symbol, and classification.

Rainfall factor

43. Rainfall factor values for the State of Colorado have been determined recently[8] by SCS and are presented in Figure 15. These data show that a value of 75 covers the Fort Carson Reservation. Thus, a value of 75 was used for this study (Table 1, column 3).

Soil erodibility factor

44. The SCS, Denver, also supplied the soil erodibility factors for the 13 field mapping units present in the six watershed study areas

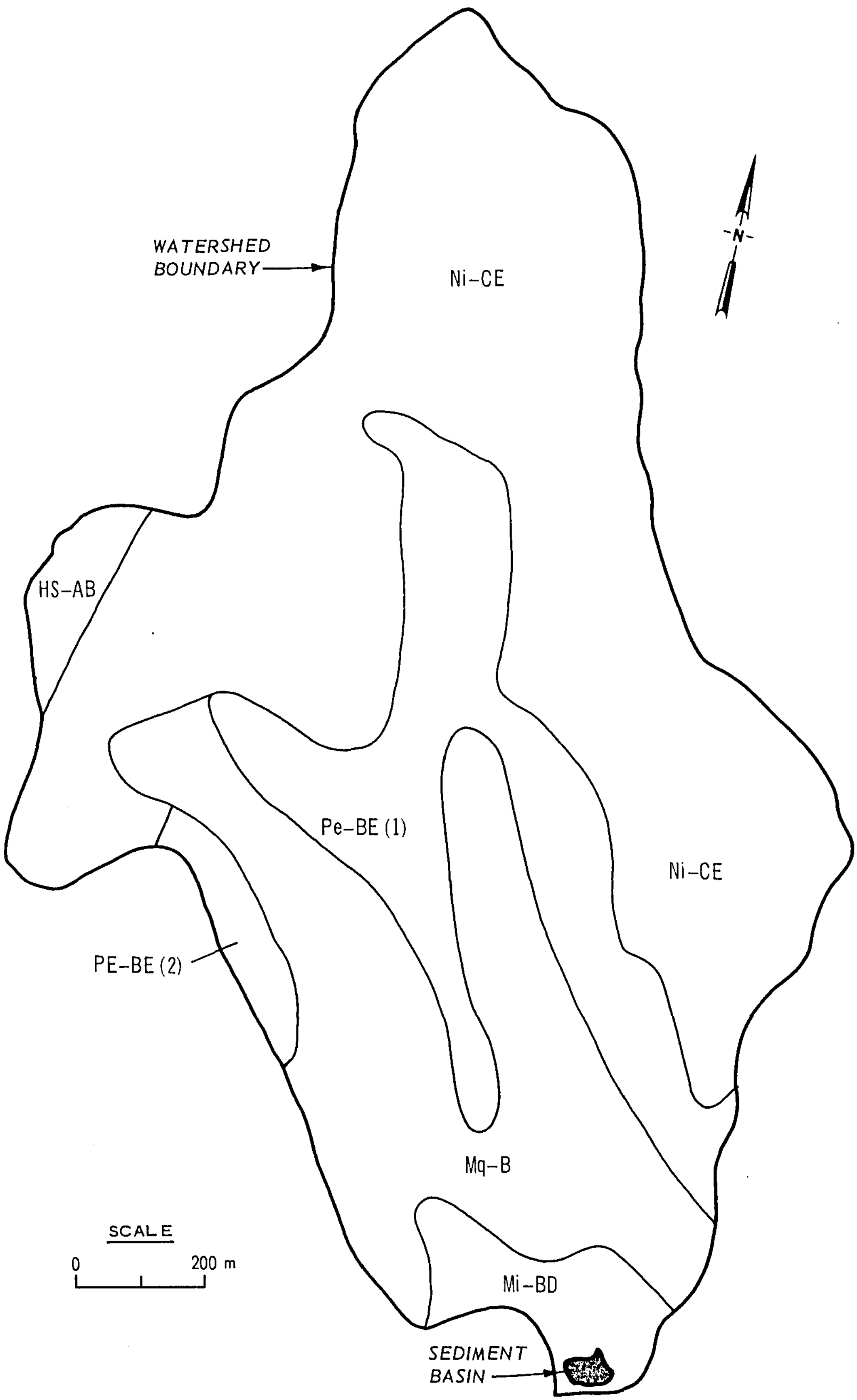


Figure 9. SCS soil series map of watershed 1

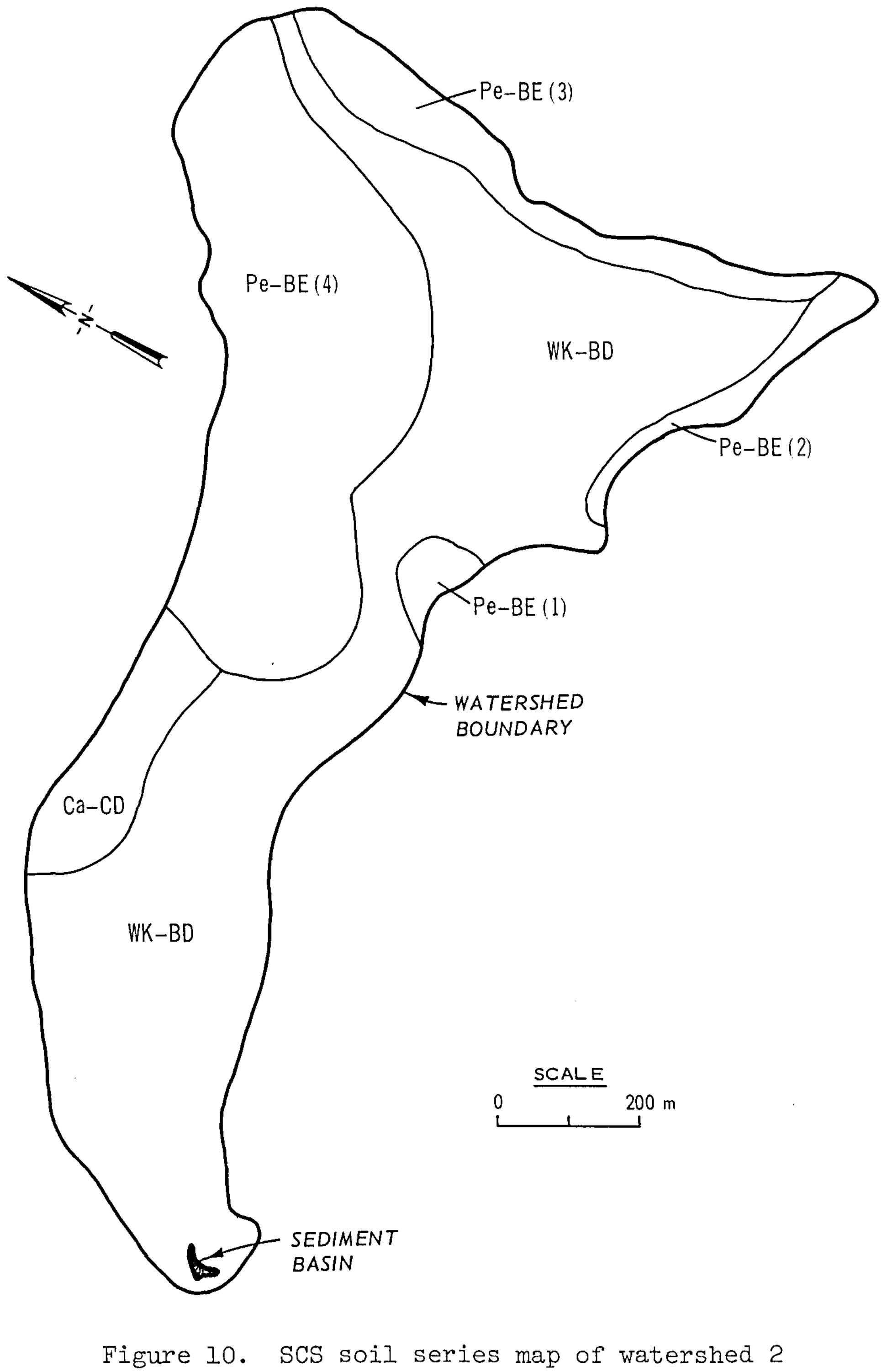


Figure 10. SCS soil series map of watershed 2

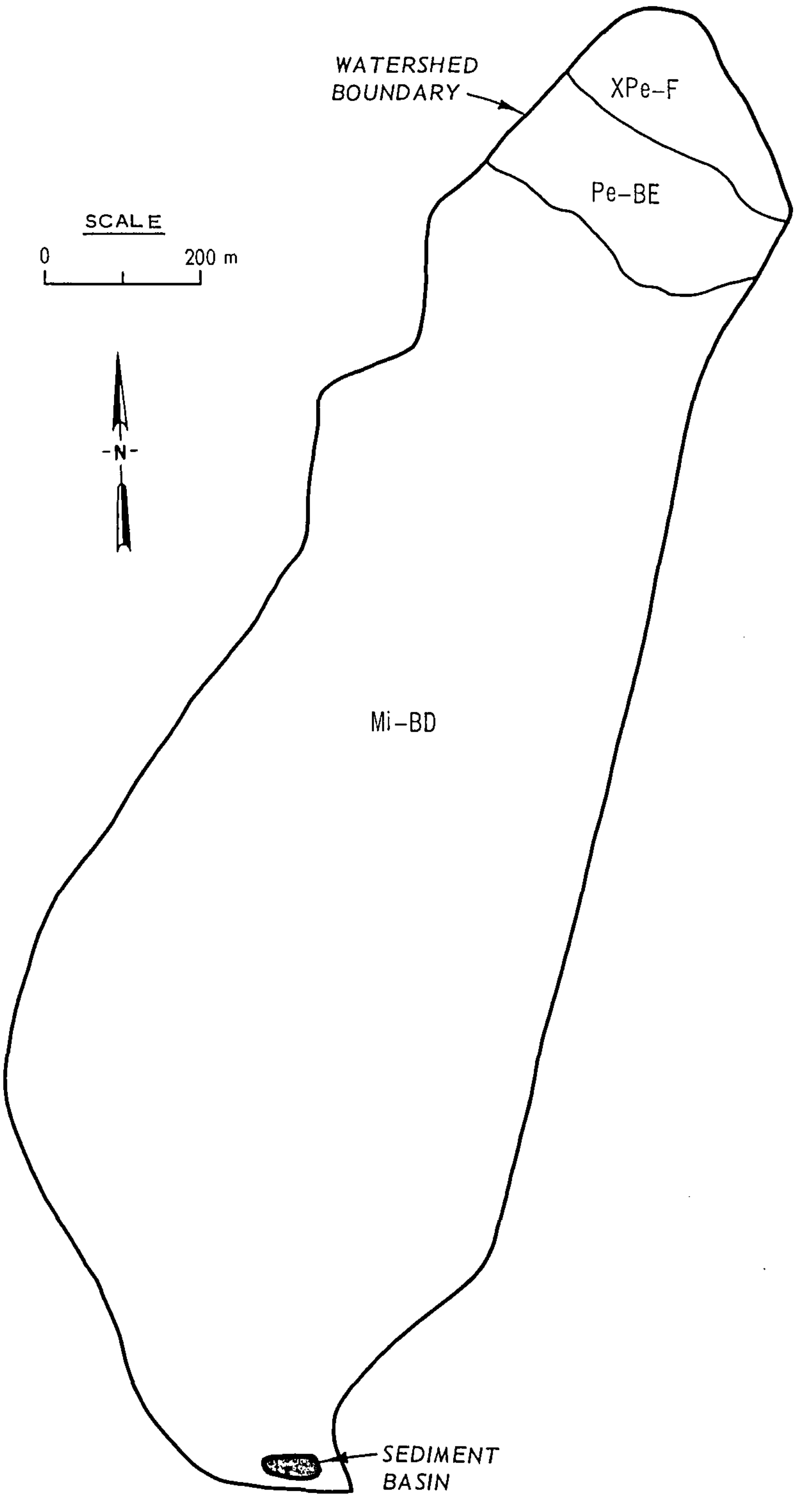


Figure 11. SCS soil series map of watershed 3

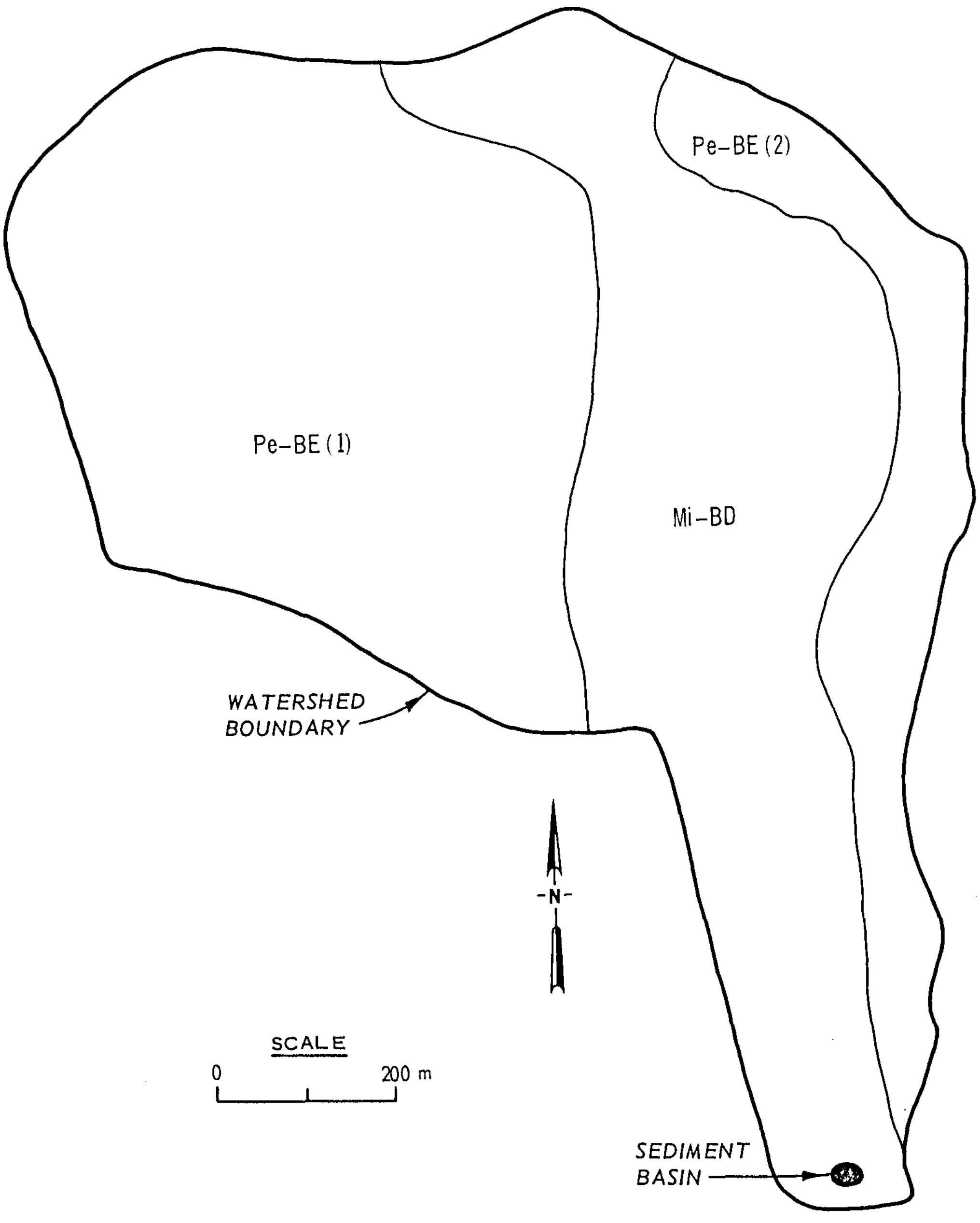


Figure 12. SCS soil series map of watershed 4

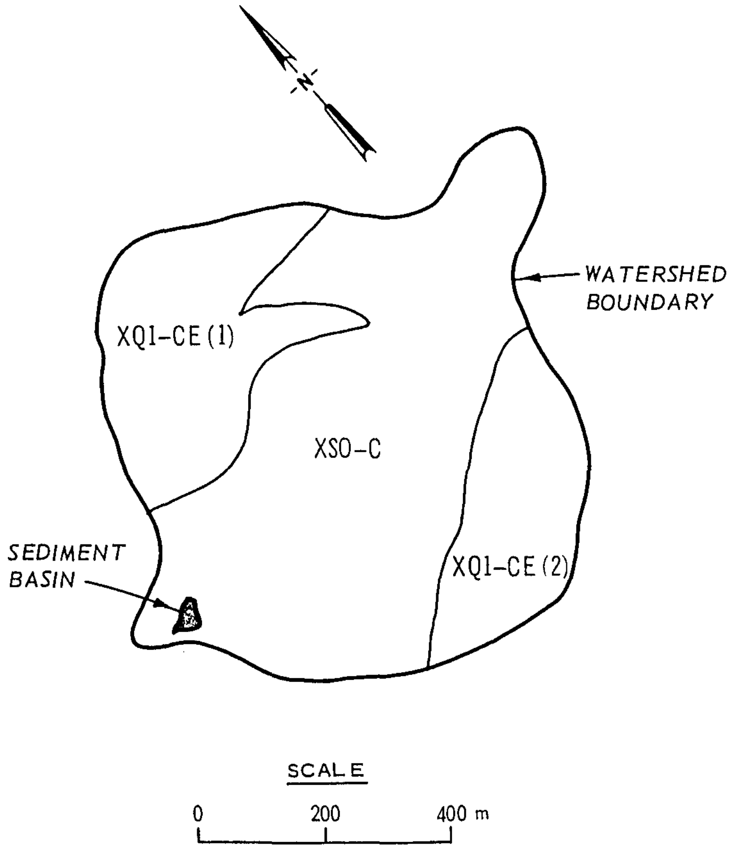


Figure 13. SCS soil series map of watershed 5

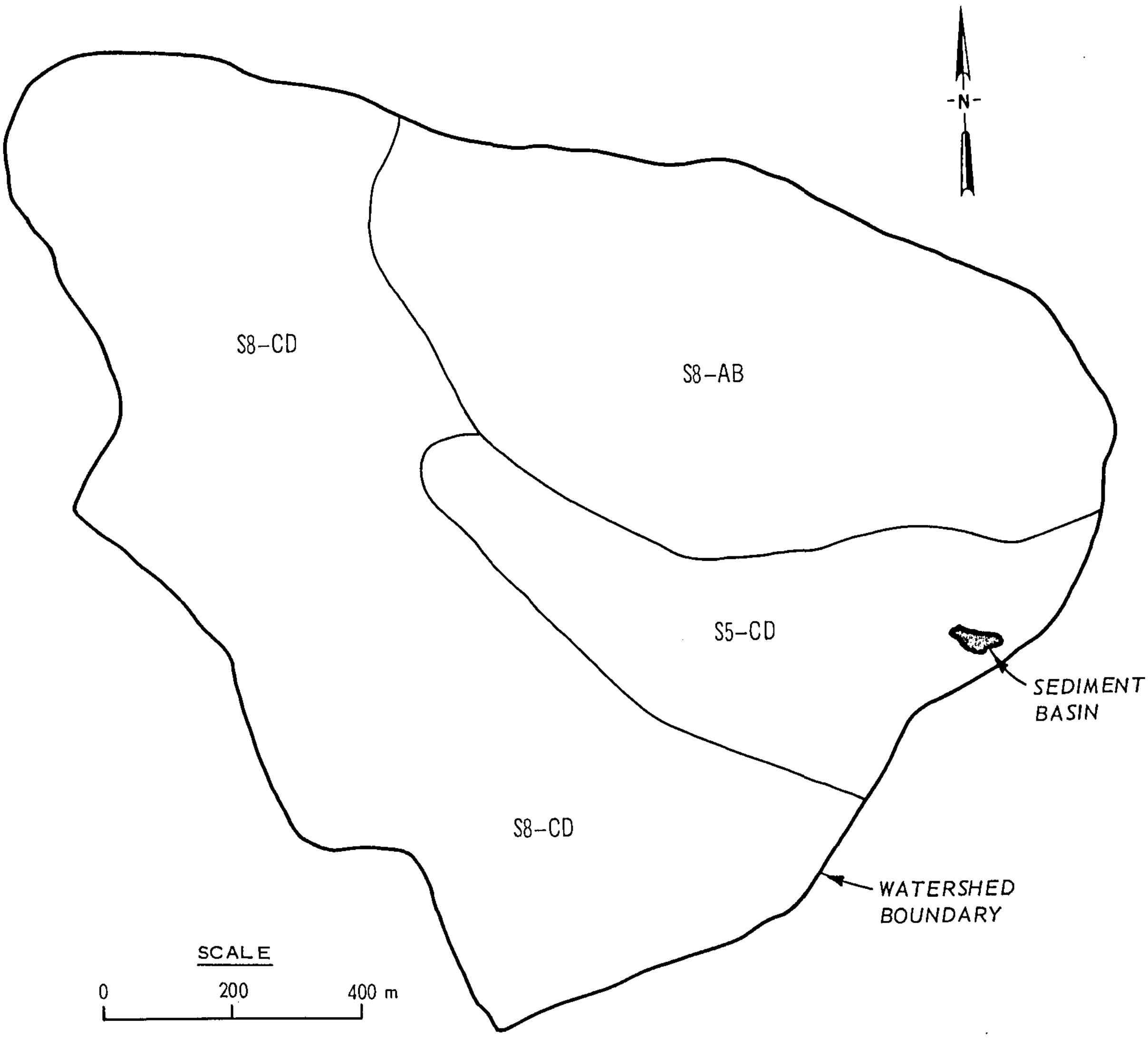


Figure 14. SCS soil series map of watershed 6

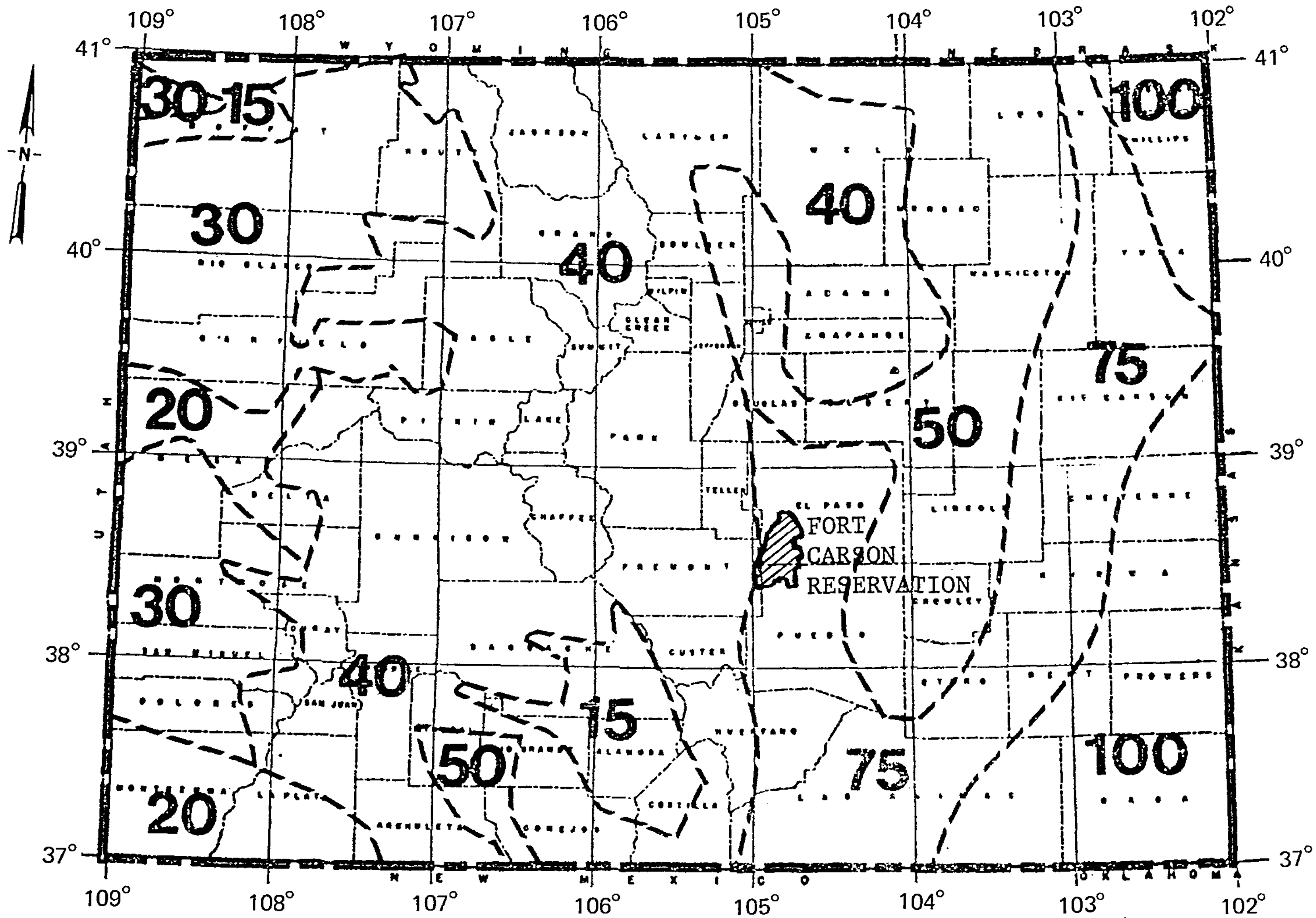


Figure 15. Rainfall factor map of Colorado

(Table 1, column 4). Table 2 lists these values by soil type.

Slope-length and gradient factor

45. The gradient(s) for a slope in a field mapping unit was determined as a percentage from the following expression:

$$s = 100 \left(\frac{E_{max} - E_{min}}{H} \right) \tag{11}$$

where

E_{max} = elevation of the highest point on a slope where overland flow can originate, e.g. "hill top" or "ridgeline" (see paragraph 20)

E_{min} = elevation of the point on a slope where sediment deposition begins from the flow starting at E_{max}, or where this flow enters a defined drainage channel (see paragraph 20)

H = horizontal distance between E_{max} and E_{min}

46. In determining representative values for E_{max}, E_{min}, and H for the irregularly shaped field mapping units, some judgment was necessary. The method used for this study was to lay out several transect lines on a topographic map of the field mapping unit, with each transect approximately perpendicular to the contour lines. The transect lines were considered to be representative of the path that surface runoff would follow during and after a storm event. The maximum and minimum topographic elevations that occurred for each measured path length were then determined and recorded. Then, to solve for s in each mapping unit, average values for E_{max}, E_{min}, and H were computed and substituted into Equation 11.

47. Slope length (λ) was computed from the Pythagorean theorem equation:

$$\lambda = \sqrt{H^2 + \left(E_{max} - E_{min}\right)^2} \tag{12}$$

For each mapping unit, the average values of E_{max}, E_{min}, and H were substituted into Equation 12 to solve for λ.

48. The slope-length and gradient factor for each mapping unit in the six watershed study areas was then computed by substituting the

values for λ and s into Equation 5 and solving for $(LS)_i$. Table 1 (column 5) lists the resulting values of $(LS)_i$ for each field mapping unit.

Composite land use factor

49. Computation of the composite land use factor (see paragraph 24) requires that the following data be known for each field mapping unit: (a) natural plant cover factor (C_{nc}), (b) percent of field mapping unit damaged by military operations (A_m), and (c) SCS cover factor for cross-slope plowing (C_{csp}). $\overline{C}_i$ was calculated for each field mapping unit (Equation 6) with the resulting values listed in Table 1 (column 9). Acquisition of the data needed for solving Equation 6 is described below.

50. Natural plant cover factor. A single value for R_i , K_i , and $(LS)_i$ was considered adequate to characterize each field mapping unit (and thus be used in Equation 2). However, because of the possibility of a wide variation over a field mapping unit of the percent and type of ground cover, the percent of canopy cover, and the plant height, a single value for C_{nc} was not used in Equation 8. An areally weighted value for C_{nc} was determined using vegetation factor complex maps constructed for each field mapping unit. These maps do account for variations in ground and canopy cover and plant height (see paragraphs 54 and 55). Thus, the weighted value of C_{nc} more realistically depicts the influence of vegetation on soil loss, rather than a single value for an entire field mapping unit.

51. The values for C_{nc} , which were obtained from Table 3, required the following information:

- a. Type and height of canopy.
- b. Percent canopy cover.
- c. Type of ground cover.
- d. Percent ground cover.

52. To provide the basic data needed to determine C_{nc} from Table 3, the WES first prepared areal maps delineating the percent of canopy and ground cover and type of ground cover (Figures 16-21) for each of the watershed study areas. These maps were prepared using the

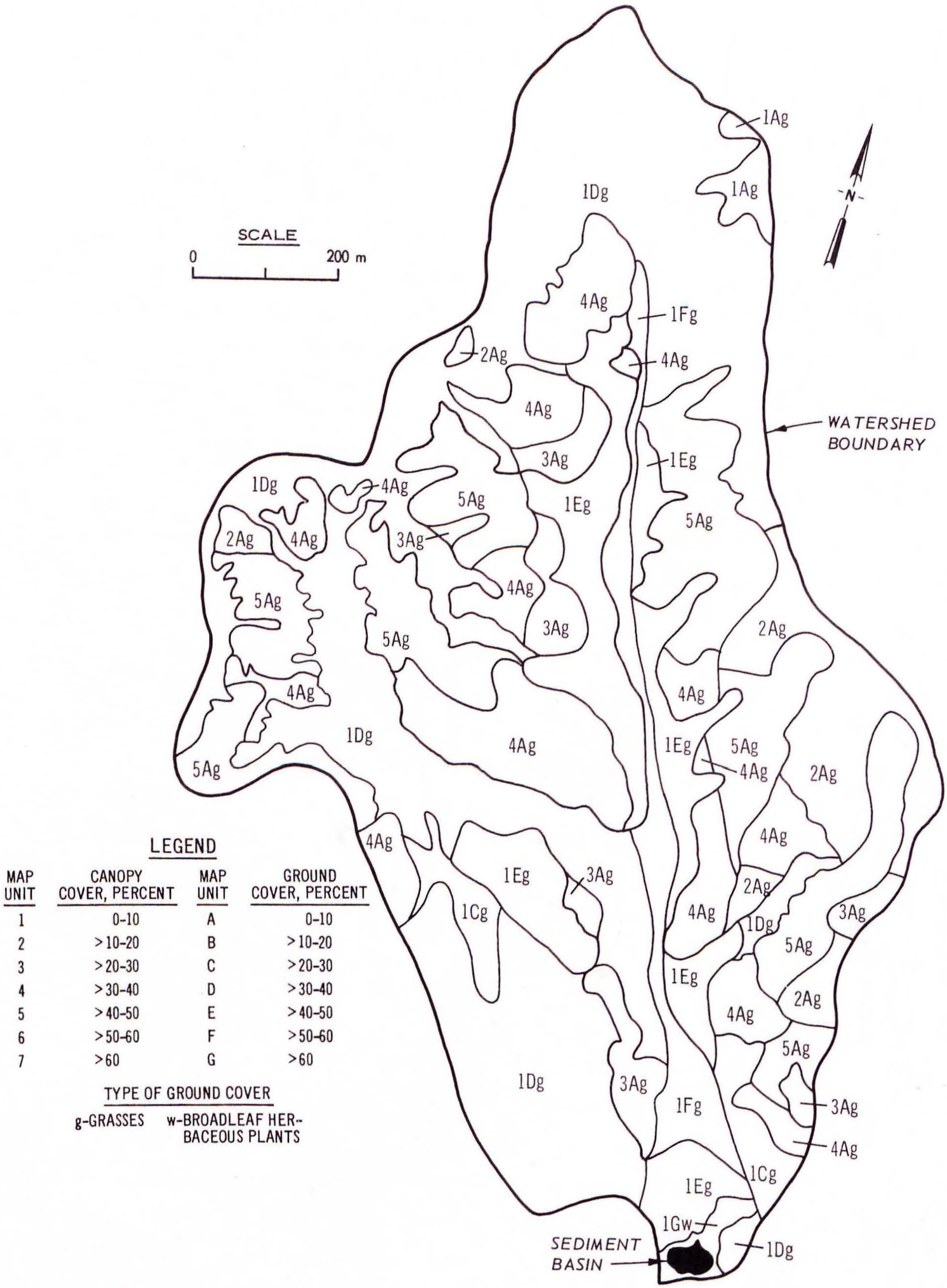


Figure 16. Percent canopy and ground cover and type of ground cover in watershed 1

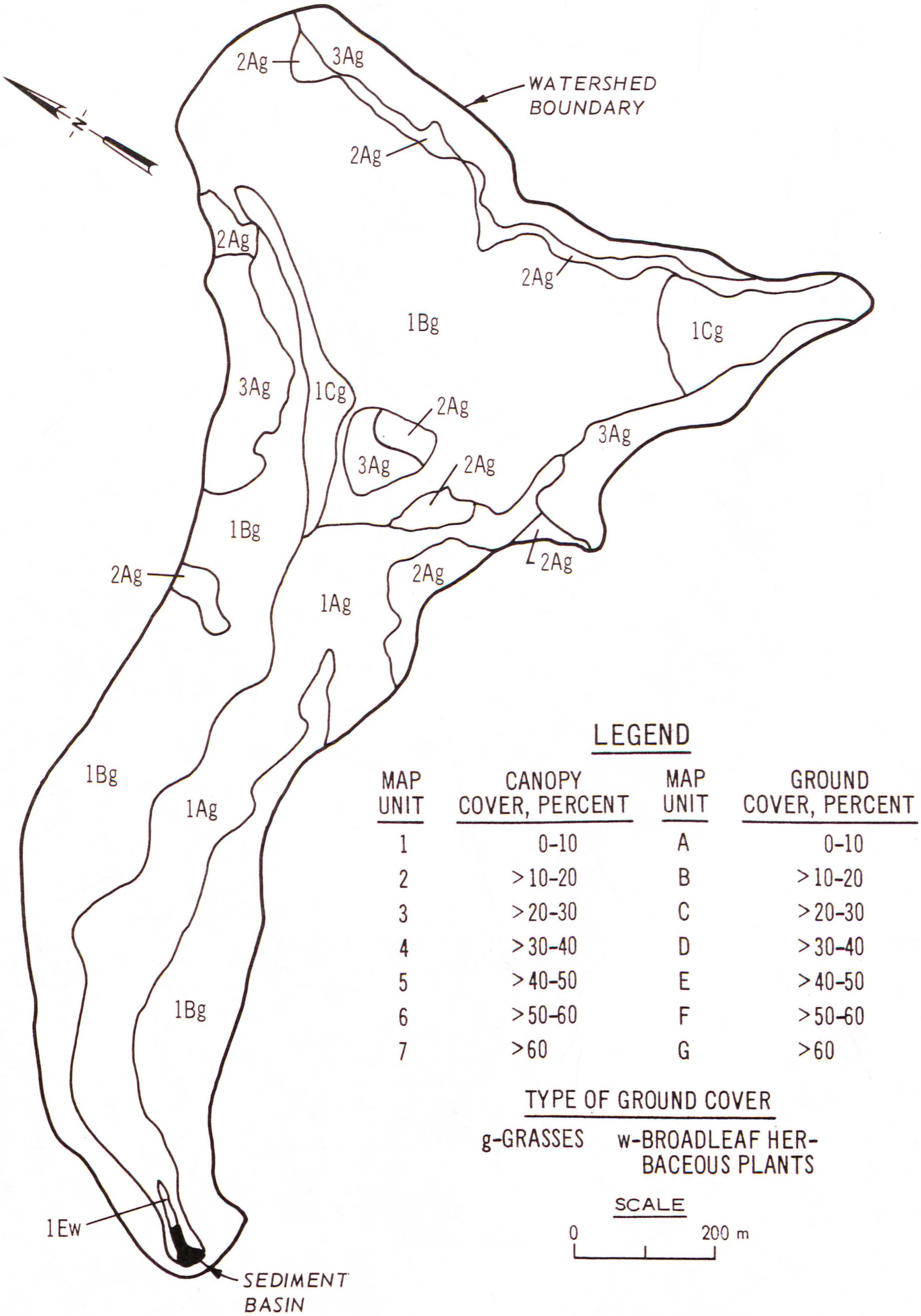


Figure 17. Percent canopy and ground cover and type of ground cover in watershed 2

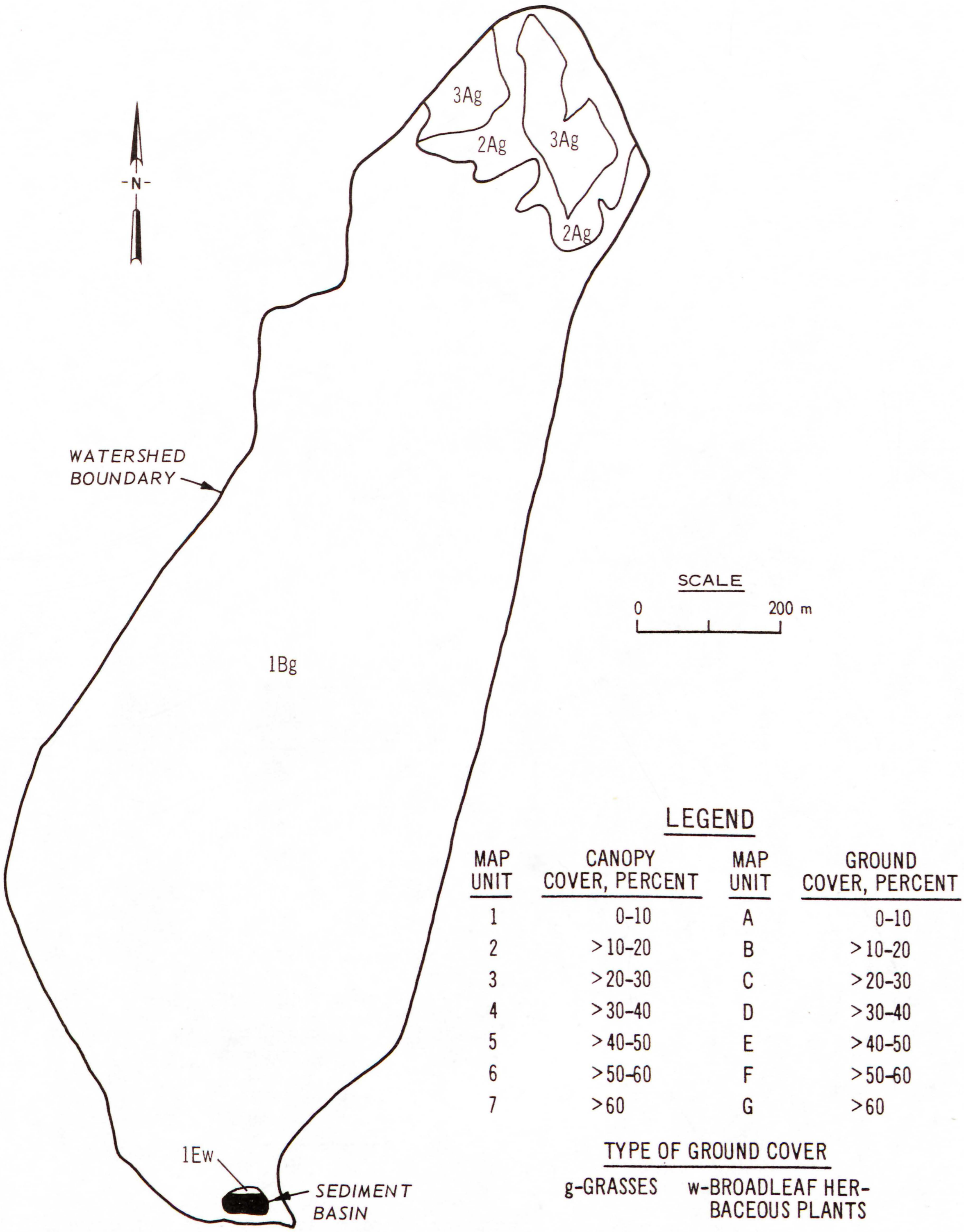


Figure 18. Percent canopy and ground cover and type of ground cover in watershed 3

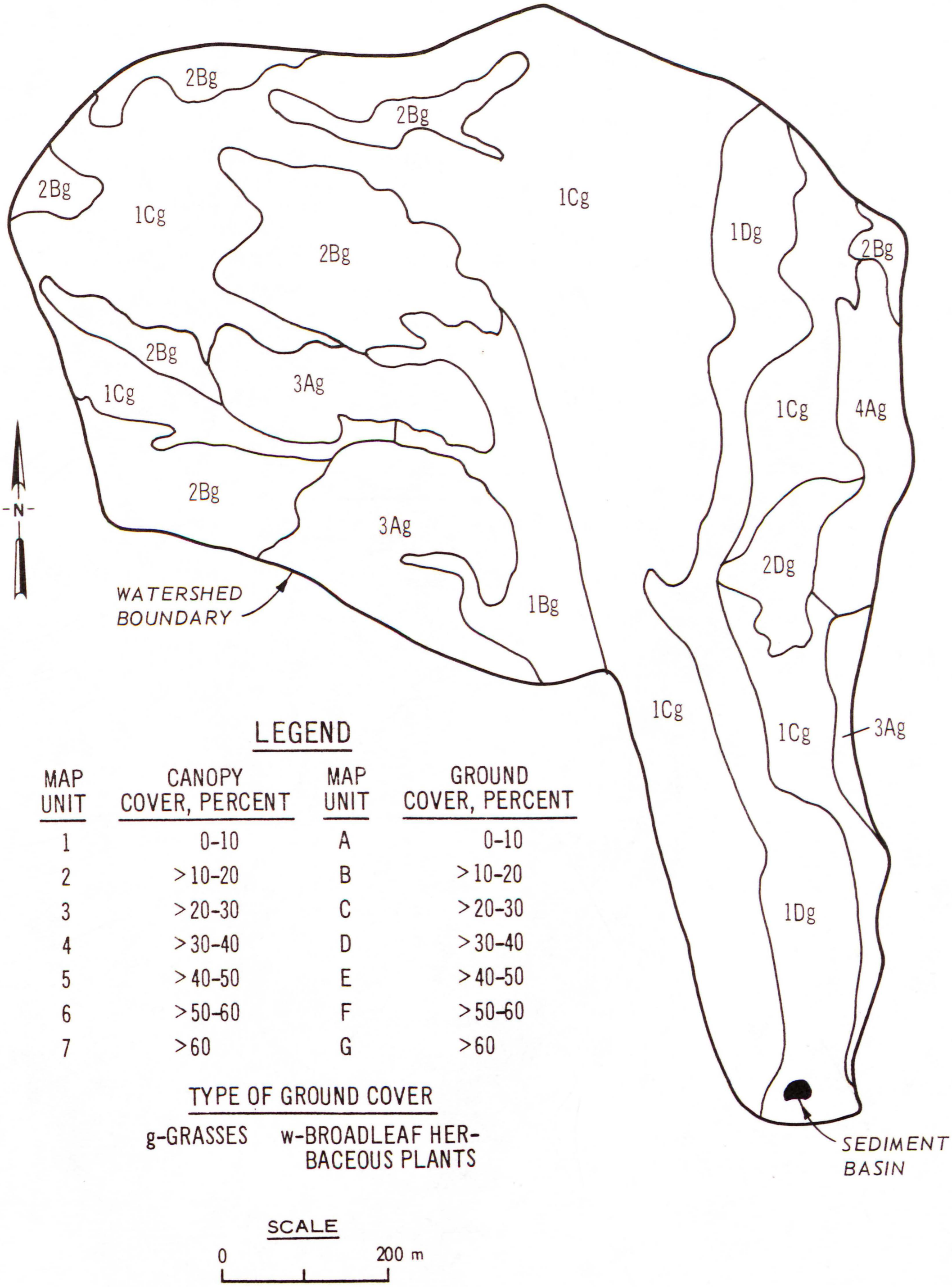


Figure 19. Percent canopy and ground cover and type of ground cover in watershed 4

LEGEND

MAP UNIT	CANOPY COVER, PERCENT	MAP UNIT	GROUND COVER, PERCENT
1	0-10	A	0-10
2	>10-20	B	>10-20
3	>20-30	C	>20-30
4	>30-40	D	>30-40
5	>40-50	E	>40-50
6	>50-60	F	>50-60
7	>60	G	>60

TYPE OF GROUND COVER

g-GRASSES   w-BROADLEAF HERBACEOUS PLANTS

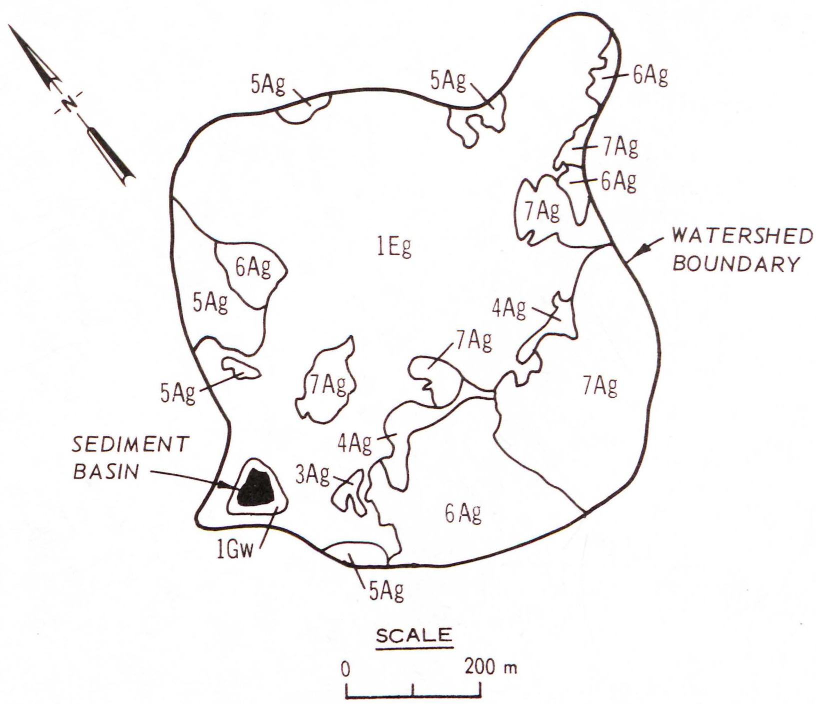
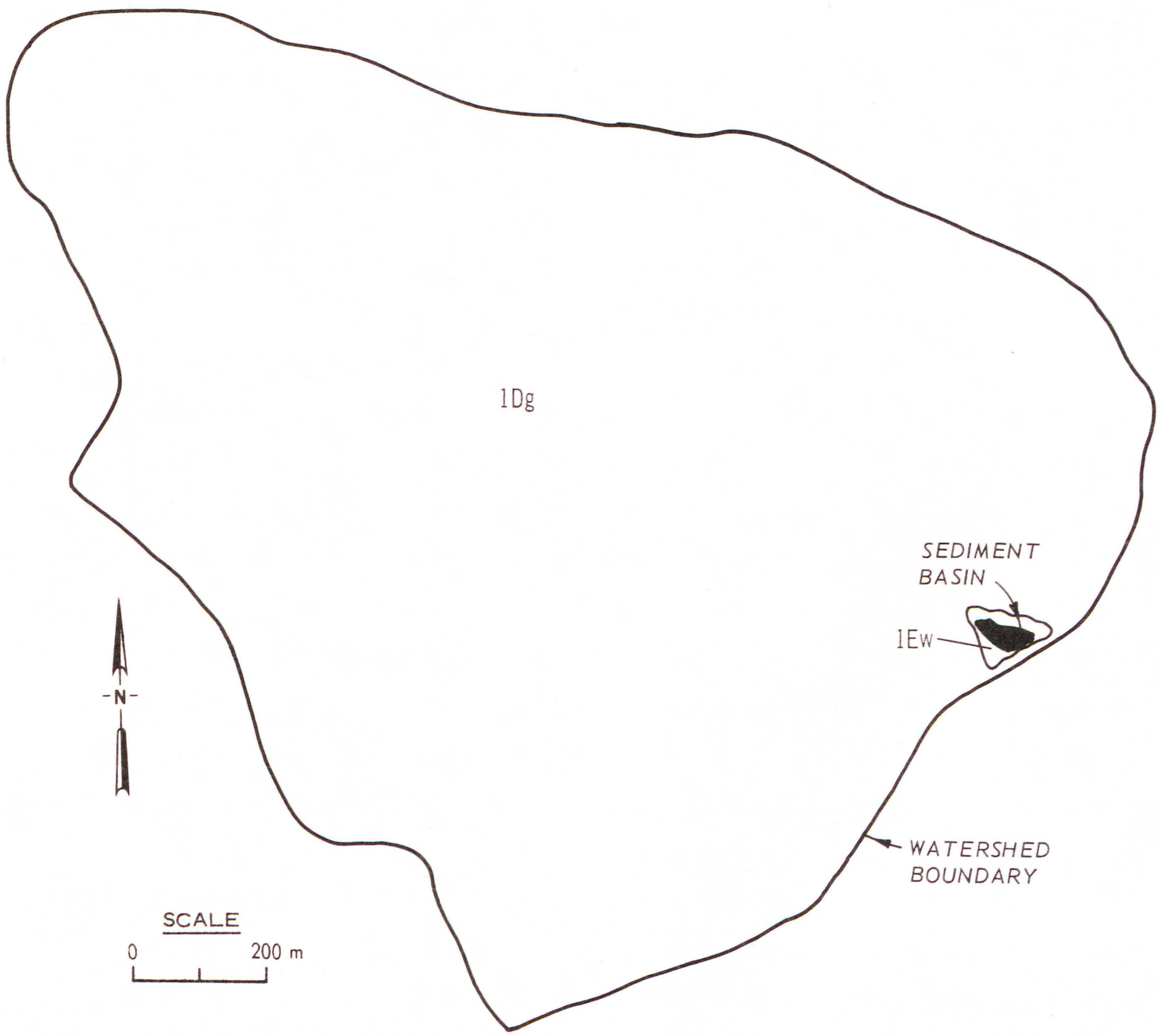


Figure 20. Percent canopy and ground cover and type of ground cover in watershed 5



LEGEND

MAP UNIT	CANOPY COVER, PERCENT	MAP UNIT	GROUND COVER, PERCENT
1	0-10	A	0-10
2	>10-20	B	>10-20
3	>20-30	C	>20-30
4	>30-40	D	>30-40
5	>40-50	E	>40-50
6	>50-60	F	>50-60
7	>60	G	>60

TYPE OF GROUND COVER

g-GRASSES w-BROADLEAF HER-BACEOUS PLANTS

Figure 21. Percent canopy and ground cover and type of ground cover in watershed 6

environmental data collected during the field program (Appendix A), air-photo interpretation techniques, topographic maps of the watershed areas, and the interpreter's personal knowledge of the area.

53. Maps depicting plant height were also prepared for each of the watershed areas (Figures 22-27) using the ground truth data collected in the area (Appendix A), air-photo interpretation techniques, and the interpreter's personal knowledge of the area.

54. Factor complex maps were then constructed for each field mapping unit using Figures 9-14 and 16-27. Figures 28-33 present the resulting maps with the boundaries of the field mapping units shown as heavy lines. The assembly of the factor complex maps required overlaying maps of the individual factors constructed at the sample scale and transferring all map unit boundaries to a new base map, such that each factor complex map element portrays the uniqueness of any given combination of factors.[9] The factor complex maps for each field mapping unit then delineate soil type, percent canopy and ground cover, type of ground cover, and plant height. Table 4 is the factor complex map legend for the field mapping units.

55. The field mapping units present in a given watershed study area were assigned unique alphabetic characters (Table 4, column 1). Each factor complex element in the field mapping unit was then represented by a different number (Table 4, column 2). The interpretation of the alphanumeric code in Table 4 (column 4) is as follows:

a. First character:

Numerical Value	Canopy Cover percent
1	0-10
2	>10-20
3	>20-30
4	>30-40
5	>40-50
6	>50-60
7	>60

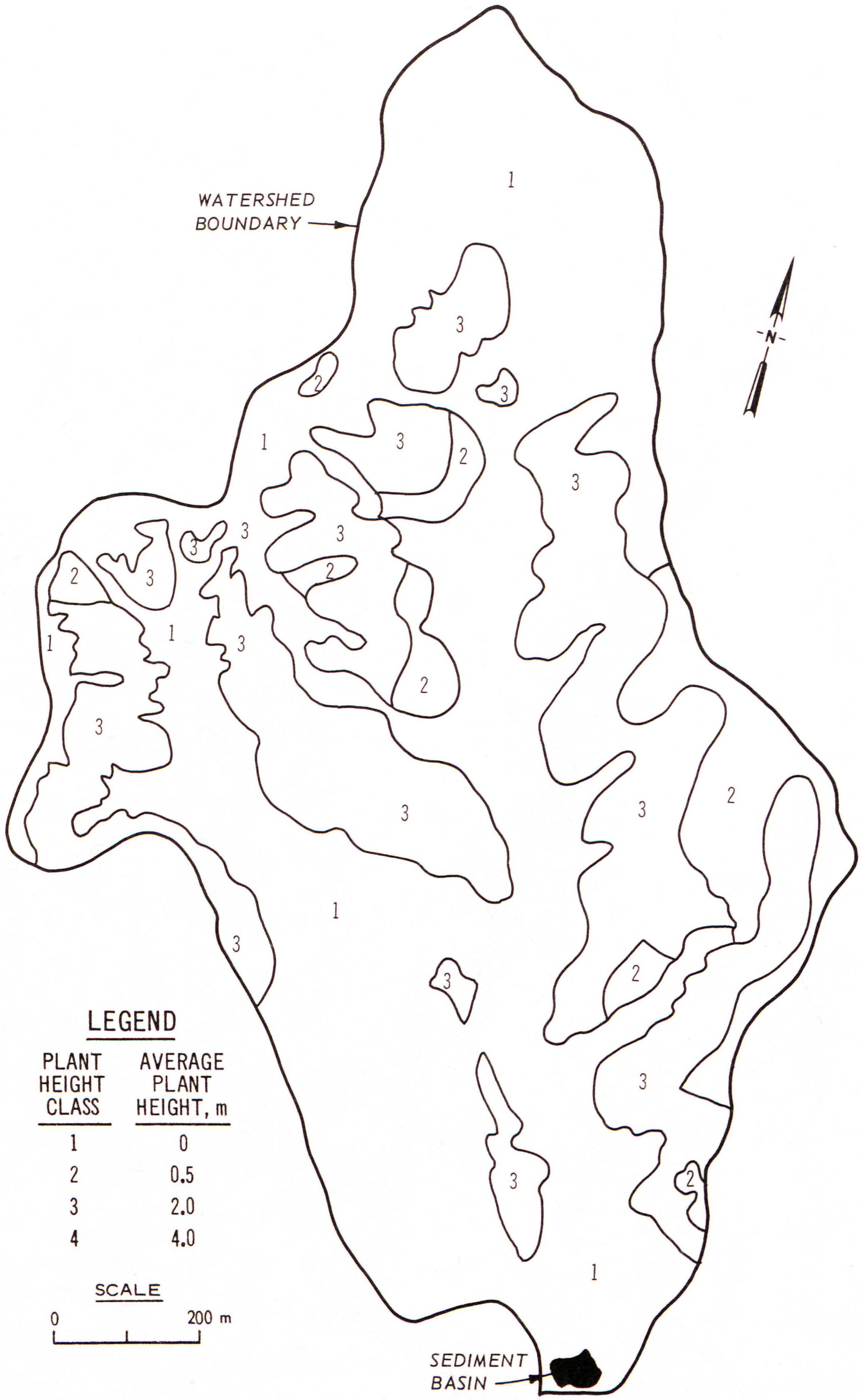


Figure 22. Plant height map of watershed 1

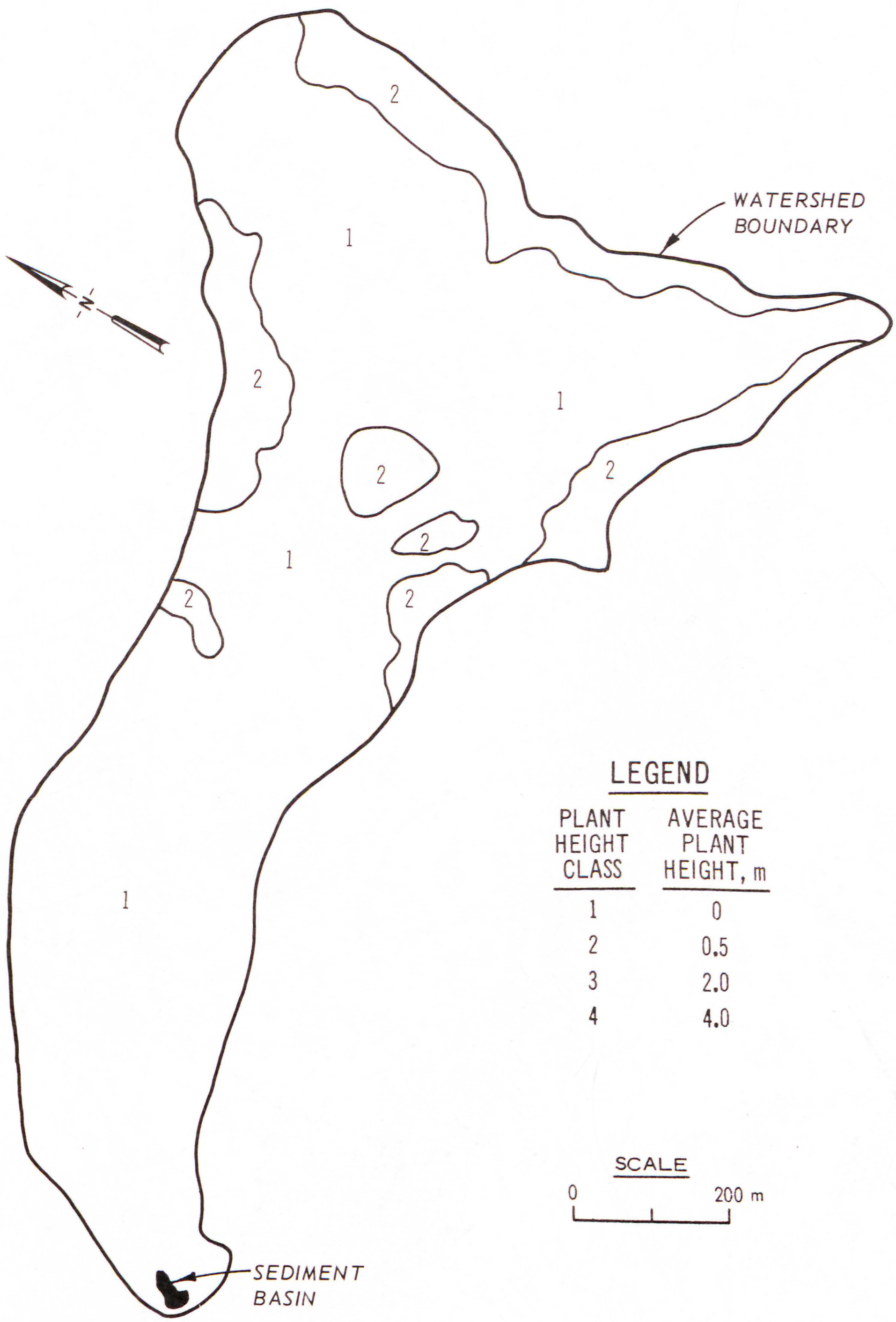


Figure 23. Plant height map of watershed 2

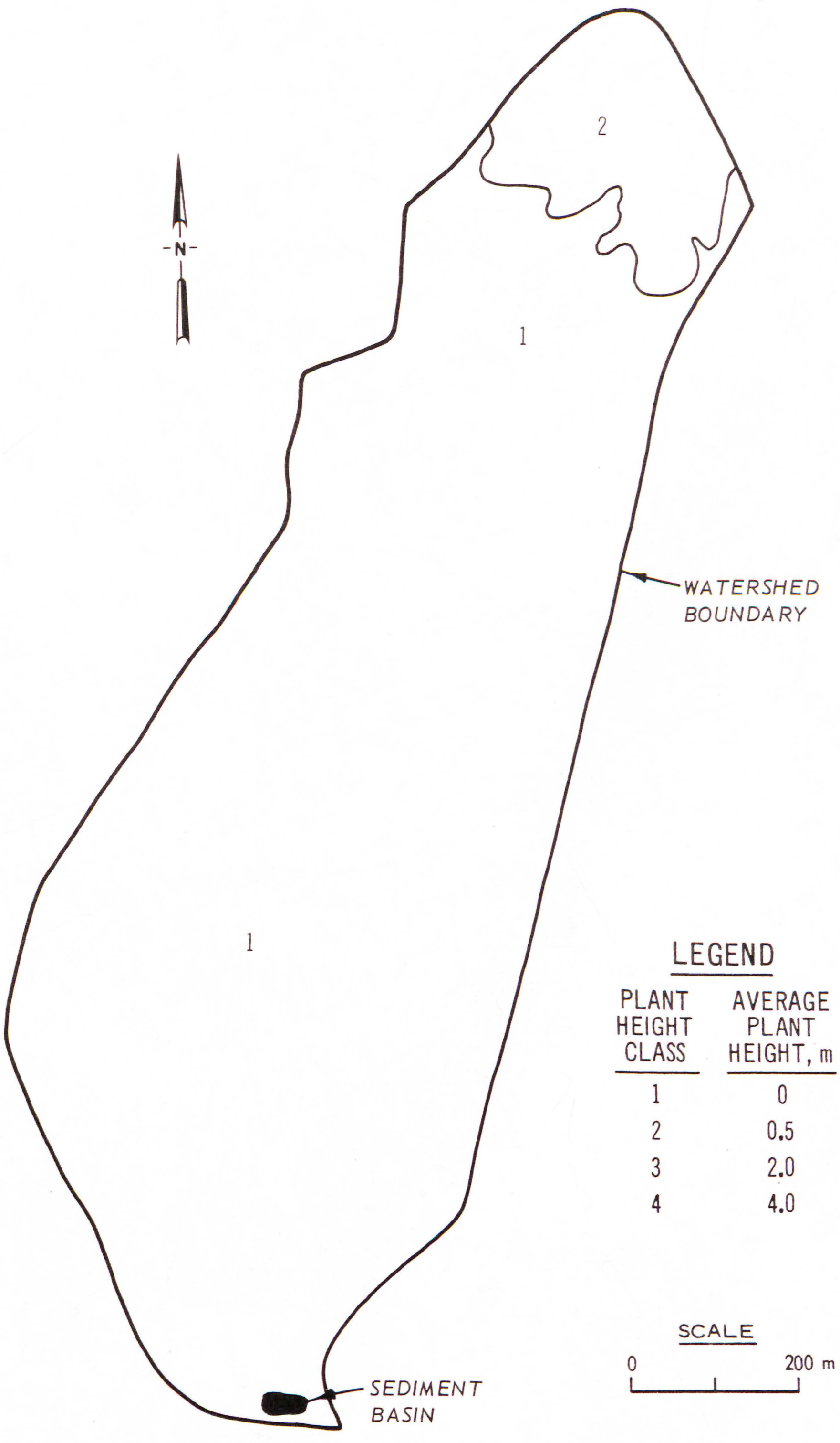


Figure 24. Plant height map of watershed 3

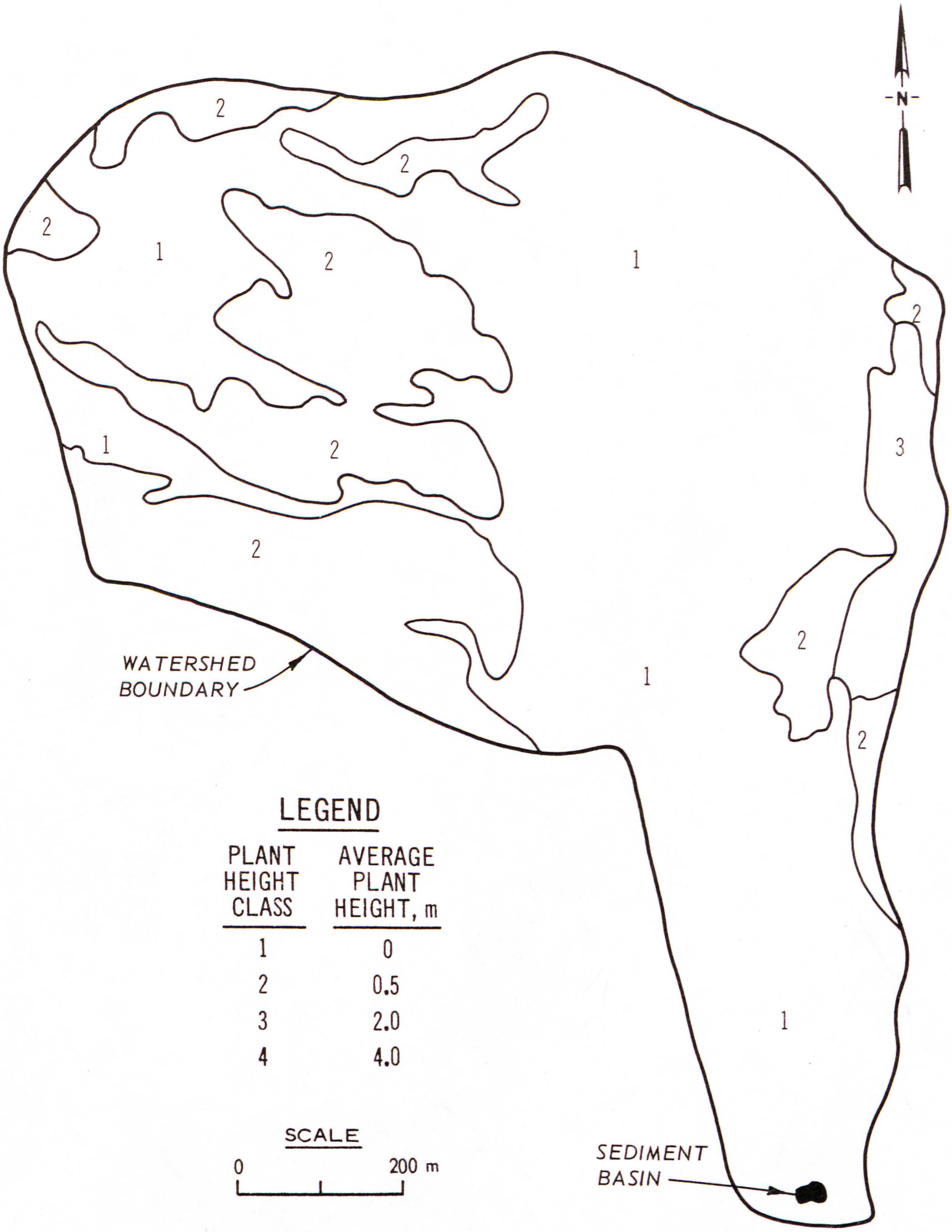
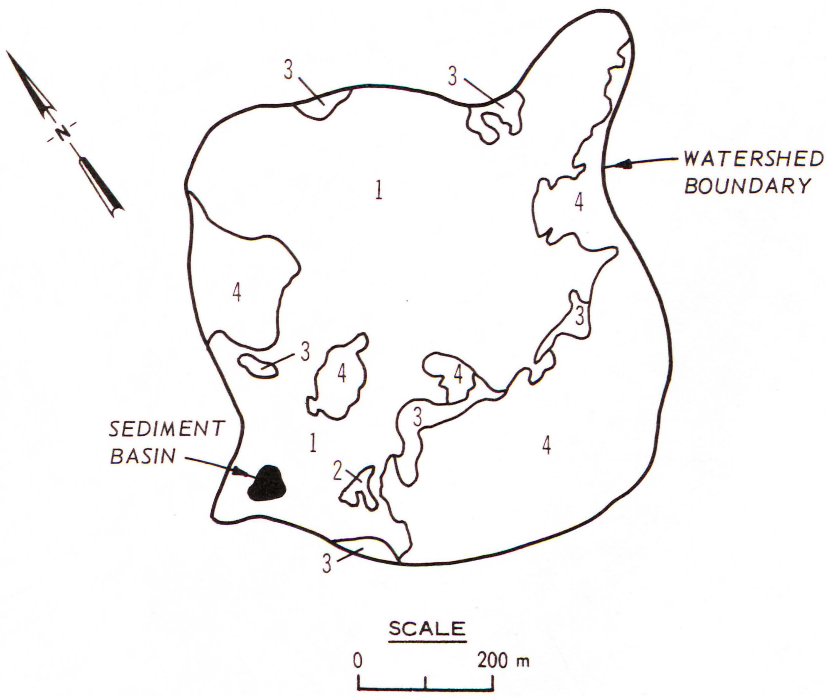


Figure 25. Plant height map of watershed 4



LEGEND

PLANT HEIGHT CLASS	AVERAGE PLANT HEIGHT, m
1	0
2	0.5
3	2.0
4	4.0

Figure 26. Plant height map of watershed 5

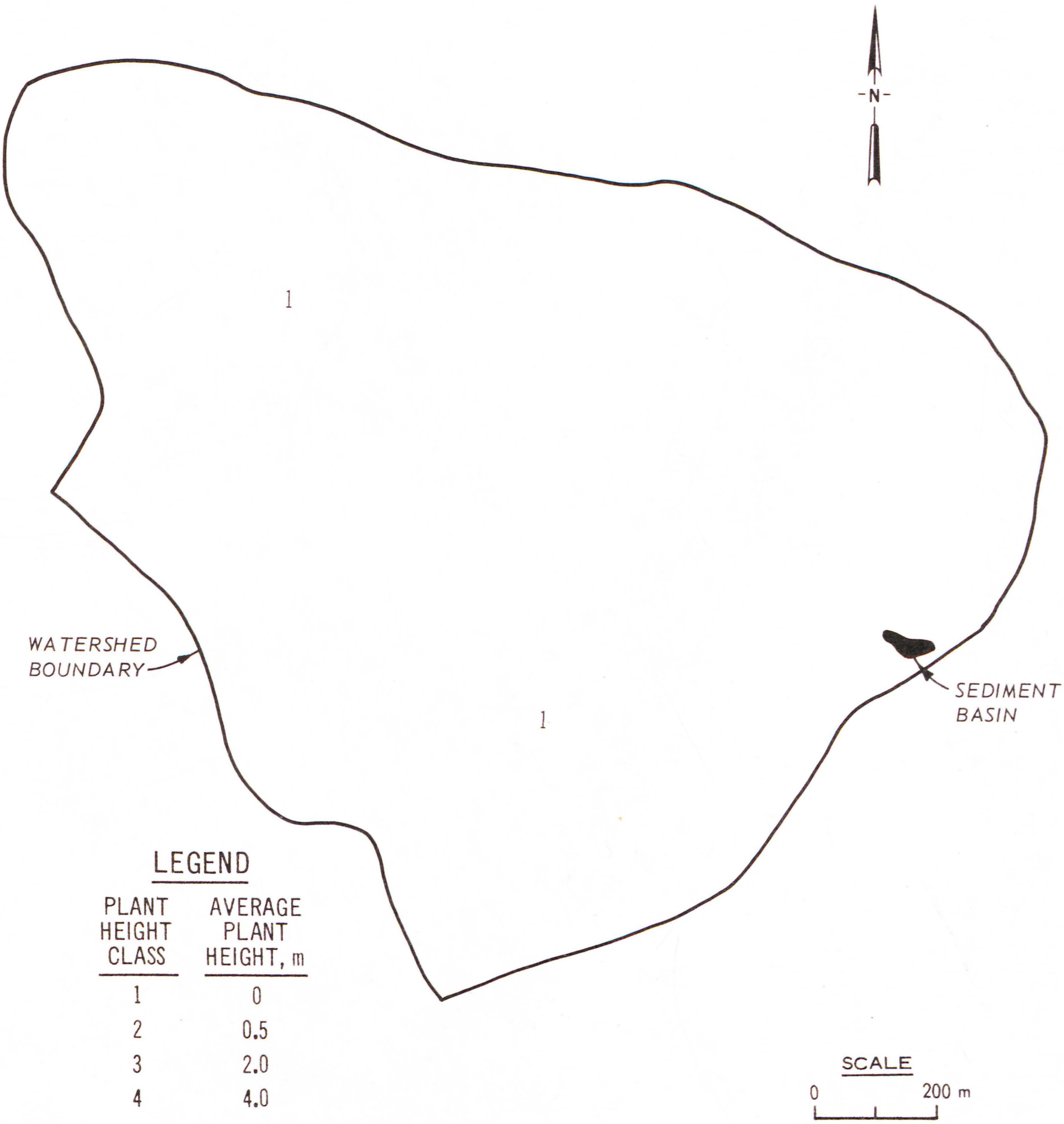


Figure 27. Plant height map of watershed 6

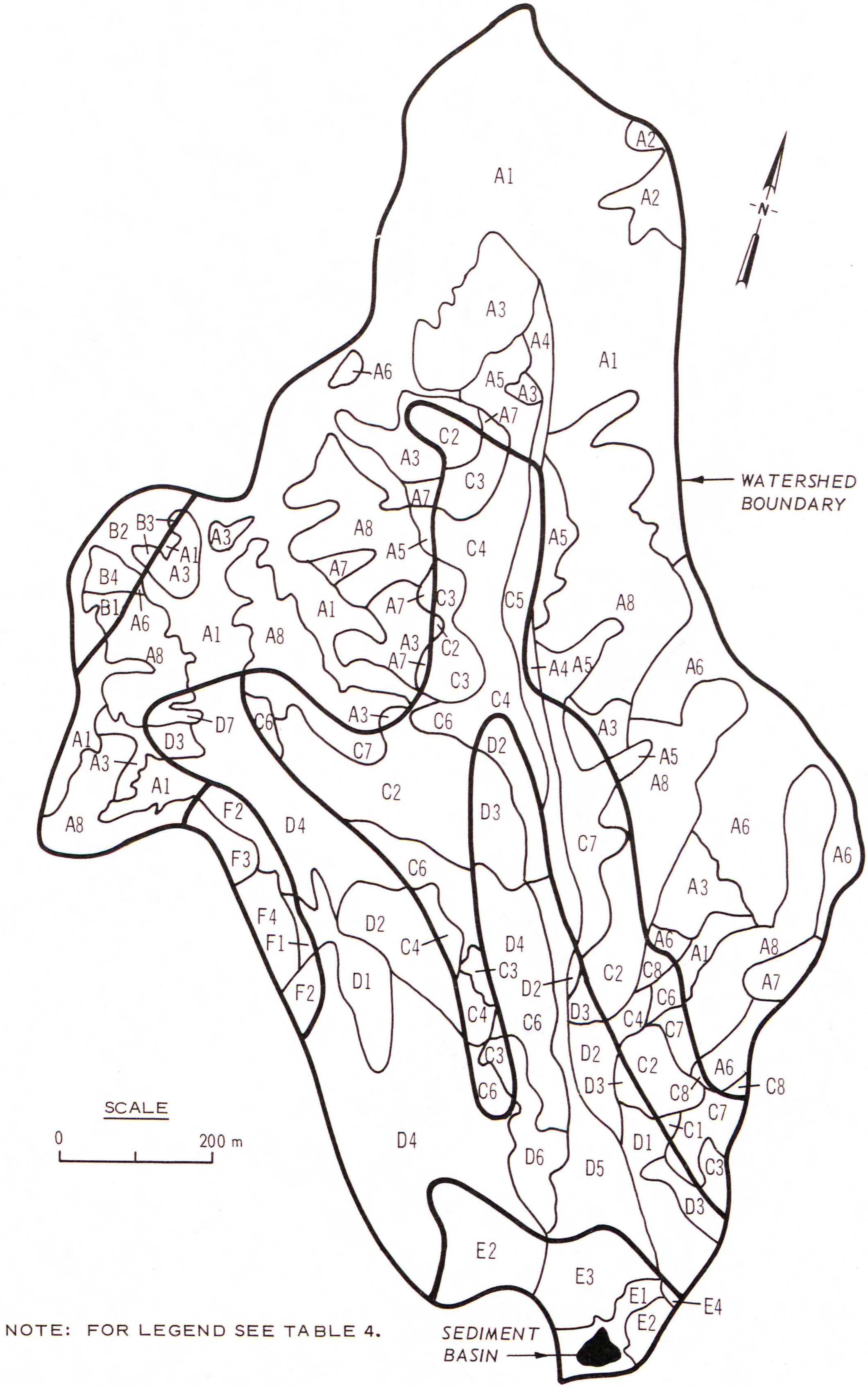


Figure 28. Field mapping unit factor complex map for watershed study area 1

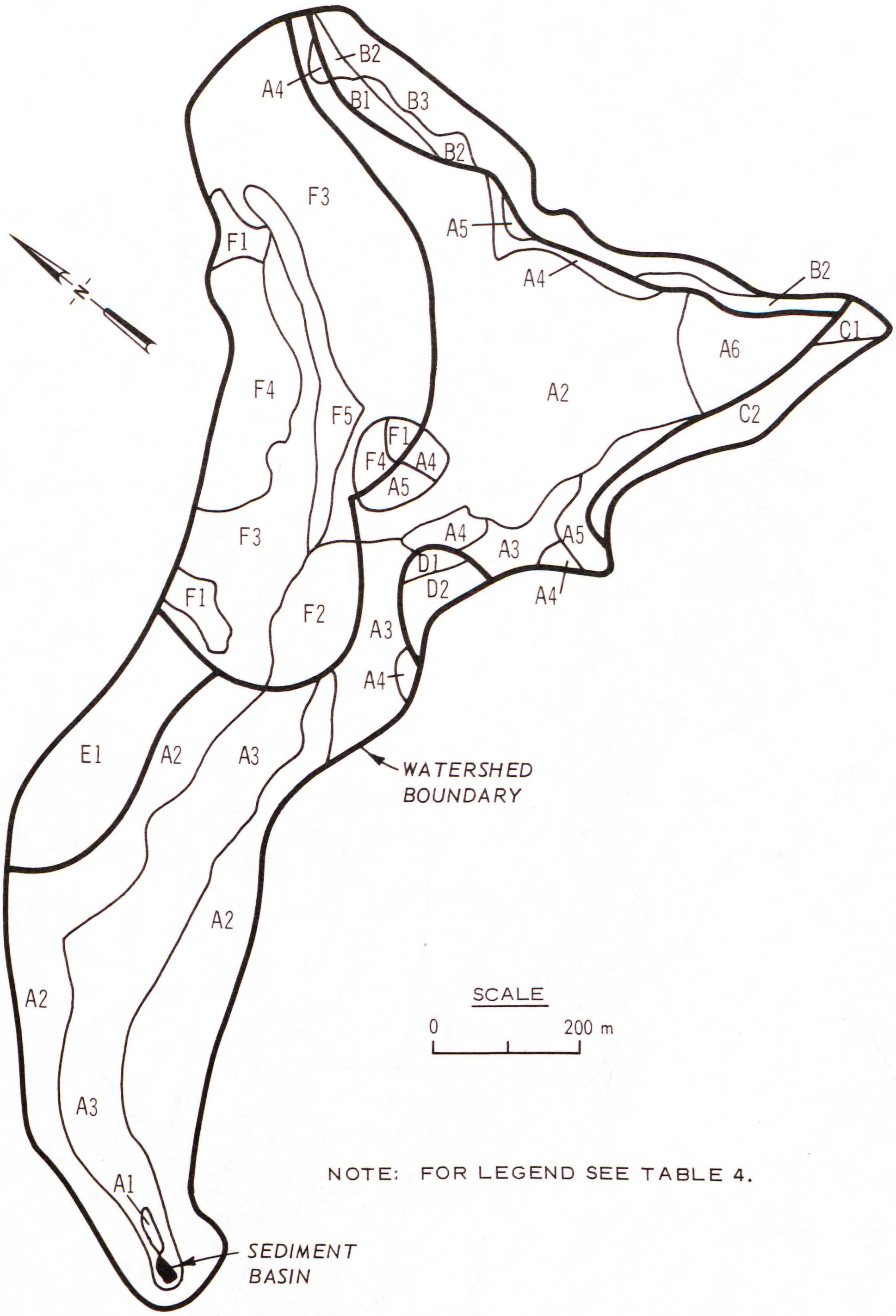


Figure 29. Field mapping unit factor complex map for watershed study area 2

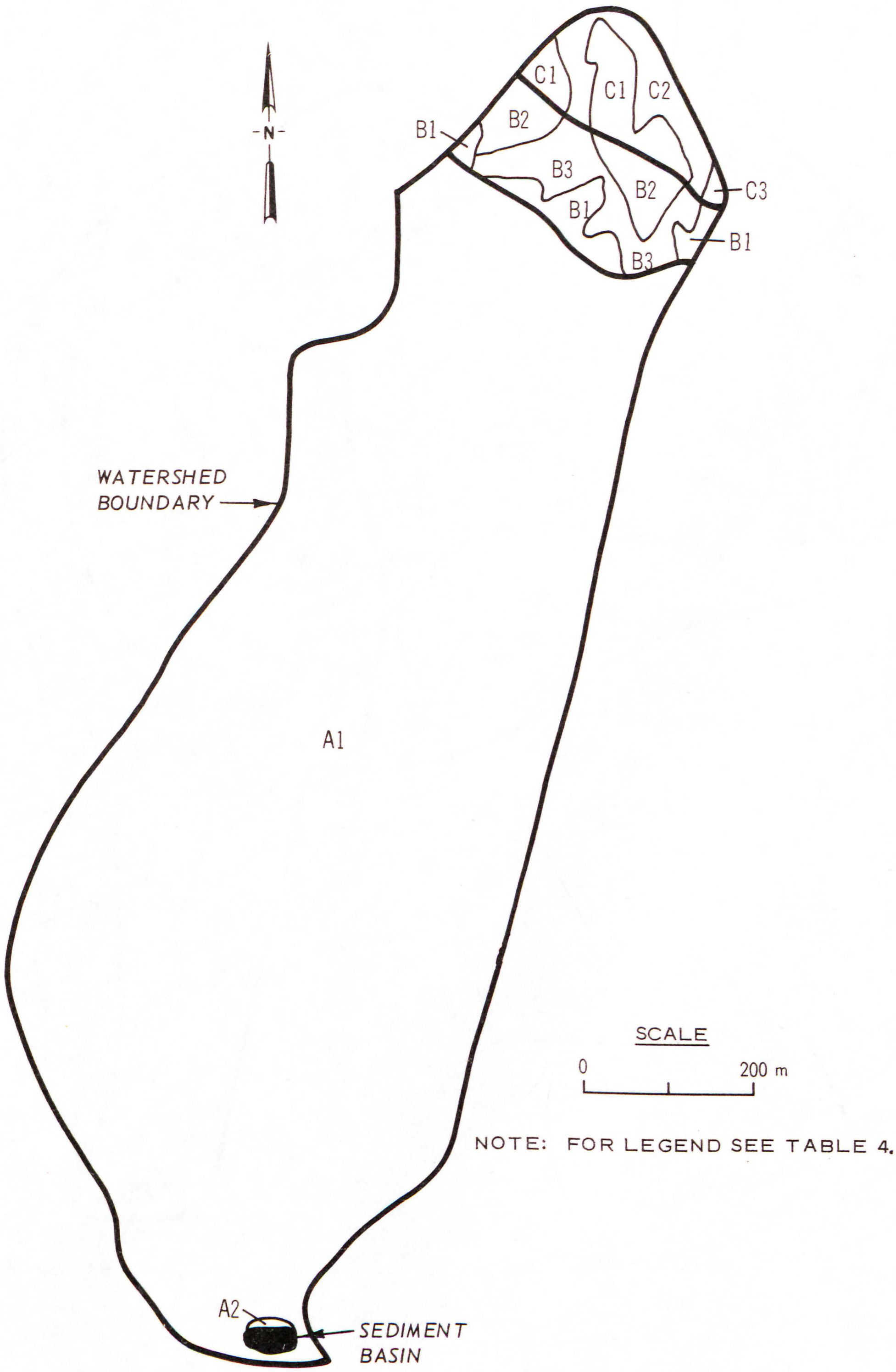


Figure 30. Field mapping unit factor complex map for watershed study area 3

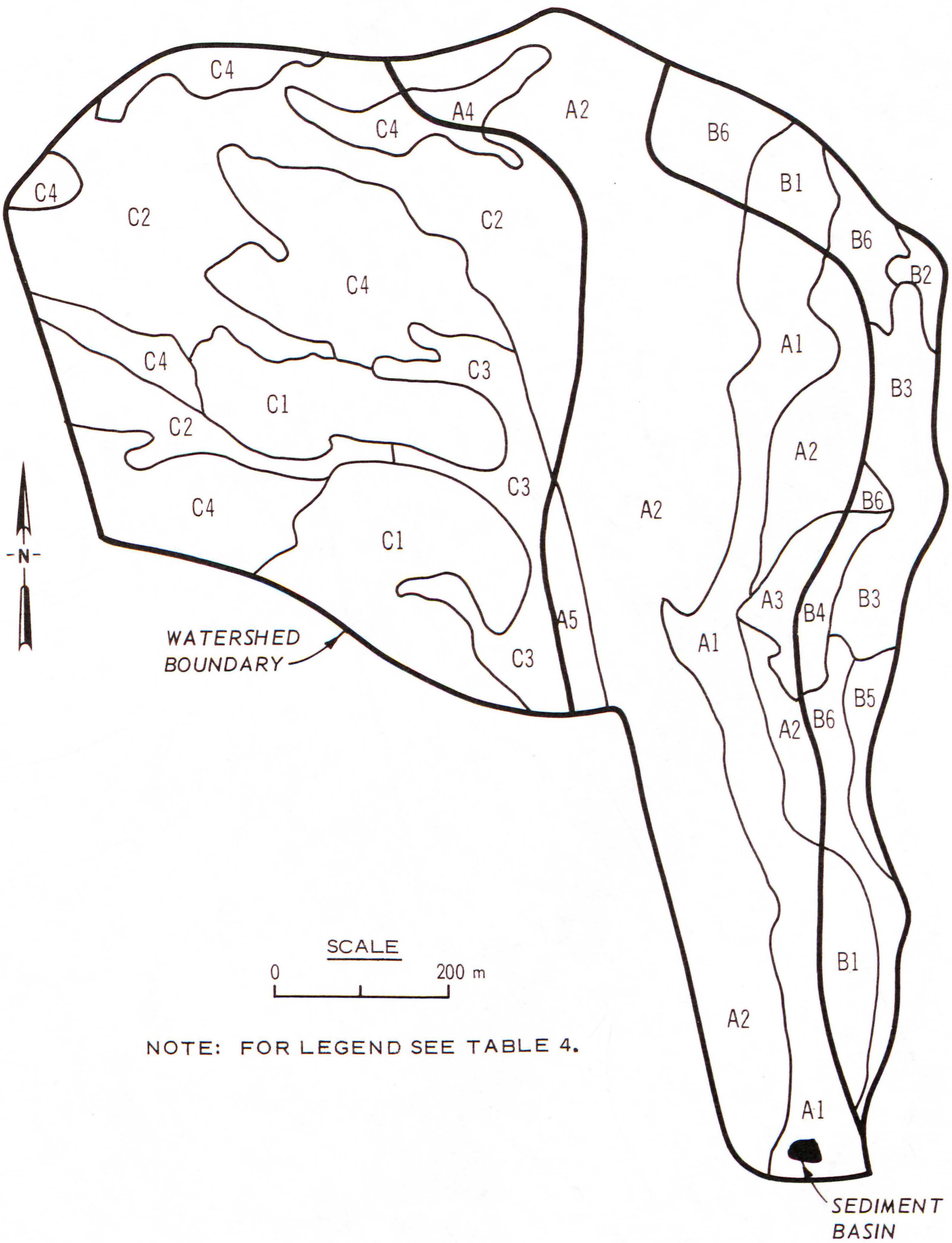
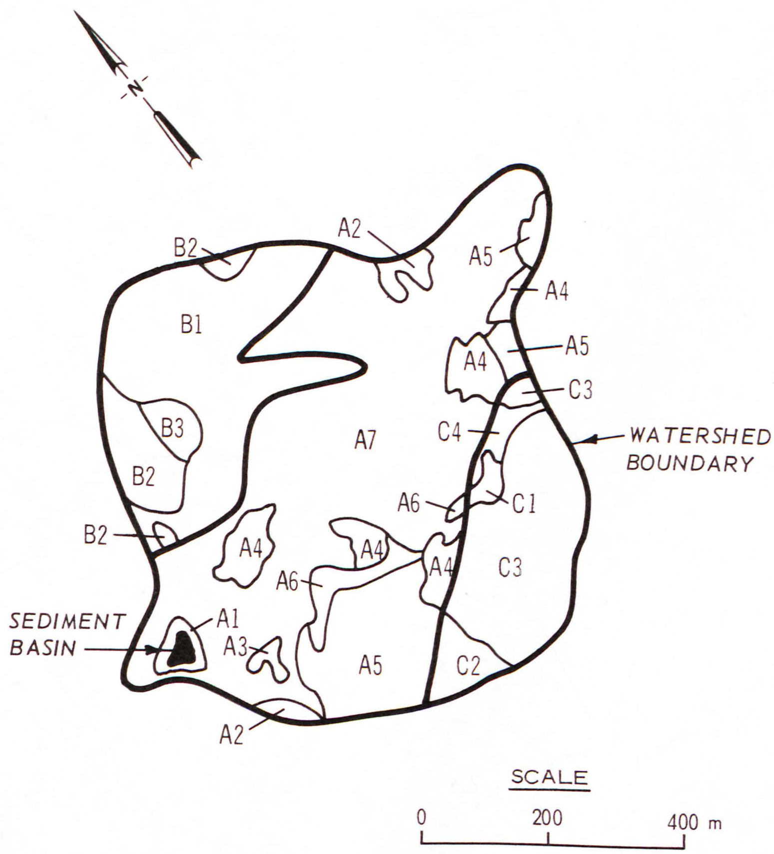


Figure 31. Field mapping unit factor complex map for watershed study area 4



NOTE: FOR LEGEND SEE TABLE 4.

Figure 32. Field mapping unit factor complex map for watershed study area 5

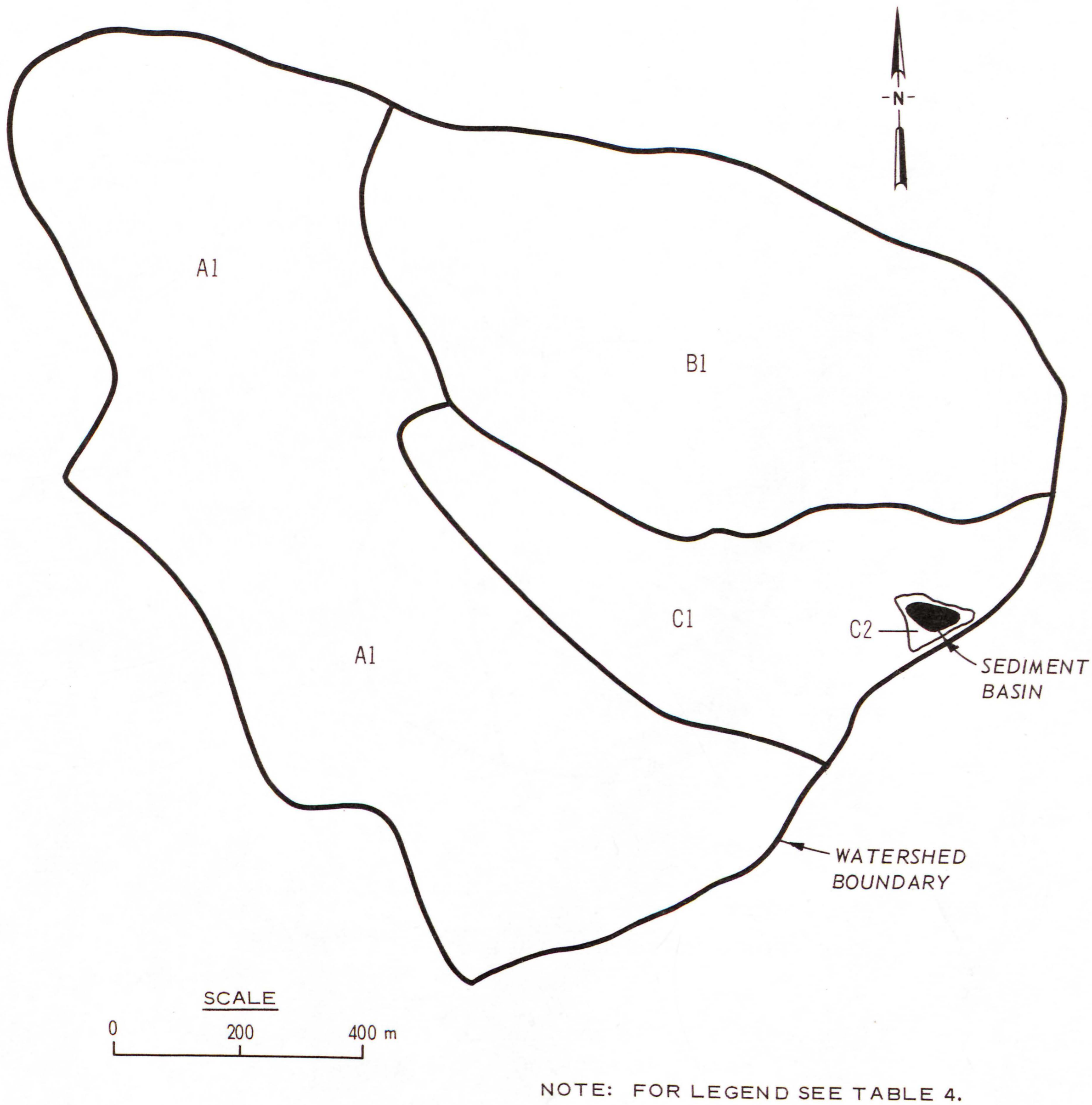


Figure 33. Field mapping unit factor complex map for watershed study area 6

b. Second character:

Alphabetic Letter	Ground Cover percent
A	0-10
B	>10-20
C	>20-30
D	>30-40
E	>40-50
F	>50-60
G	>60

c. Third character:

Alphabetic Letter	Type of Ground Cover
g	Grasses
w	Broad leaf herbaceous plants

For example, the first alphanumeric code in Table 4 (column 4) is translated through the above tabulations as class 1 for percent canopy cover (0-10), class D for percent ground cover (>30-40), and g for a ground cover of grasses. The numeric code (Table 4, column 5) is interpreted as follows:

Plant Height Class	Average Plant Height, m
1	0
2	0.5
3	2.0
4	4.0

56. The natural cover factor for each factor complex element (C_{nc_ℓ}) present in a field mapping unit was then determined by the following sequence:

a. The plant height class determined from Table 4 (column 5) is used to select the proper plant height class in Table 3.

b. The canopy cover class was determined from the first character of the alphanumeric code in Table 4 (column 4). This number is then used to select the proper canopy cover class in Table 3 (column 1).

c. The type of ground cover was determined from the third character of the alphanumeric code in Table 4 (column 4). This letter is then used to select the proper line position in Table 3 (column 2).

d. The ground cover class was determined from the second character of the alphanumeric code in Table 4 (column 4). This letter is used to select the proper ground cover class in Table 3, which finally determines the location and numerical value of $C_{nc_{\ell}}$ in Table 3.

e. C_{nc} for each field mapping unit* is then obtained by solving

$$C_{nc} = \sum_{\ell=1}^{\ell=r} \left(\frac{A_{\ell}}{A_c} \right) C_{nc_{\ell}} \tag{13}$$

where

r = number of factor complex elements in a field mapping unit

A_{ℓ} = area of factor complex element

A_c = area of field mapping unit

Table 1 (column 6) lists the resulting value of C_{nc} for each field mapping unit. Note that the smaller C_{nc} becomes in Table 3 the higher the percentage of ground cover and canopy cover, e.g., the smaller the value of C_{nc} the more protection afforded the in situ soil against erosion by the natural vegetation cover.

57. Percent of field mapping unit damaged by military training activities. Military training activities have caused significant damage to both trees and grass cover in watershed study areas 1-5. Damage to the woodland vegetation consists of branches and complete trees (junipers and pinyon pine species) being overridden by training vehicles and/or being cut down by personnel (Appendix B). Damage to the grassland vegetation has resulted from multiple passes of training vehicles across the terrain, which in turn destroy the grass cover and create numerous roads and trails that dissect the watershed area (Figure 34). To determine the percent of each field mapping unit damaged by military training activities (A_m), maps were constructed for each watershed, delineating areas having less than 10 percent areal damage to the vegetation and the in

* Note that the values of the factor complex element derived from Table 3 do not reflect different levels of management, e.g., light or heavy grazing, select timber removal, etc.[10]

Figure 34. Network of vehicle trails in watershed 1 (1975)

situ soil as well as those areas having damage equal to or greater than 10 percent damage. Figures B4-B8, stereo-aerial photography, and information collected during on-site inspections were used to prepare these maps. Each of these factors was collectively integrated by an interpreter to produce an areal damage map for each field mapping unit (a sample map is shown as Figure 35).

58. A_m was then calculated as follows:

$$A_m = \frac{A_{mu}}{A_{fm}} \tag{14}$$

where

A_{mu} = area of field mapping unit having damage to the vegetation and in situ soil greater than or equal to 10 percent

A_{fm} = area of field mapping unit

Values of A_{mu} and A_{fm} were determined from the areal damage maps by means of random-dot grid templates (see paragraph 60). Table 1

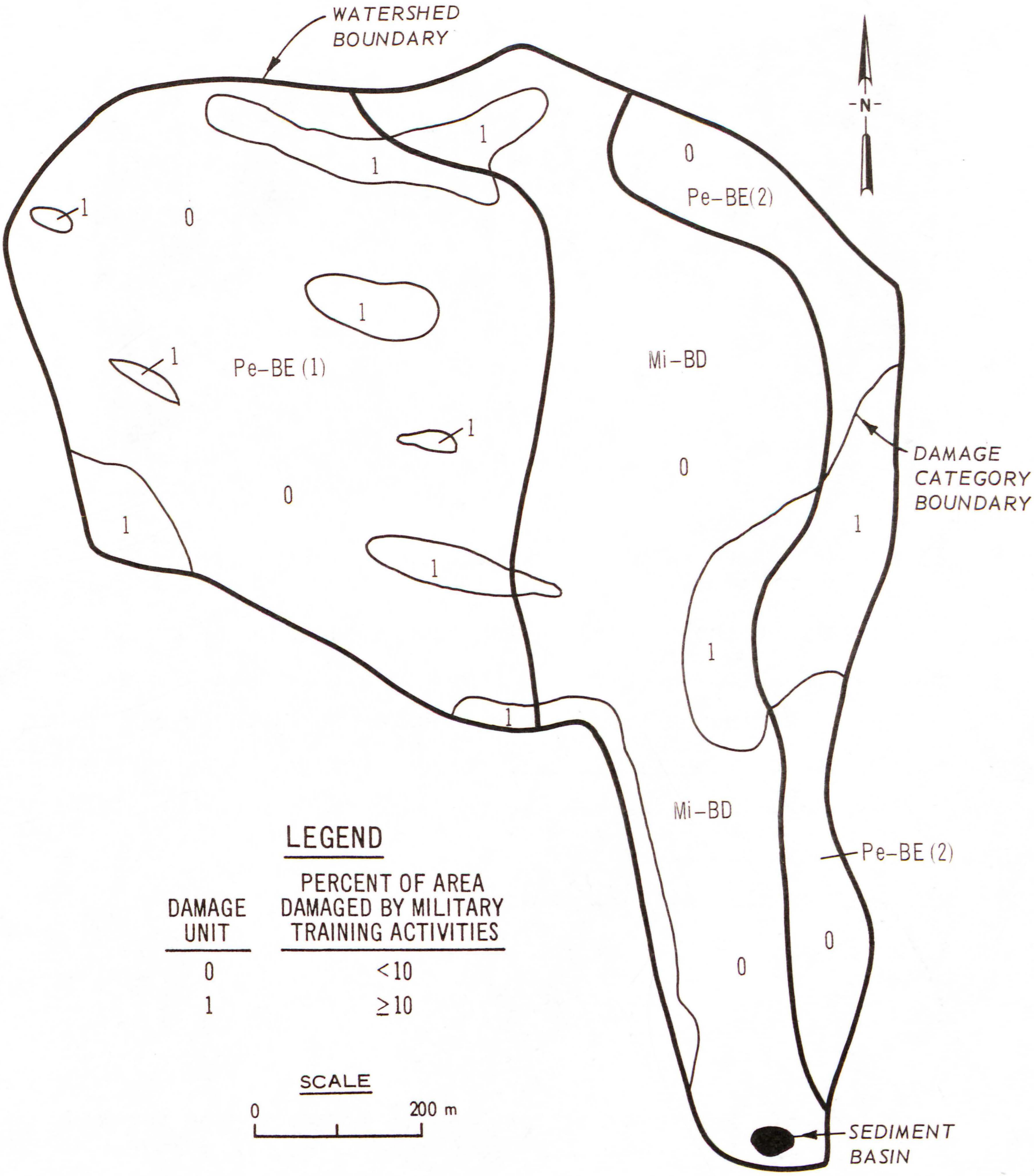


Figure 35. Sample areal damage map used to determine the percent of field mapping units damaged by military training activities (watershed study area 4)

(column 7) lists the numerical values of A_m computed for each field mapping unit.

59. <u>SCS cover factor for cross-slope plowing</u>. The SCS cover factor for cross-slope plowing (C_{csp}) was determined for each field mapping unit by initially determining a representative slope gradient for the unit. This gradient was then related to C_{csp} by data provided in Reference 11, which is reproduced below:

Slope-Gradient Range, percent	Cover Factor for Cross-Slope Plowing (C_{csp})
>7	0.75
7.1-12	0.80
12.1-18	0.90
>18.1	0.95

To develop a representative slope-gradient value for each field mapping unit, a slope-gradient grid* array (Appendix C) that included the boundaries of the field mapping unit was initially generated. After digitizing the boundaries of the field mapping unit (digitization is described in Appendix C), the resulting data base was overlaid with the slope-gradient grid array using an automated process.[12] The resulting array provided a grid of slope gradients within the boundaries of the field mapping unit. The equation for calculating a representative slope-gradient for each unit (S_w) is expressed as

$$S_w = \frac{\sum_{i=1}^{i=\beta} S_i}{\beta} \tag{15}$$

where

β = number of slope-gradient values in the field mapping unit

S_i = slope-gradient value at the i^{th} grid point

C_{csp} was computed by entering the calculated value of S_w into the correct slope-gradient range in the tabulation above. Table 1 (column 8) lists the resulting values of C_{csp}.

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* Grid spacing was 25 m.

Percent of watershed study
area occupied by field mapping unit

60. The percent of each watershed study area occupied by the constituent field mapping units was calculated statistically from Figures 9-14 with random-dot grid templates (such as those manufactured by the Charles Bruning Company, Memphis, Tennessee).[13] The template used for this study had a degree of precision of at least 95 percent. Table 1 (column 14) lists the resulting values.

PART IV: ASSESSMENT OF THE IMPACT OF MILITARY TRAINING ACTIVITIES ON SOIL LOSS

61. The procedures discussed in Part II for calculating the WEI and the data developed in Part III are used in Part IV herein to assess the impact of military training activities on soil loss at Fort Carson. This assessment is divided into four sections: (a) development of a predictive technique to estimate average annual sediment yield for watersheds in the Fort Carson region, (b) estimates of the average annual sediment yield of the six watershed study areas, (c) estimates of the remaining life of the six sediment catchment basins based on various military training schedules, and (d) estimates of the percent of the accumulated sediment volume in the catchment basins of the six watershed study areas that are directly attributable to military training activities. Although this report is limited to an assessment of soil erosion on the Fort Carson Reservation, it will be evident that the assessment technique is applicable to other military installations conducting field training and nonmilitary land use activities where there are existing sediment catchment basins.

Development of Predictive Technique to Estimate Average Annual Sediment Yield

62. A predictive technique to estimate the average annual sediment yield for watersheds in the Fort Carson region was developed based on measured accumulated sediment volume in the catchment basins of the six watershed study areas (see paragraph 40) and the corresponding WEI calculated from Equation 8.

63. The average annual sediment yield can be calculated as follows:

$$Y_{aa} = \frac{V_B \rho}{A_t T_s} \qquad (16)$$

where

ρ = density of sediment; this value is assumed to be 1.765 tons/m^3 for the Fort Carson area

A_t = planar area of watershed, m^2 (see paragraphs 30-35)

T_s = age of basin in 1975, years (see paragraph 29)

64. By using Equation 16, the average annual sediment yield was calculated for each watershed study area. The results are provided in the following tabulation:

Watershed Study Area	Average Annual Sediment Yield metric tons/km^2	tons/acre*
1	118.8	0.53
2	248.8	1.11
3	60.5	0.27
4	22.4	0.10
5	425.9	1.90
6	0	0

65. The next step was the computation of the erosion index for each field mapping unit using Equation 2, i.e. multiplying the values of R_i , K_i , $(LS)_i$, and $\overline{C}_{it}$ in Table 1 (columns 3, 4, 5, and 12) to obtain the values of $(EI)_i$ (Table 1, column 13). Note that the time-weighted composite land use factor $\overline{C}_{it}$ (Table 1, column 12) was used in Equation 2 instead of $\overline{C}_i$ to account for the fact that watershed study areas 1, 2, 3, and 4 (Figure 1) were acquired in 1965, and no troop training occurred in these basins prior to that date. Data for the length of time that the watershed study areas had been used for non-military and military purposes (T_v and T_m , respectively; see paragraph 24) were obtained from the land management personnel at Fort Carson; these values were used to compute the ratios listed in Table 1 (columns 10 and 11).

66. By substituting $\overline{C}_{it}$ for $\overline{C}_i$, Equation 2 now becomes $(EI)_i = R_i K_i (LS)_i \overline{C}_{it}$, and the erosion index can be computed for each field mapping unit as a function of the impact of military training

* The yield for each watershed study area is also provided here in U. S. customary units to facilite comparison with the literature that traditionally expresses yield in tons/acre.

activities. The WEI is then calculated by summing the product of the $(EI)_i$ and A_{f_i} values (Table 1, columns 13 and 14, respectively) for all field mapping units in each watershed. Table 1 (column 15) presents the values for WEI, computed with Equation 8, for watersheds 1-6.

67. The final step in the development of the predictive equation was correlating the average annual sediment yield (see paragraph 64) with the corresponding WEI. Figure 36 shows a plot of these data with a derived least-square regression line of best fit through the data points. The regression equations are

$$Y_{aa} = -13.27 + 1.86\,(WEI) + 0.19\,(WEI)^2 \tag{17a}$$

$$Y_{aa} = -0.06 + 0.008\,(WEI) + 0.0009\,(WEI)^2 \tag{17b}$$

where Y_{aa} in Equation 17a is in terms of metric tons/km^2 and in 17b, in tons/acre. Inherent in this correlation is the understanding that the accumulated sediment volume as measured in a catchment basin does not reflect the total watershed yield; a portion of the eroded soil may be deposited as bed material in the higher elevations above the catchment basin, while some of the material reaching the sediment basin may not be deposited there but instead transported downstream by overflow through the spillway.

68. Equation 17 provides a predictive capability for estimating average annual sediment yield for watersheds that have environmental and land use parameters similar to those exhibited in the six watershed study areas. Because care was taken in the selection of the study areas to ensure that they were representative of conditions found on the Fort Carson Reservation, the equation should be applicable for any watershed on or near the reservation. It should be noted, however, that the equation is based on only six data points, and correlations based on this number of data points cannot be used with complete confidence. For this reason, it is recommended that additional watersheds at Fort Carson, where sediment basins exist, be analyzed to further validate the predictive equation. Boring data are available for two other sediment

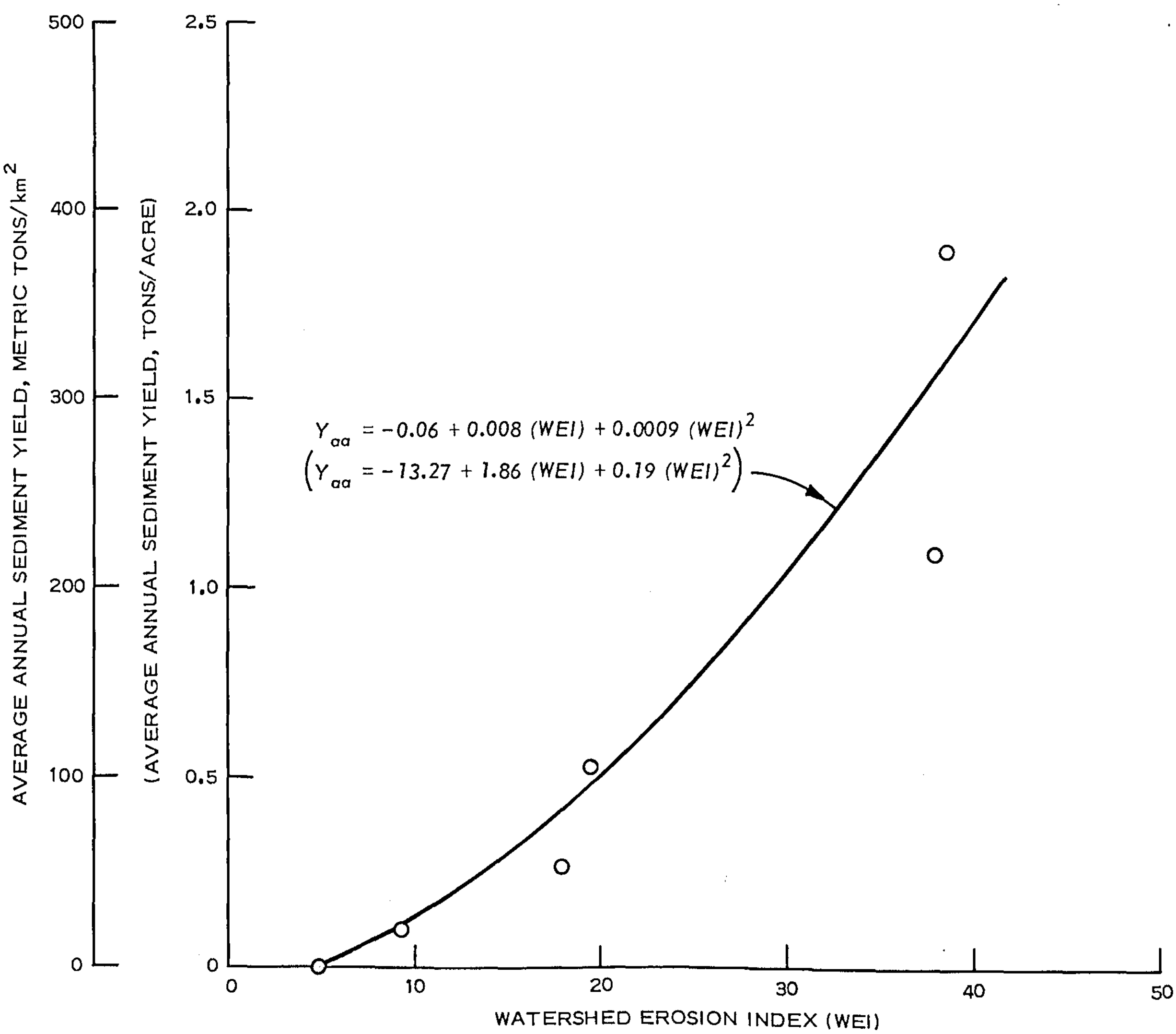

Figure 36. Relation between average annual sediment yield and the WEI for the six watershed study areas

catchment basins that could be used immediately for validation purposes.

Estimates of Average Annual Sediment Yield in Six Watershed Study Areas

69. By substituting in Equation 17, estimates of average annual sediment yield were made for watershed study areas 1-5. Since the amount of sediment in the basin at the time of the SCS survey was negligible (see paragraph 40), the sediment yield was not estimated for watershed study area 6.

70. To arrive at a means of describing the use of the land for troop training at intensities other than those maintained in 1975, Equation 6 was modified to become:

$$\overline{C}_i = C_{nc} + NA_m \left(C_{csp} - C_{nc}\right) \tag{18}$$

where N represents a scalar multiplier determining the level of military training activities, i.e., 0 for no military training activities, 1 for the same level as 1975, 2 for double the military activities, etc. The WEI values were computed by substituting four values of N in Equation 18 to obtain values for $\overline{C}_i$ that reflect four schedules of military training activity. The results are tabulated in metric units as follows:

Average Annual Watershed Sediment Yield for Different Military Training Schedules (N), metric tons/km^2

Watershed	Natural Cover Conditions (N = 0)	Training Schedule of 1975 Continues Unchanged (N = 1)	Double the Training Schedule of 1975 (N = 2)	Triple the Training Schedule of 1975 (N = 3)
1	42.6	96.4	170.4	262.2
2	302.6	347.4	390.0	432.6
3	82.9	82.9	82.9	85.2
4	13.4	20.2	29.1	35.9
5	277.9	354.2	432.6	517.8

The computed values of yield in U.S. Customary units are as follows:

Watershed	Natural Cover Conditions (N = 0)	Training Schedule of 1975 Continues Unchanged (N = 1)	Double the Training Schedule of 1975 (N = 2)	Triple the Training Schedule of 1975 (N = 3)
	Average Annual Watershed Sediment Yield (tons/acre) for Different Military Training Schedules (N), tons/acre			
1	0.19	0.43	0.76	1.17
2	1.35	1.55	1.74	1.93
3	0.37	0.37	0.37	0.38
4	0.06	0.09	0.13	0.16
5	1.24	1.58	1.93	2.31

Note that the values in the column N = 1 compare favorably with the actual values listed in paragraph 64. Furthermore, the values of average annual watershed sediment yield for N = 1 are in good comparison with values (0 to 448.3 metric tons/km^2/year or 0-2 tons/acre/year) determined from an SCS erosion study conducted in June 1976 in the Fort Carson area.[14] These values also fall within the range of values (22.4 to 515.5 metric tons/km^2/year or 0.1 to 2.3 tons/acre/year) predicted by the results of a study conducted in eastern Wyoming on small watersheds similar to those found at Fort Carson.[15] The values of yield predicted for N = 0, 2, and 3 will assist land use planners in assessing the impact of a change in the 1975 military activity level.

71. The comparisons discussed in paragraph 70 indicate that the soil losses occurring in the six watershed study areas at Fort Carson are not significantly different from those losses in small watersheds found in other areas of the Rocky Mountain Foothills region.[15] Conversations with SCS personnel, who conducted the 1976 erosion study in the Fort Carson area, substantiate this fact.

72. Under typical temperate climatological conditions, new topsoil forms at a rate of about 336.5 metric tons/km^2/year.[16] The soil losses for the watershed study areas range from 20.2 to 354.2 metric tons/km^2/year under present land use conditions (see tabulation in paragraph 70). On this basis, it may be possible that in some areas, on the

Fort Carson Reservation, particularly those protected from direct attack by prevailing winds, soil is being formed faster than it is being lost. The Fort Carson area, however, is considered to be semiarid and not temperate. Therefore, most probably the rate of new topsoil formation is less than 336.5 metric tons/km^2/year because of the relatively slow rate of natural revegetation and vegetation growth due to the low annual precipitation, the exposure of large maneuver areas to attack by winds, and the frequency and intensity of troop training. Thus, a strong and vigilant program in the conservation of soil resources is needed at Fort Carson to offset the damaging effects of the troop training activities on the semiarid, fragile ecosystem.

Estimates of Remaining Life of Sediment Catchment Basins

73. The remaining life of a sediment catchment basin on the Fort Carson Reservation can be estimated for watersheds where (a) troop training activities may have been stopped either permanently or temporarily; (b) the training activities will remain at the 1975 schedule level; or (c) the training activites will be increased by a multiple (i.e., double, triple, etc.) of the 1975 training schedule. The remaining life of a basin can be approximated by first calculating a value for WEI and solving Equation 17 to obtain a value for Y_{aa} and then substituting this value into the following equation to yield a value for B_ℓ :*

$$B_\ell = \frac{V_c \rho}{Y_{aa} A_t} \tag{19}$$

where

B_ℓ = remaining life of sediment basin, years

V_c = remaining volume of basin (the basin volume between the elevation of the sediment surface and a plane projected across the basin at the elevation of the spillway crest)

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* This approach assumes that the entire yield is deposited in the sediment catchment basin.

In practice, the effectiveness of a basin for sediment retention is substantially reduced as the level of the sediment surface approaches the spillway crest elevation. Thus, the estimate provided by Equation 19 is optimistic for estimating effective basin life but can be used in making projections for planning purposes and for preliminary basin design studies.

74. Sufficient survey data was obtained in the field to calculate the original catchment basin design volume (V_D) for watershed study areas 1, 2, and 5. These volumes were determined using the procedures described in Appendix D. The remaining basin capacity (V_c) could then be computed by subtracting the accumulated sediment volume (V_B) from V_D. The results are tabulated below:

Watershed Study area	V_D m^3	V_B m^3	V_c m^3
1	8,393	1,531	6,862
2	3,602	2,960	642
5	23,458	2,825	20,633

75. Predictions of remaining basin life as of 1975 were made for watersheds 1, 2, and 5 for four different values of N (see paragraph 70). These basin life estimates are tabulated below:

	Remaining Life (B_ℓ) (from 1975) of Sediment Basin for Different Military Training Schedules, years			
Watershed Study Area	Natural Cover Conditions (N = 0)	Training Schedule of 1975 Continues Unchanged (N = 1)	Double the Training Schedule of 1975 (N = 2)	Triple the Training Schedule of 1975 (N = 3)
1	188.0	83.0	47.0	31.0
2	3.2	2.8	2.5	2.2
5	278.0	218.0	179.0	149.0

76. Upon initial inspection, it would appear that the sediment catchment basins in watershed study areas 1 and 5 were designed with storage capacities greater than those necessary to retain the sediment transported into the basins, and the basin in watershed study area 2

with too small a storage capacity. The conclusion that the basin in watershed study area 2 was underdesigned is probably justified since 98 percent of its holding capacity was filled with sediment after a period of only 18 years (1957 to 1975) and should be completely full of sediment following the summer rains in 1978. This estimate is based on the assumption that land usage for military training will remain generally at the 1975 level through 1978. Watershed study area 2 is a candidate for engineering design studies to determine what type of new structure or remedial work is best suited to reestablish effective soil erosion control. More will be said later about the design of the basins in watershed study area 2 after brief comments about the design of the basins in watershed study areas 1 and 5.

77. Considering that the sediment basins in watershed study areas 1 and 5 have respectively a B_ℓ of 31 and 149 years based on a projected increase in troop training activities of three times that of 1975, it can be concluded that the basins were overdesigned in terms of sediment storage capacity. This conclusion is invalid, however, without knowledge of the original design criteria. It may have been that the basins were designed primarily on the basis of providing water storage capacity for the surface runoff from a 50- or 100-year-frequency storm event. It is during such storms that abrupt changes in land morphology occur due to dramatic and often devastating erosion and deposition. Damage to the landscape from one such storm can be equivalent to the damage done over several decades under normal conditions. A basin structure designed to be effective in controlling runoff and erosion during a period of abnormally high rainfall will probably appear to be overdesigned.

78. The sediment basin in watershed study area 2 was constructed in 1957 prior to acquisition of this land by Fort Carson in 1965. The watershed area has been subjected to troop training pressures for 8 years as of 1975. This land was probably used for grazing prior to acquisition by Fort Carson. The percent ground cover, as shown in Figure 17, is the lowest for any of the watersheds studied, ranging from 0 to 20 percent with a considerable area of 0 to 10 percent ground cover coinciding with the soil series WK-BD (Figure 10) which has a

relatively high erodibility factor of 0.35 (Table 1, column 4). Most of the remaining area not covered by the WK-BD soil series contains the Pe-BE soil series with a soil erodibility factor of 0.23 associated with the highest slope-length and gradient factors (33.39 and 32.65) recorded in Table 1 (column 5) for any of the field mapping units. Based on these considerations, serious soil erosion problems would be anticipated to occur in watershed study area 2 due to natural causes only; however, intensive military training activities have further contributed to soil loss.

79. In contrast, note that about two thirds of watershed study area 6 contains two soil series with the highest erodibility factor (0.37) occurring in all six watershed study areas (Table 1, column 4). However, the average annual sediment yield is so small in this watershed that no sediment surface was apparent at the time of the SCS sediment surveys (see paragraph 38). The lack of measurable soil loss was due to the very low topographic relief (slope-length and gradient factors ranging from 0.95 to 1.47) and the relatively good ground cover. Figure 21 shows all but a small area around the sediment basin with a 30 to 40 percent ground cover of grass. This ground cover is the best shown for any of the six watersheds and is reflected by the relatively low value of 0.13 for C_{nc} (Table 1). Without a doubt, the vegetation cover and topographic slope are the two most important natural terrain factors influencing the annual sediment yields in the watersheds studied. The magnitude of these terrain factor effects on sediment yield probably was not reliably estimated in designing the basin for watershed study area 2.

80. Personnel responsible for future engineering and design of sediment basins at Fort Carson can use the following equation to determine the basin volume required for sediment deposition (V_s) for a given design life:

$$V_s = \frac{Y_{aa} \cdot D_\ell \cdot A_t}{\rho} \qquad (20)$$

where D_ℓ represents design life of basin. Then, V_s can be increased to accommodate water storage capacity based on the design storm characteristics, subject to constraints imposed by such factors as site topography and available resources of financing, manpower, equipment, and construction materials. Engineering judgment will always be required to decide the final design trade-offs after all the pertinent and competing factors in a sediment catchment basin study are considered.

Estimates of the Accumulated Sediment Volume Attributable to Military Training Activities

81. The accumulated sediment volume in each of the watershed study area catchment basins in 1975 that was directly attributable to the effects of military training activities can be computed by use of an equation correlating the measured accumulated sediment volume (see paragraph 40) and the computed WEI for each of the six watershed study areas (Table 1, column 15). A least-squares fit to the data pairs (Figure 37) results in

$$V_B = 73.6 \text{ WEI} - 233.27 \tag{21}$$

That portion of the sediment volume accumulated in each of the six watershed basins attributable to the effects of military training activities can then be determined as follows:

- a. Compute the WEI values using Equations 2, 5, 8, 13, and 18 based on the natural vegetation cover ($N = 0$ in Equation 18).
- b. Substitute each of these WEI values for $N = 0$ into Equation 21 and solve for $V_{B(N=0)}$.
- c. Substitute each of the WEI values for $N = 1$ (Table 1, column 15) into Equation 21 and solve for $V_{B(N=1)}$.

The accumulated sediment volume attributable to the effects of military training activities (V_{Bm}) is then equal to the difference in the values for $V_{B(N=0)}$ and $V_{B(N=1)}$. These values were calculated for each

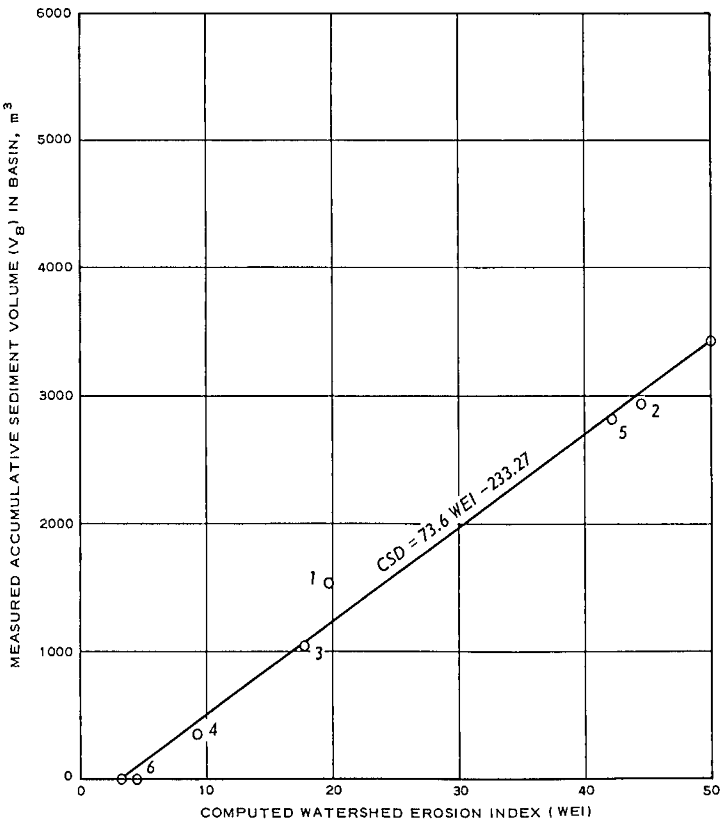

Figure 37. Relation between the computed WEI and the measured accumulated sediment volume (V_B) for the six watershed study areas

of the basins in the six watershed study areas and expressed as a percentage of the accumulated sediment volume with the following equation:

$$V_{Bm} = 100\left(1 - \frac{V_{B_{(N=0)}}}{V_{B_{(N=1)}}}\right) \tag{22}$$

The computed values for V_{Bm} are as follows:

Watershed Study Area	Accumulated Sediment Volume Attributable to the Effects of Military Training Activities (V_{Bm}), percent
1	32
2	4
3	1
4	9
5	23
6	0

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

82. Based on this study, the following conclusions were reached:

a. An equation for predicting average annual sediment yield for watersheds on the Fort Carson Reservation was developed (see paragraph 67). This methodology can provide reliable engineering data for use in the development of design parameters for new sediment retention structures on the Fort Carson Reservation (see paragraph 80).

b. The soil losses in the six watershed study areas analyzed at Fort Carson are not significantly different from those losses experienced in other small watersheds in the Rocky Mountain Foothills region (see paragraphs 71 and 72). However, over most of Fort Carson, the annual rate of topsoil formation is probably less than the annual soil loss rate because of the relatively slow rate of natural revegetation and vegetation growth due to the low annual precipitation, the exposure of large maneuver areas to attack by wind erosion, and the frequency and intensity of troop training. Thus, a strong and vigilant program in the conservation of soil resources is needed at Fort Carson to offset the damaging effects of the troop training activities on the semiarid, fragile ecosystem.

c. Although the contents of this report are directed toward the analysis and assessment of soil erosion at Fort Carson, the approach used for analyzing the impact of military training activities on soil erosion is applicable to other military installations conducting field training and nonmilitary land use activities, where there are existing sediment basins (see paragraph 61).

d. Military training operations have caused significant damage to both trees and grass cover in watershed study areas 1-5. Damage to the woodland vegetation consists of branches and complete trees (junipers and pinyon pine species) being overridden by training vehicles and/or being cut down by personnel (see paragraph 57). Damage to the grassland vegetation has resulted from multiple passes of training vehicles across the terrain, which in turn destroy the grass cover and create numerous roads and trails that dissect the watershed area (see paragraph 57).

Recommendations

83. Based on the results of this study, it is recommended that:

   a. Additional watersheds at Fort Carson with existing sediment catchment basins be analyzed to further validate the predictive methodology (see paragraph 68).

   b. A computer program be written to perform the calculation of average annual sediment yield automatically for a user who provides the data required to compute the WEI.

   c. The methodology developed herein be used to estimate the effective life of other sediment catchment basins at Fort Carson that are silting in at a rapid rate, so that plans can be made for future control structures or other conservation measures.

   d. The methodology developed herein be used to determine basin capacity required for sediment retention in all future engineering design studies for new basin construction at Fort Carson.

   e. If new lands are acquired, the soil erosion assessment techniques should serve to establish baseline erosion conditions and evaluate the impact of introducing training activities in areas where existing soil losses are highest.

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Table 1

Data Used To Compute Watershed Erosion Index (WEI)

Watershed Number (1)	SCS Field Mapping Unit (2)	Rainfall Factor R_i (3)	Erodibility Factor K_i (4)	Slope-Length and Gradient Factor $(LS)_i$ (5)	Natural Plant Cover Factor C_{nc} (6)	Percent of Field Mapping Unit Damaged by Military Training Activities A_m (7)	SCS Cover Factor for Cross-Slope Plowing C_{csp} (8)	Composite Land Use Factor $\overline{C}_i$ (9)	Time Ratio for Non-Military Usage Conditions T_v/T_s (10)	Time Ratio for Military Training Activities T_m/T_s (11)	Time-Weighted Composite Plant Cover Land Use Factor $\overline{C}_{it}$ (12)	Erosion Index for Mapping Unit $(EI)_i$ (13)	Portion of Watershed Occupied by Field Mapping Unit A_{f_i} (14)	Watershed Erosion Index WEI (15)
1	Mi-BD	75	0.37	0.86	0.13	0.00	0.75	0.13	5/15	10/15	0.13	3.00	0.02	19.33
	Mq-B		0.35	3.89	0.25	0.40	0.75	0.45			0.38	38.80	0.20	
	Pe-BE(1)		0.23	5.20	0.21	0.30	0.90	0.42			0.35	31.41	0.17	
	Ni-CE		0.10	3.91	0.23	0.25	0.80	0.37			0.32	9.39	0.57	
	HS-AB		0.20	1.37	0.31	0.25	0.75	0.42			0.38	8.00	0.02	
	Pe-BE(2)		0.23	5.50	0.23	0.25	0.95	0.41			0.35	33.00	0.02	
2	WK-BD	75	0.35	2.91	0.36	0.05	0.75	0.38	8/18	10/18	0.37	28.27	0.56	38.04
	Ca-CD		0.31	1.16	0.26	0.05	0.75	0.29			0.28	7.50	0.06	
	Pe-BE(1)		0.23	2.38	0.36	0.10	0.80	0.40			0.38	16.00	0.01	
	Pe-BE(2)		0.23	33.39	0.29	0.00	0.95	0.29			0.29	167.00	0.03	
	Pe-BE(3)		0.23	32.65	0.31	0.15	0.95	0.41			0.37	208.33	0.06	
	Pe-BE(4)		0.23	2.92	0.28	0.05	0.75	0.30			0.29	14.61	0.28	
3	Mi-BD	75	0.37	2.54	0.26	0.00	0.75	0.26	18/28	10/28	0.26	18.32	0.90	17.91
	Pe-BE		0.23	3.36	0.31	0.10	0.80	0.36			0.33	19.25	0.04	
	XPe-F		0.15	2.74	0.33	0.10	0.90	0.39			0.35	10.83	0.06	
4	Pe-BE(1)	75	0.23	2.31	0.23	0.15	0.75	0.31	18/28	10/28	0.26	10.36	0.44	9.37
	Mi-BD		0.37	1.82	0.17	0.15	0.75	0.26			0.20	10.10	0.40	
	Pe-BE(2)		0.23	1.07	0.21	0.25	0.75	0.35			0.26	4.81	0.16	
5	XQ1-CE(1)	75	0.30	6.47	0.15	0.10	0.90	0.23	0/25	25/25	0.23	33.48	0.23	38.47
	XQ1-CE(2)		0.30	18.14	0.30	0.00	0.95	0.30			0.30	122.42	0.19	
	XSO-C		0.28	2.68	0.17	0.10	0.75	0.23			0.23	12.95	0.58	
6	S8-AB	75	0.28	0.95	0.13	0.00	0.75	0.13	0/25	25/25	0.13	2.61	0.33	5.05
	S8-CD		0.37	1.47	0.13	0.05	0.75	0.16			0.16	6.52	0.52	
	S5-C		0.37	1.01	0.13	0.10	0.75	0.19			0.19	5.33	0.15	

Table 2

SCS Soil Series Field Mapping Unit Data

SCS Soil Series Field Mapping Unit		Classification		Erodibility Factor (K_i)
Symbol	Name	USCS*	USDA	
Mi-BD	Modell-Manual Silty Loam	CL; CL-ML, CL	Loam; loam	0.37
Mq-B	Minnequa-Manuel Loams	ML-CL; CL-ML, CL	Loam; loam	0.35
Pe-Be	Penrose-Minnequa Complex	ML; ML	Loam; silty loam, loam	0.23
Ni-CE	Cascajo Gravelly Sandy Loam, 5-25 percent slopes	GW-GM	Gravelly sandy loam	0.10
HS-AB	Stoneham Loam	ML or SM	Loam	0.20
WK-BD	Kim-Wiley Loams	ML-CL; ML-CL	Loam; loam	0.35
Ca-CE	Razor-Gaynor Clays, eroded	CL or CH	Clay	0.31
XPe-F	Penrose-Rock Outcrop Complex	ML	Loam	0.15
XQ1-CE	Rizozo-Neville Complex, 3-60 percent slopes	CL-ML; SM, ML	Loam, sandy loam	0.30
XSO-C	Santana Loam, 0-5 percent slopes	ML	Loam	0.28
S8-AB	Santana Loam, 0-3 percent slopes	ML	Loam	0.28
S8-CD	Wiley Silt Loam, 3-9 percent slopes	CL-ML, CL	Silt	0.37
S5-C	Wiley Silt Loam, 3-9 percent slopes	CL-ML, CL	Silt	0.37

* USCS--Unified Soil Classification System.

Table 3

Factor Complex Element Natural Vegetation Cover Values (C_{nc})*

Canopy Cover Class (Percent Cover**) (1)	Type† (2)	Ground Cover Class (Percent Cover) A(0-10) (3)	B(>10-20) (4)	C(>20-30) (5)	D(>30-40) (6)	E(>40-50) (7)	F(>50-60) (8)	G(>60) (9)
		Plant Height Class 1 (No Appreciable Canopy)						
1(0-10)	g	0.39	0.26	0.18	0.13	0.086	0.057	0.012
	w	0.40	0.29	0.22	0.17	0.14	0.11	0.043
		Plant Height Class 2 (Canopy of Tall Weeds or Low Brush, 0.5-m Fall Height††)						
2(>10-20)	g	0.35	0.24	0.17	0.12	0.082	0.054	0.013
	w	0.36	0.27	0.20	0.16	0.13	0.10	0.042
3(>20-30)	g	0.31	0.22	0.15	0.11	0.077	0.051	0.013
	w	0.32	0.24	0.18	0.15	0.12	0.095	0.041
4(>30-40)	g	0.28	0.20	0.14	0.10	0.071	0.048	0.012
	w	0.29	0.22	0.17	0.14	0.11	0.091	0.040
5(>40-50)	g	0.25	0.17	0.13	0.090	0.067	0.045	0.012
	w	0.28	0.20	0.15	0.13	0.11	0.87	0.039
6(>50-60)	g	0.21	0.13	0.11	0.082	0.060	0.043	0.012
	w	0.22	0.17	0.14	0.12	0.098	0.082	0.039
7(>60)	g	0.15	0.12	0.090	0.070	0.053	0.039	0.011
	w	0.16	0.13	0.11	0.098	0.085	0.074	0.038
		Plant Height Class 3 (Canopy of Low Brush, 2-m Fall Height††)						
2(>10-20)	g	0.36	0.25	0.16	0.12	0.081	0.054	0.013
	w	0.37	0.28	0.20	0.17	0.13	0.10	0.043
3(>20-30)	g	0.34	0.24	0.16	0.11	0.079	0.051	0.013
	w	0.36	0.27	0.20	0.16	0.13	0.10	0.042
4(>30-40)	g	0.33	0.22	0.15	0.11	0.074	0.051	0.013
	w	0.33	0.25	0.19	0.15	0.12	0.098	0.042
5(>40-50)	g	0.31	0.21	0.14	0.10	0.071	0.050	0.013
	w	0.31	0.24	0.18	0.15	0.12	0.095	0.042
6(>50-60)	g	0.29	0.20	0.14	0.10	0.069	0.048	0.012
	w	0.29	0.22	0.17	0.14	0.12	0.093	0.041
7(>60)	g	0.25	0.18	0.13	0.095	0.069	0.047	0.012
	w	0.25	0.20	0.16	0.13	0.11	0.089	0.040
		Plant Height Class 4 (Canopy of Trees with No Appreciable Amount of Low Brush, 4-m Fall Height††)						
2(>10-20)	g	0.37	0.26	0.17	0.12	0.085	0.056	0.013
	w	0.38	0.28	0.21	0.17	0.13	0.10	0.042
3(>20-30)	g	0.36	0.25	0.17	0.12	0.085	0.056	0.013
	w	0.37	0.28	0.21	0.16	0.13	0.10	0.042
4(>30-40)	g	0.35	0.24	0.16	0.12	0.082	0.054	0.013
	w	0.36	0.27	0.20	0.16	0.13	0.10	0.042
5(>40-50)	g	0.35	0.23	0.16	0.11	0.079	0.053	0.013
	w	0.35	0.26	0.20	0.16	0.13	0.10	0.042
6(>50-60)	g	0.33	0.23	0.16	0.11	0.077	0.052	0.013
	w	0.34	0.25	0.19	0.16	0.13	0.099	0.042
7(>60)	g	0.31	0.22	0.15	0.11	0.077	0.052	0.013
	w	0.32	0.24	0.18	0.15	0.12	0.096	0.041

Note: Adapted from Reference 8.

* All values shown assume random distribution of mulch or vegetation.

** Percentage of total ground surface area that is obscured by the canopy in a vertical projection.

† g--ground cover is grass or decaying, compacted duff or litter.
w--Ground cover is mostly broadleaf herbaceous plants (with little lateral-root network near the surface) or undecayed residue.

†† Average fall height of water drops from canopy to the soil surface.

Table 4

Factor Complex Map Legend for Field Mapping Units

Field Mapping Unit Designation (1)	Factor Complex Element Number (2)	SCS Soil Type (3)	Canopy Cover, Ground Cover, and Type of Ground Cover Classes (4)	Plant Height Class (5)
		Watershed 1		
A	1	Ni-CE	1Dg	1
	2		1Ag	1
	3		4Ag	3
	4		1Fg	1
	5		1Eg	1
	6		2Ag	2
	7		3Ag	2
	8		5Ag	3
B	1	HS-AB	5Ag	3
	2		1Dg	1
	3		4Ag	3
	4		2Ag	2
C	1	Pe-BE(1)	1Cg	1
	2		4Ag	3
	3		3Ag	2
	4		1Eg	1
	5		1Fg	1
	6		1Dg	1
	7		5Ag	3
	8		2Ag	2
D	1	Mq-B	1Cg	1
	2		1Eg	1
	3		4Ag	3
	4		1Dg	1
	5		1Fg	1
	6		3Ag	2
	7		5Ag	2
E	1	Mi-BD	1Gw	1
	2		1Dg	1
	3		1Eg	1
	4		1Cg	1
F	1	Pe-BE(2)	1Cg	1
	2		1Dg	1
	3		5Ag	3
	4		4Ag	3

(Continued)

Table 4 (Continued)

Field Mapping Unit Designation (1)	Factor Complex Element Number (2)	SCS Soil Type (3)	Canopy Cover, Ground Cover, and Type of Ground Cover Classes (4)	Plant Height Class (5)
		Watershed 2		
A	1	WK-BD	1Ew	1
	2		1Bg	1
	3		1Ag	1
	4		2Ag	2
	5		3Ag	2
	6		1Cg	1
B	1	Pe-BE(3)	1Bg	1
	2		2Ag	2
	3		3Ag	2
C	1	Pe-BE(2)	1Cg	1
	2		3Ag	2
D	1	Pe-BE(1)	1Ag	1
	2		2Ag	2
E	1	Ca-CD	1Bg	1
F	1	Pe-BE(4)	2Ag	2
	2		1Ag	1
	3		1Bg	1
	4		3Ag	2
	5		1Cg	1
		Watershed 3		
A	1	Mi-BD	1Bg	1
	2		1Ew	1
B	1	Pe-BE	1Bg	1
	2		3Ag	2
	3		2Ag	2
C	1	XPe-F	3Ag	2
	2		2Ag	2
	3		1Bg	1
		Watershed 4		
A	1	Mi-BD	1Dg	1
	2		1Cg	1
	3		2Dg	2

(Continued)

Table 4 (Concluded)

Field Mapping Unit Designation (1)	Factor Complex Element Number (2)	SCS Soil Type (3)	Canopy Cover, Ground Cover, and Type of Ground Cover Classes (4)	Plant Height Class (5)
		Watershed 4 (Continued)		
A	4	Mi-BD	1Dg	1
	5		1Bg	1
B	1	Pe-BE(2)	1Dg	1
	2		2Bg	1
	3		4Ag	3
	4		2Dg	2
	5		3Ag	2
	6		1Cg	1
C	1	Pe-BE(1)	3Ag	2
	2		1Cg	1
	3		1Bg	1
	4		2Bg	2
		Watershed 5		
A	1	XSO-C	1Gw	1
	2		5Ag	3
	3		3Ag	2
	4		7Ag	4
	5		6Ag	4
	6		4Ag	3
	7		1Eg	1
B	1	XQ1-CE(1)	1Eg	1
	2		5Ag	3
	3		6Ag	4
C	1	XQ1-CE(2)	4Ag	3
	2		6Ag	4
	3		7Ag	4
	4		1Eg	1
		Watershed 6		
A	1	S8-CD	1Dg	1
B	1	S8-AB	1Dg	1
C	1	S5-CD	1Dg	1
	2		1Ew	1

(Sheet 3 of 3)

APPENDIX A: NATURAL VEGETATION DESCRIPTION

1. Figures 16-21 (percent canopy and ground cover and type of ground cover) and Figures 22-27 (plant height) of the main text were prepared based on data collected by the WES.

2. Woody vegetation data collected by the WES in 50-m-diam cells were as follows:

   a. Species name (scientific and common).

   b. Density of each species.

   c. Canopy cover (ground area covered by crowns).

   d. Species height range.

   e. Species average height.

Table A1 summarizes these data. The densities of the tree species in the sample cells were adjusted to a unit area of 1000 m^2, so that a direct comparison between cells could be made. This was accomplished by dividing the area of the sample cell into 1000 m^2 and multiplying this quotient by the total number of trees measured in the sample cell.

3. The grassland-type vegetation within the watersheds was described by sampling 2- by 2-m plots. These plots were sampled by measuring and recording data on the following attributes:

   a. Species name (scientific and common).

   b. Density (number of stems per unit area).

   c. Ground area covered.

   d. Height range.

   e. Average height.

For the density measurements of the grass-type species, a subsample (0.4 m^2) of the 4-m^2 plot was established and a count of stems by species was made. The equation used to compute the number of grass stems occurring in the total sample area (4-m^2) was

$$N_2 = N_1\left(\frac{A_2}{A_1}\right) \tag{A1}$$

where

N_2 = number of grass stems in 4-m^2 plot

N_1 = number of grass stems in 0.4-m^2 subsample

A_2 = area of plot ($4\ m^2$)

A_1 = area of subsample plot ($0.4\ m^2$)

Table A2 summarizes the data obtained on the open grassland vegetation. Figure A1 shows quantitatively how the plant cover by grassland vegetation compared among all six watersheds.

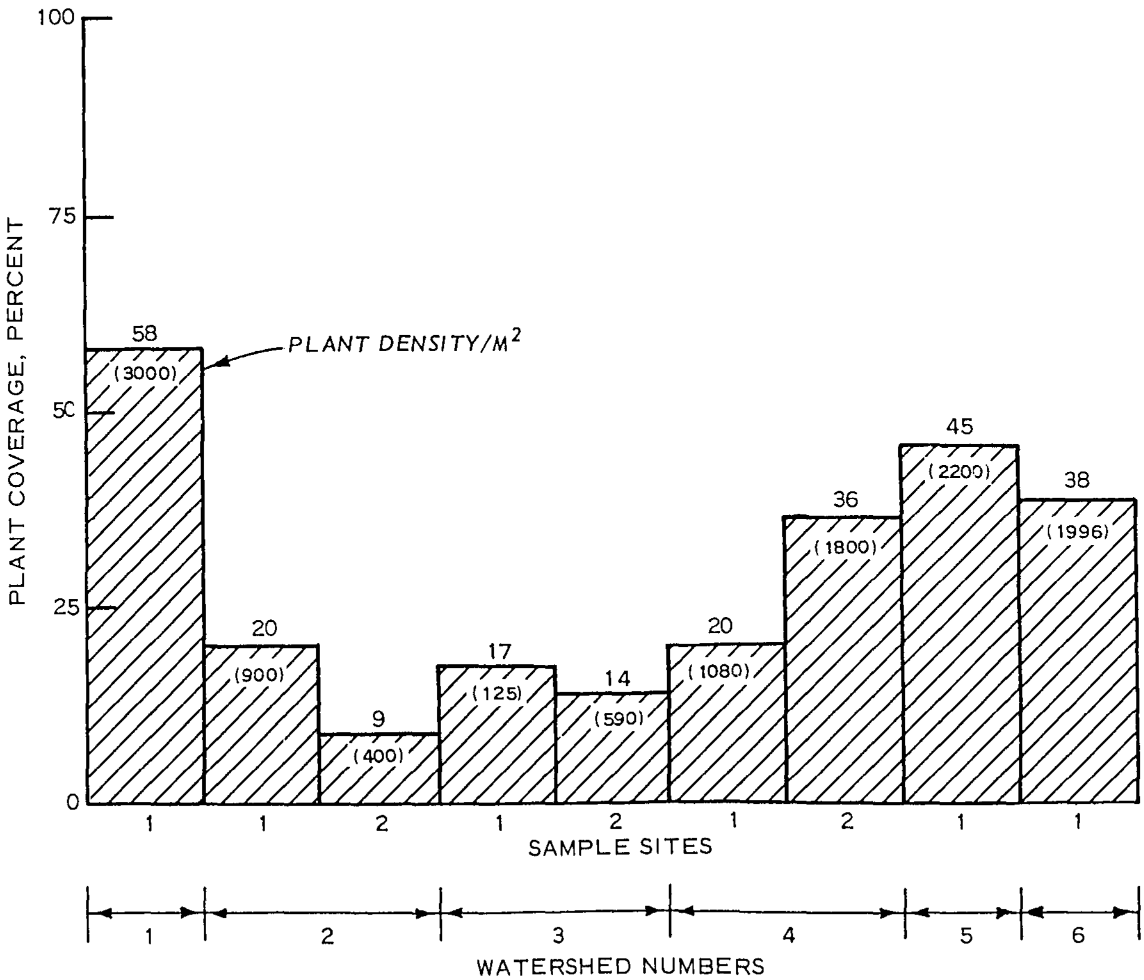

Figure A1. Percent coverage by grassland vegetation in watersheds 1-6

Table A1

Woody Vegetation Sample Data Collected in Watershed Study Areas

Scientific Name	Common Name	Density Trees/100 m^{2}*	Canopy Cover percent	Height Range cm	Average Height cm
	Watershed 1 - Sample 1 (1840 5536**)				
Juniperus monosperma	one-seed juniper	22	13	150-450	320
Pinus edulis	pinyon pine	10	5	130-500	301
	Watershed 1 - Sample 2 (1854 5500)				
Juniperus monosperma	one-seed juniper	16	17	200-500	334
Pinus edulis	pinyon pine	20	12	40-600	326
	Watershed 1 - Sample 3 (1845 5468)				
Juniperus monosperma	one-seed juniper	25	21	60-550	300
Pinus edulis	pinyon pine	1	1	350	350
	Watershed 2 - Sample 1 (0588 5773)				
Cercocarpus montanus	mountain mahogany	26	1	30-160	67
Juniperus monosperma	one-seed juniper	35	19	100-500	272
Pinus edulis	pinyon pine	12	3	100-450	209
	Watershed 4 - Sample 1 (2217 5591)				
Cercocarpus montanus	mountain mahogany	1	1	100	120
Juniperus monosperma	one-seed juniper	16	16	120-600	296
Pinus edulis	pinyon pine	2	2	70-650	380
	Watershed 5 - Sample 1 (0908 6832)				
Cercocarpus montanus	mountain mahogany	45	1	40-160	100
Juniperus monosperma	one-seed juniper	26	18	60-430	270
Pinus edulis	pinyon pine	89	49	100-600	342

* See paragraph 2.
** Military grid coordinates.

Table A2

Grassland Vegetation Sample Data Collected in Watershed Study Areas

Scientific Name	Common Name	Density, No. of Stems/m^2*	Ground Area Covered percent	Height Range cm	Average Height cm
	Watershed 1 - Sample 1 (1842 5500)				
Bouteloua gracilis	Blue grama	2800	50	10-30	20
Sporobolus cryptandrus	Sand dropseed	120	5	10-30	25
Salsola kali	Russian thistle	4	1	30-50	30
Bouteloua curtipendula	Side oats grama	24	1	10-20	15
Kochia scoparia	Kochia	3	1		
	Watershed 2 - Sample 1 (0476 5720)				
Bouteloua gracilis	Blue grama	844	15	5-20	10
Salsola kali	Russian thistle	5	3	20-50	30
Eurotia lanata	Winterfat	23	1	10-30	20
Sporobolus cryptandrus	Sand dropseed	18	<1	20-40	25
Sitanion hystrix	Bottle brush squirreltail	16	<1	10-30	20
	Watershed 2 - Sample 2 (0487 5723)				
Sitanion hystrix	Bottle brush squirreltail	389	6	20-40	30
Helianthus annulus	Sunflower	10	1	30-40	30
Salsola kali	Russian thistle	5	1	20-30	20
Sphaeralcea coccinea	Scarlet globe mallow	4	<1	10-20	12
	Watershed 3 - Sample 1 (1168 5271)				
Salsola kali	Russian thistle	27	16	30-60	45
Bouteloua gracilis	Blue grama	95	<1	5-15	6
Sphaeralcea coccinea	Scarlet globe mallow	3	<1	10-20	15
	Watershed 3 - Sample 2 (1173 5280)				
Bouteloua gracilis	Blue grama	587	13	5-20	10
Salsola kali	Russian thistle	4	<1	20-40	25
	Watershed 4 - Sample 1 (2217 5591)				
Bouteloua gracilis	Blue grama	1050	20	10-30	25
Oryzopsis hymenoides	Indian ricegrass	30	<1	15-25	20
	Watershed 4 - Sample 2 (2202 5586)				
Bouteloua gracilis	Blue grama	1740	35	10-30	20
Sporobolus cryptandrus	Sand dropseed	50	<1	20-35	25
Sphaeralcea coccinea	Scarlet globe mallow	4	<1	10-20	15
	Watershed 5 - Sample 1 (0908 6832)				
Bouteloua gracilis	Blue grama	2040	35	15-30	20
Haplopappus spinulosus	Golden weed	30	6	20-30	20
Stipa robusta	Sleepy needlegrass	137	3	30-70	60
Erigeron strigosus	Daisy fleabane	10	<1	15-40	30
	Watershed 6 - Sample 1 (2526 6981)				
Bouteloua gracilis	Blue grama	1520	30	15-35	25
Sporobolus cryptandrus	Sand dropseed	150	3	20-40	30
Chenopodium album	Lambsquarter	2	<1	10-20	10
Sphaeralcea coccinea	Scarlet globe mallow	3	<1	5-20	11

* Based on 4-m^2 sample plots (see paragraph 3).

APPENDIX B: DEVELOPMENT OF MAPS DEPICTING WOODY VEGETATION DAMAGE

1. The Fort Carson Reservation contains eight training areas that are used extensively for military training operations by the U. S. Army 4th Infantry Division (Mechanized). The Division presently (1977) consists of 22,000-25,000 men, and the training levels vary in magnitude from activities involving a few men and vehicles in each training group to brigade-size maneuvers involving 4,000 to 5,000 men and between 300 and 400 wheeled and tracked vehicles.

2. Since many of the training exercises include large numbers of vehicles at one time, damage to both trees (junipers and pinyon pines) and grass-type vegetation has been quite extensive, leading to accelerated soil losses in these areas. The loss of vegetative cover in many of the training areas is particularly important because vegetation recovers slowly due to the limited rainfall that many of the areas receive (Reference 17* and Report 3 of this series).

3. The WES conducted field surveys in the watershed study areas during 1975 and 1976 for the purpose of determining the different types and magnitudes of pressures being imposed on the environment by military training activities. These surveys were designed to provide quantitative data on the damage to both the woody and open grassland vegetation.

Description of Woody Vegetation Damage

4. Vegetation sample cells, 50 m in diameter, were established for damage assessment in watershed study areas 1, 2, 4, and 5. Watershed study area 6 was not sampled since it contained no woody vegetation. Watershed study area 3 was also not sampled, but ground photographs were taken so that damage to the vegetation could be estimated. An assessment of damage was made by recording data on each tree within the sample

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* Raised numbers refer to similarly numbered items in "References" on pp. 81-82 at end of main text.

Figure B1. Vegetation (juniper) damaged by vehicle override during training maneuver in watershed study area 1

cell that contained any visible sign of stress as a result of training operations. The different types of damages noted were those resulting from vehicle contact and/or override (Figure B1) and the cutting of trees and branches (Figure B2) by training personnel. The survey of vegetation damage was made by inspecting each tree occurring within the 50-m-diam sample cell and recording the following information:

- a. Damage to branching structure (i.e. broken branches, etc.).
- b. Damage to stem.
- c. Damage to roots (i.e. plant uprooted).
- d. No damage.
- e. Stump only.
- f. Tree dying (as a result of training pressures).

Vegetation sample data were obtained at three locations in watershed 1 and at one location in watersheds 2, 4, and 5.

5. Table B1 presents the results of data obtained in the 50-m-diam sample cells. These data include the present (1975) tree population, the estimated tree population prior to military use (determined

Figure B2. Remains of juniper tree after being cut down by training personnel in watershed study area 1

by adding the number of one-seed juniper and pinyon pine stumps in 1000 m^2 to the 1975 tree density), the population of trees with some type of damage due to military training activities, and the percentage of the 1975 tree population with damage. The population figures (Table B1) for the various sample cells within the watershed areas are all based on a unit area of 1000 m^2 so that a direct comparison between sample data sets can be made (see paragraph 2, Appendix A).

6. The change in tree density (number/unit area) since the start of military training activities can be evaluated by comparing the measured 1975 tree population and the estimated tree population prior to military use (Table B1, columns 4 and 5, respectively). It is significant that watersheds 1, 2, and 4 contained considerable damage and watershed 5 had only 18 percent damage (Table B1, column 7). This low percentage of damage in watershed 5 is attributed to the fact that steep ground slopes, surface rock, and boulders occurring in the area are effective barriers to vehicles used in the training exercises.

7. The juniper, which is the most predominant species on the Fort

Carson Reservation, is known to be quite sensitive to damage resulting from contact with a moving armored tracked vehicle or heavy truck. Therefore, it was assumed that any major damage to the branches, stem, and/or root system would probably result in the eventual death of the tree. The pinyon pine is also considered to be quite sensitive to damage but to a lesser degree than the juniper. To illustrate the possible long-range effects of training operations on the woody vegetation, a plot of the number of standing trees in 1975 as compared with the number of trees existing prior to 1975 (determined from the sum of the stumps and standing trees) was prepared as shown in Figure B3. These data indicate that the woody vegetation population in 1975, as represented by the 1000-m^2 areas in watersheds 1, 2, and 4, could be approaching possible extinction, at least in the vicinity of these watersheds, unless future training exercises can be accomplished without further damage to the woody vegetation.

Preparation of Maps

8. To determine the extent of damage to the woody vegetation within the watershed study areas, a map was prepared for each watershed showing damage according to five factor mapping classes. The following tabulation presents these classes relating the percentage of the tree population with some type of physical (external) damage due to military training operations that were established for mapping watersheds 1, 2, 3, 4, and 5:

Damage Unit Symbol	Trees with Damage Due to Military Training, percent
1	0-10
2	>10-25
3	>25-50
4	>50-75
5	>75

Then, the maps were constructed using the vegetation data collected during the field surveys (see paragraphs 4-7), standard air-photo interpretation techniques, and the interpreter's personal knowledge of the mapped watershed areas.

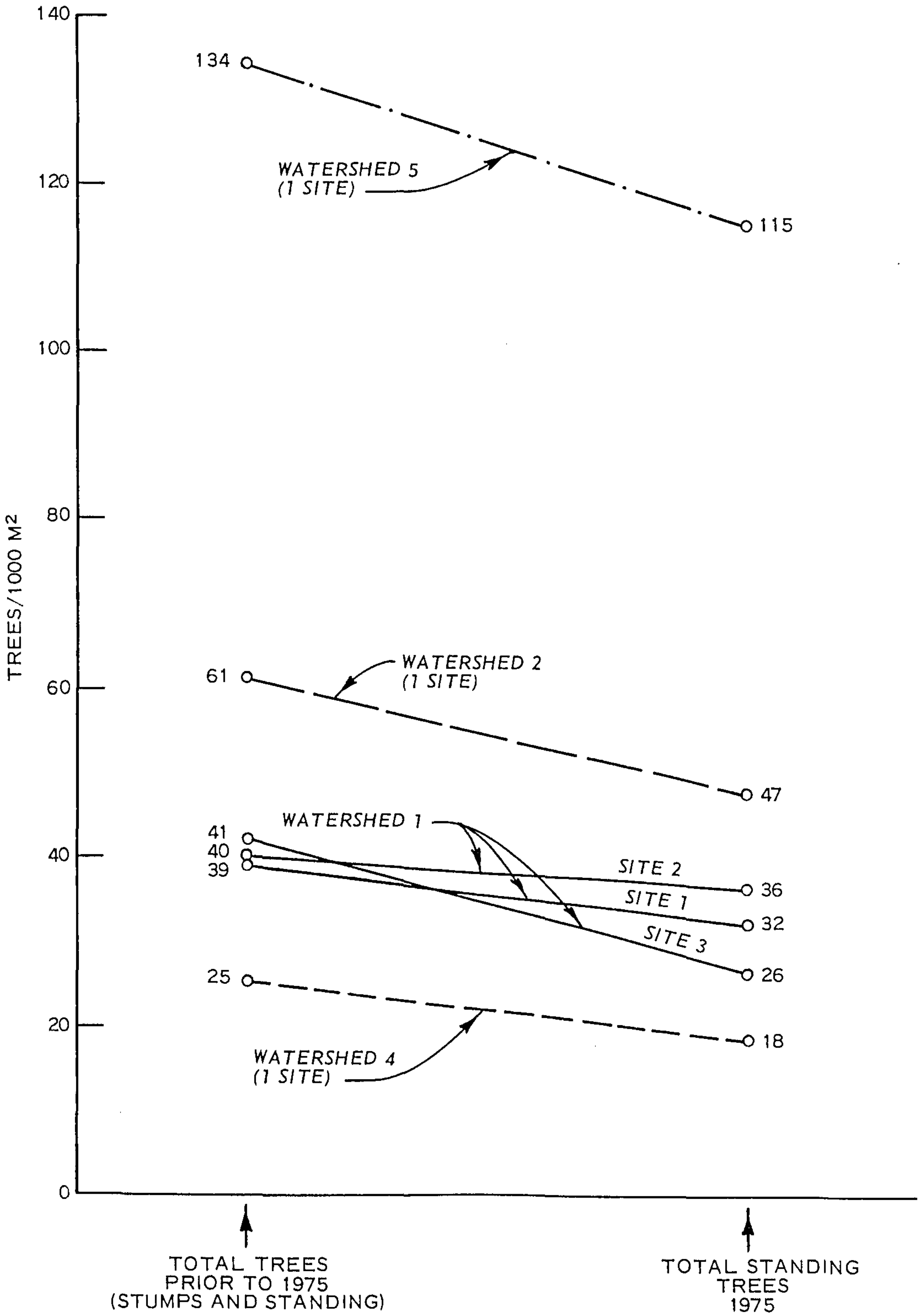

Figure B3. Decline in tree populations in watersheds 1, 2, 4, and 5 (watersheds 3 and 6 not sampled)

9. The air-photo interpretation was accomplished through a series of steps, the first being to obtain the necessary overlapping photographs of the watershed study areas. This was followed by a stereoscopic examination of the overlapping prints, whereby the various photographic tone and texture patterns, as well as their correlation to terrain features, were identified. For the photographic patterns covering areas where sample data had been collected (e.g. data on vehicle damage to trees), the class ranges data for that particular site were used. In those patterns without ground truth data, the class ranges for each damage class were assigned by extrapolation from the points of known ground truth data, through associations of similar patterns, and through the interpreter's knowledge of the area. After all the identified patterns had been outlined on the air photos, a map unit symbol representing a factor class was assigned to each respective pattern. In effect, the result was a map portraying five factor classes that characterized the damage to the tree population within the watershed areas. Figures B4-B8 are the resulting maps depicting the areal damage to woody vegetation.

10. Within most of the woody areas that had undergone heavy military use, the grass cover was almost completely destroyed, as is evident in Figure B9, and the soil surface had been scarified (and eroded) to a point that it would be most difficult to reestablish vegetation ground cover without bringing in some additional surface soil material. The soil surface in such areas had also undergone some degree of compaction as a result of the vehicle traffic. This is detrimental to vegetation growth since the infiltration rate for precipitation is reduced and resistance to root penetration is increased. Such disturbances in the fragile ecosystem that exists at Fort Carson cause an immediate reduction in biomass productivity.

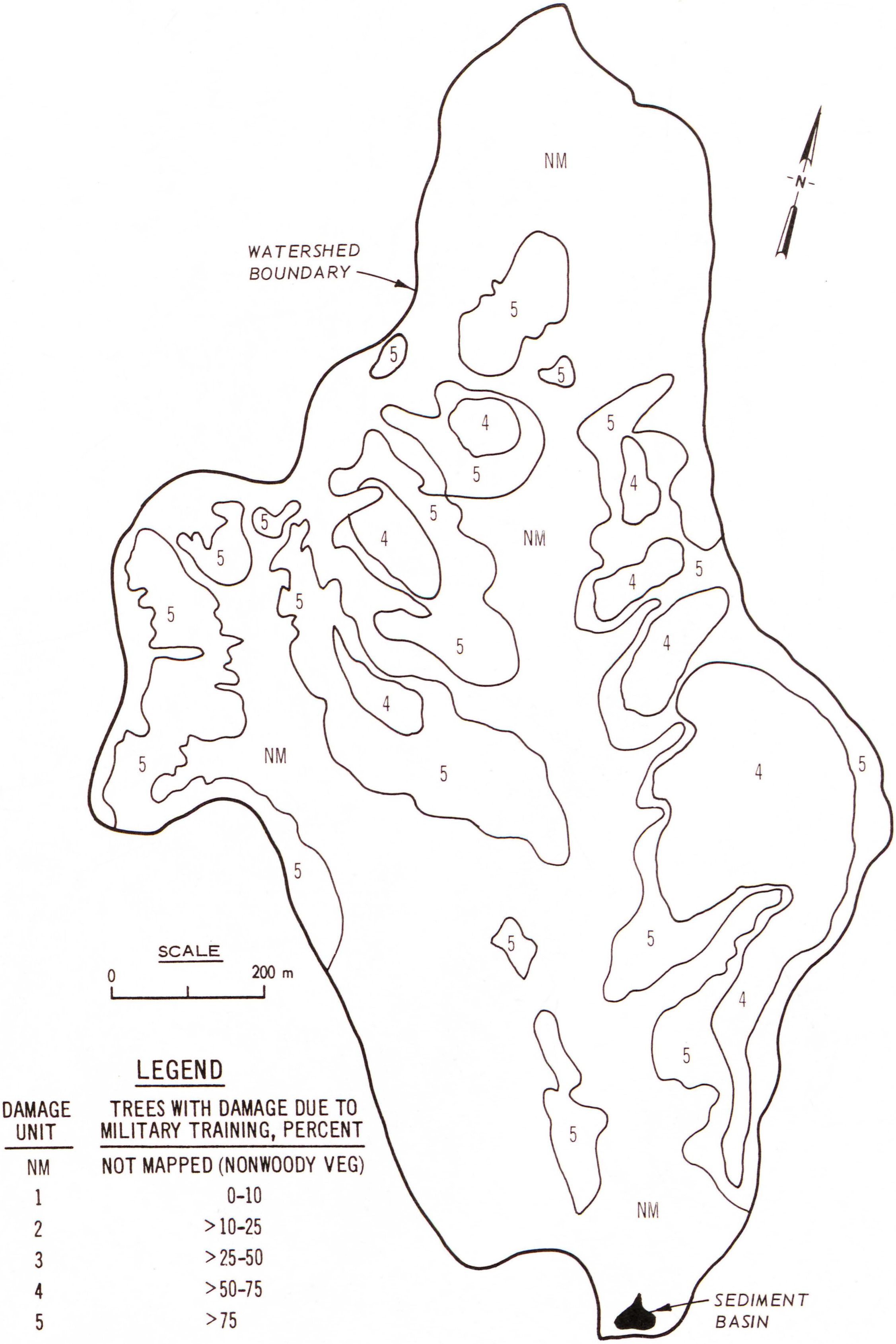

Figure B4. Areal damage to woodland vegetation in watershed 1

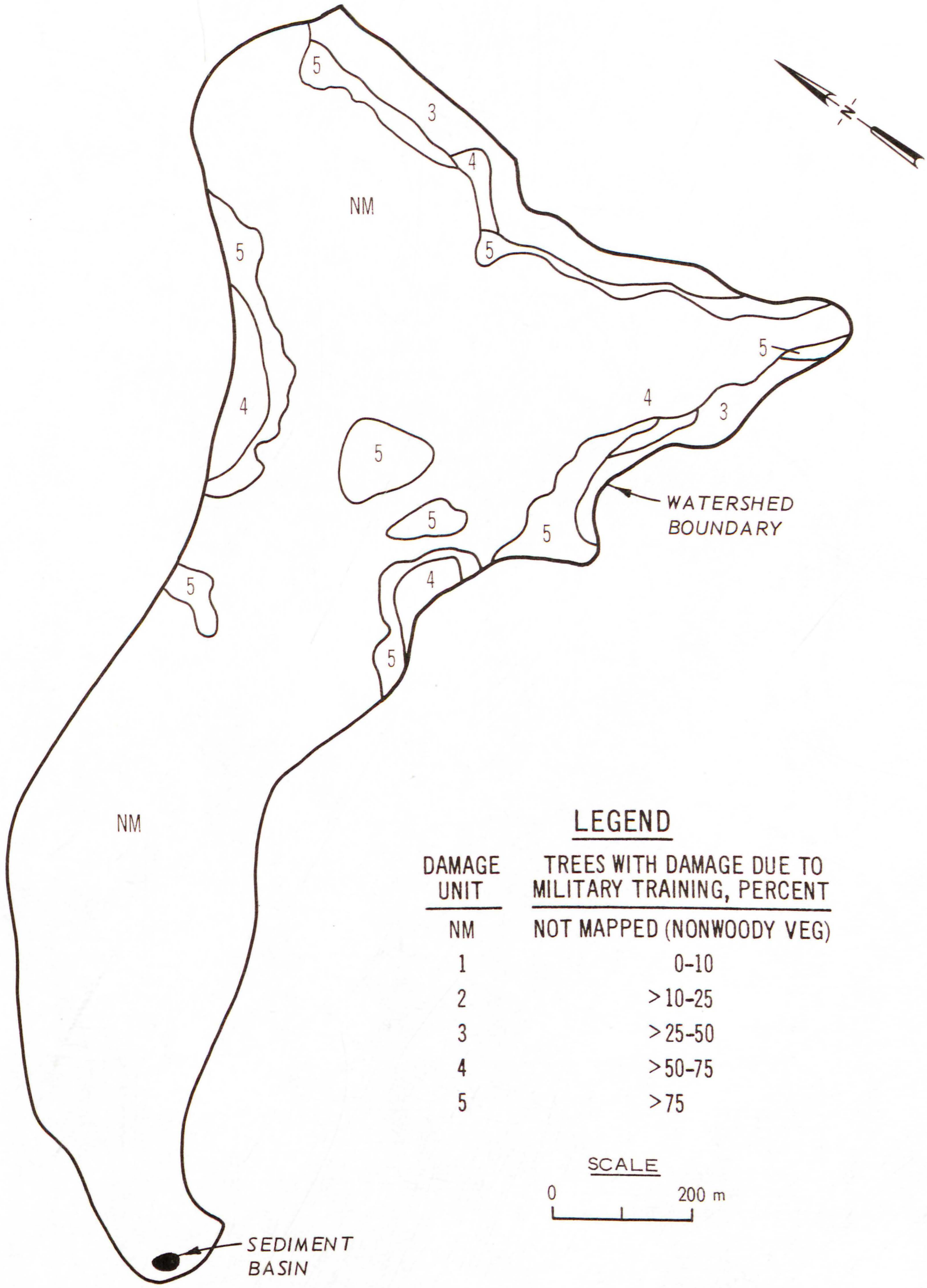

Figure B5. Areal damage to woodland vegetation in watershed study area 2

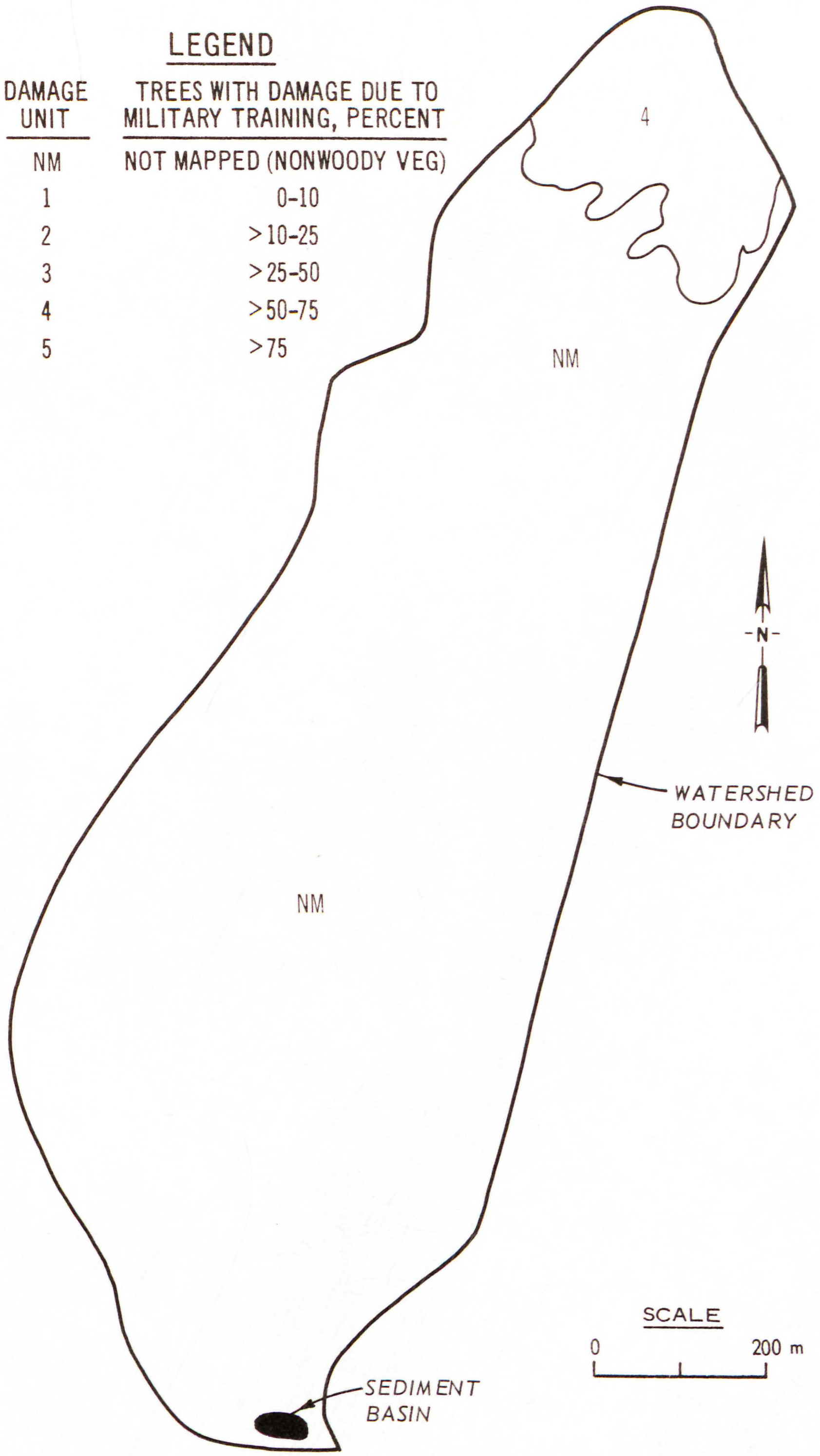

Figure B6. Areal damage to woodland vegetation in watershed study area 3

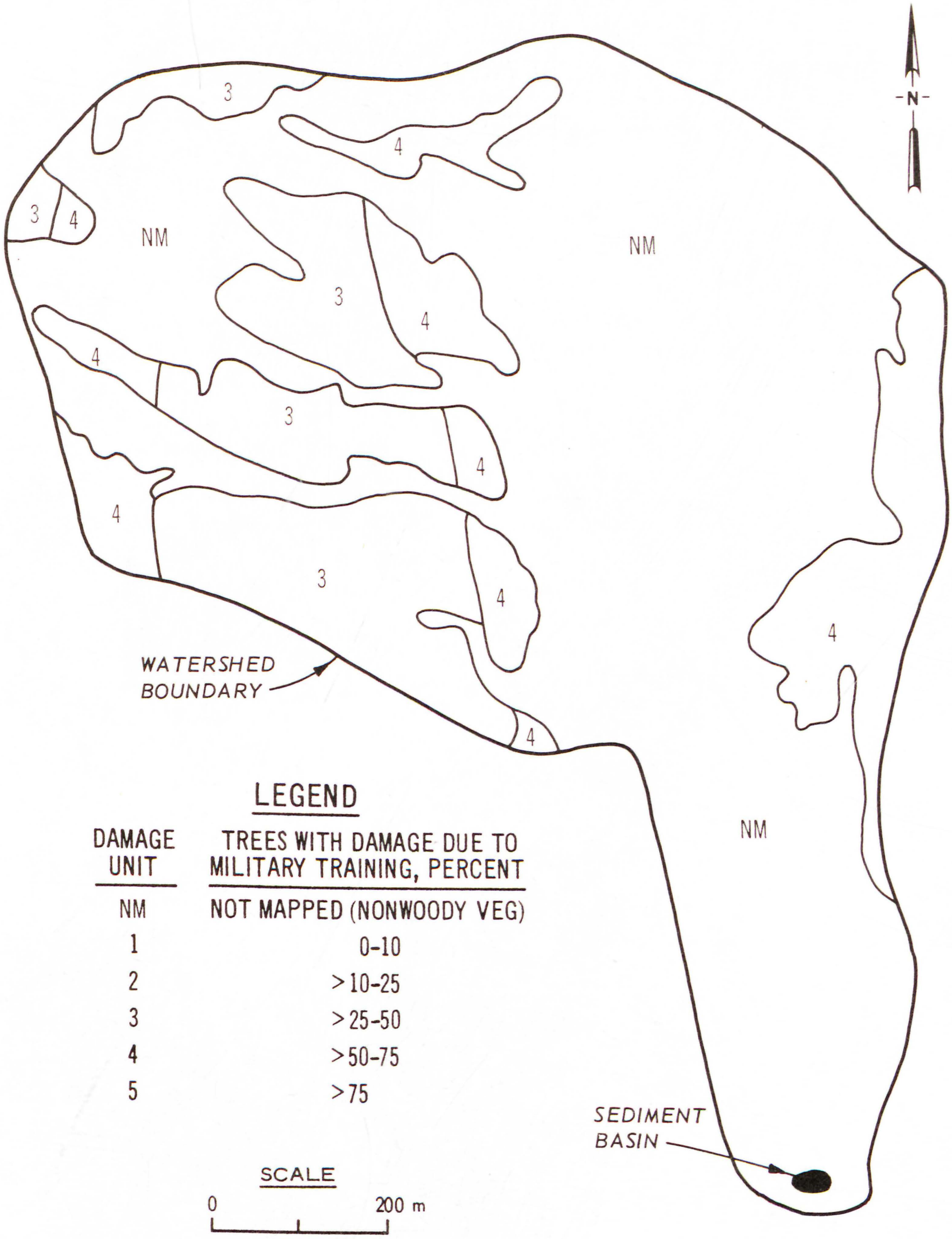

Figure B7. Areal damage to woodland vegetation in watershed study area 4

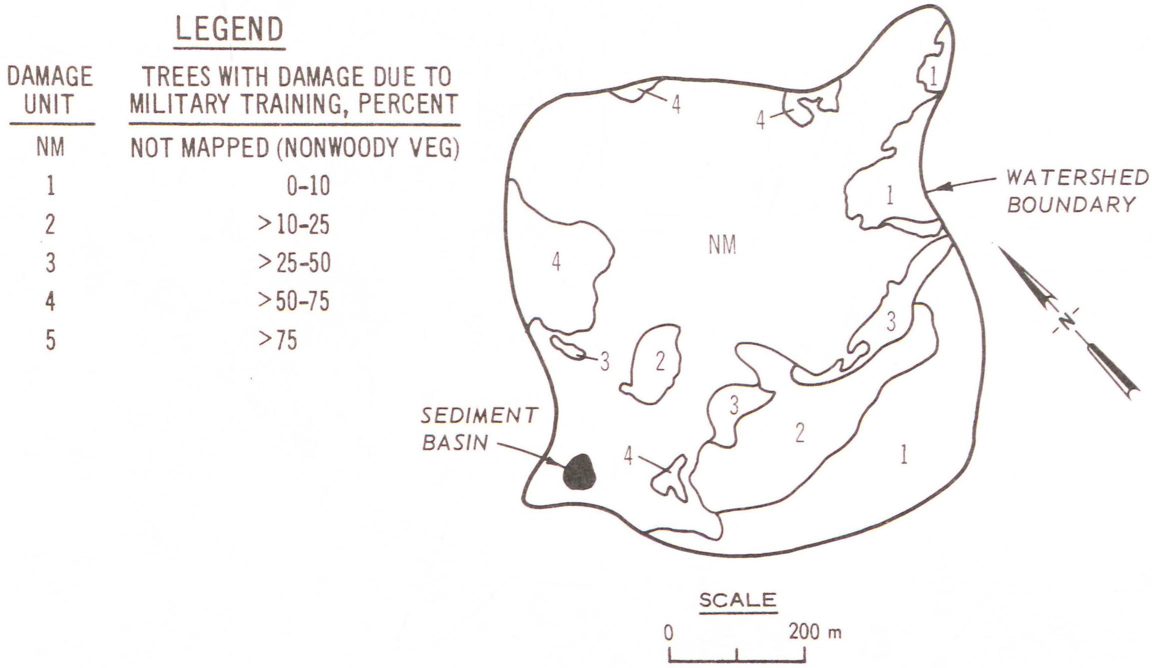

Figure B8. Areal damage to woodland vegetation in watershed study area 5

Figure B9. Loss of grass cover beneath stands of juniper and pinyon pine

Table B1

Tree Density* of Sample Cells in Watersheds, Fort Carson, Colorado

Watershed No. (1)	Sample Cell No. (2)	Sample Cell Location in Watershed (Military Grid Coordinates) (3)	Measured 1975 Tree Population Trees/1000 m^2 (4)	Estimated Tree Population Prior to Military Use,** Trees/1000 m^2 (5)	Damaged Tree Population Trees/1000 m^2 (6)	Percent of 1975 Tree Population with Damage (7)
1	1	18405536	32	39	23	71.9
1	2	18545500	36	40	22	61.1
1	3	18455468	26	41	22	84.6
2	1	05885773	47	61	37	78.7
4	1	22175591	18	25	11	61.1
5	1	09086832	115	134	21	18.2

Note: No sample cells taken in watershed study areas 3 and 6.

* These figures are for one-seed juniper (Juniperus monosperma) and pinyon pine (pinus edulis), the principal tree species found on Fort Carson.

** Determined by adding the number of one-seed juniper and pinyon stumps in 1000 m^2 to the 1975 tree density.

APPENDIX C: PROCEDURE FOR CALCULATING TOPOGRAPHIC SLOPE GRADIENTS

1. An automated procedure for calculating slope data and constructing slope maps has been developed by the WES. This procedure, which was used to calculate slope data for the six watershed study areas, consists of three sequential parts: (a) digitization of contour data, (b) automated calculation of elevation grid arrays, and (c) use of the computer program SLOPEMAP[7] to compute a slope value for each grid point location. Each of these steps is described briefly in the following paragraphs.

Digitization of Contour Data

2. The basic source of data needed to generate digitized topographic data is a contour map such as shown in Figure C1. To transform the contour data into proper form for determining the slope gradient, the contour lines are first digitized using a line-follower device (Figure C2), which consists of a cursor with an actuating switch. The output from the cursor goes directly to a preprogrammed magnetic tape unit. As the operator follows the contour line, keeping the crosshairs of the cursor on the contour line at all times (Figure C3), the switch on the cursor is activated at a sufficient number of places along the contour to define the sinuosity. Each time this input switch is triggered, x and y values are recorded; the elevation (z value) is entered through an input keyboard to the magnetic tape deck. In this manner, the contour lines are digitized and stored on the magnetic tape in the form of xyz coordinates. As for any coordinate system, there must be a fixed reference. In the case of topographic maps, this reference is the geographic coordinate of the upper left corner of a map or area being digitized.

Construction of Elevation Grid Arrays

3. The magnetic tape containing the digitized contour data is

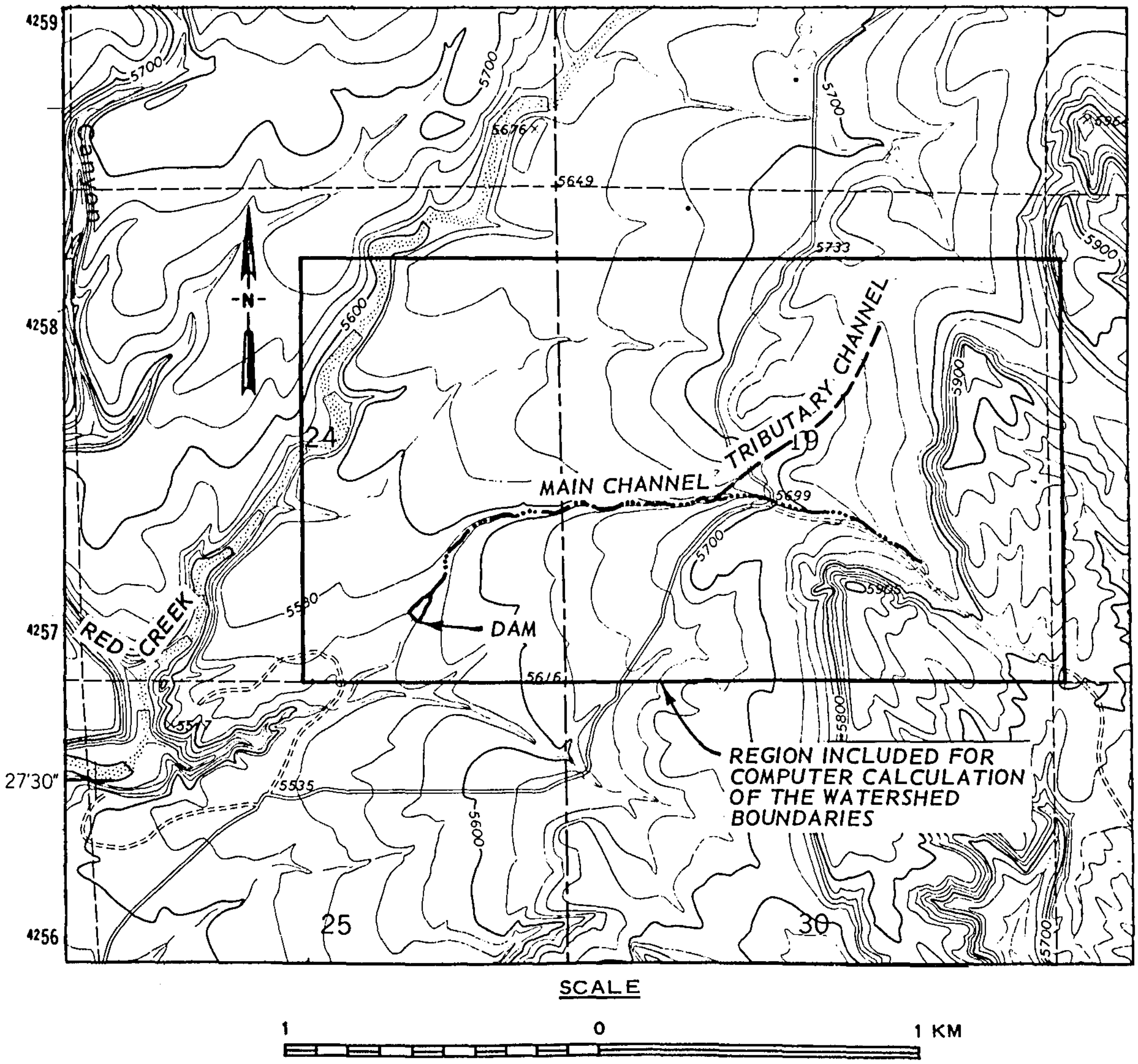

Figure C1. U. S. Geological Survey 1:24,000-scale topographic map showing boundary of area used in digitizing contours for watershed study area 2

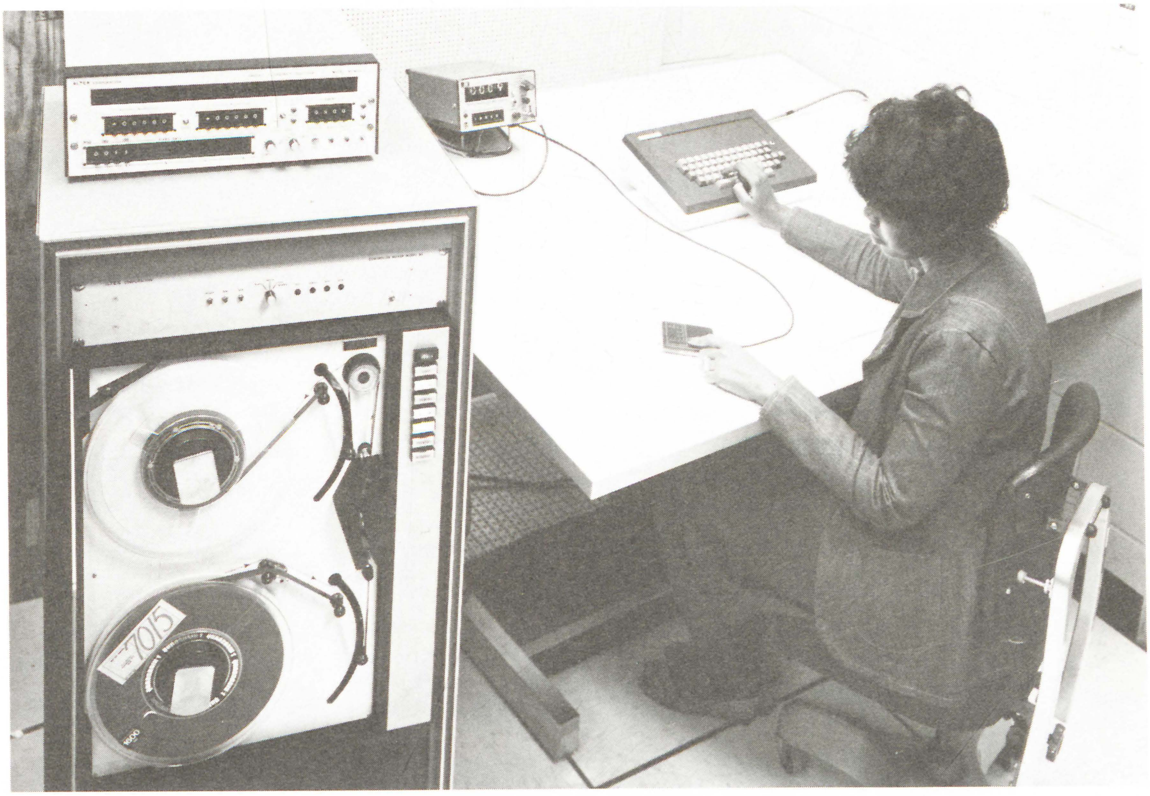

Figure C2. Technician transforming contour lines from topographic map into digitized data

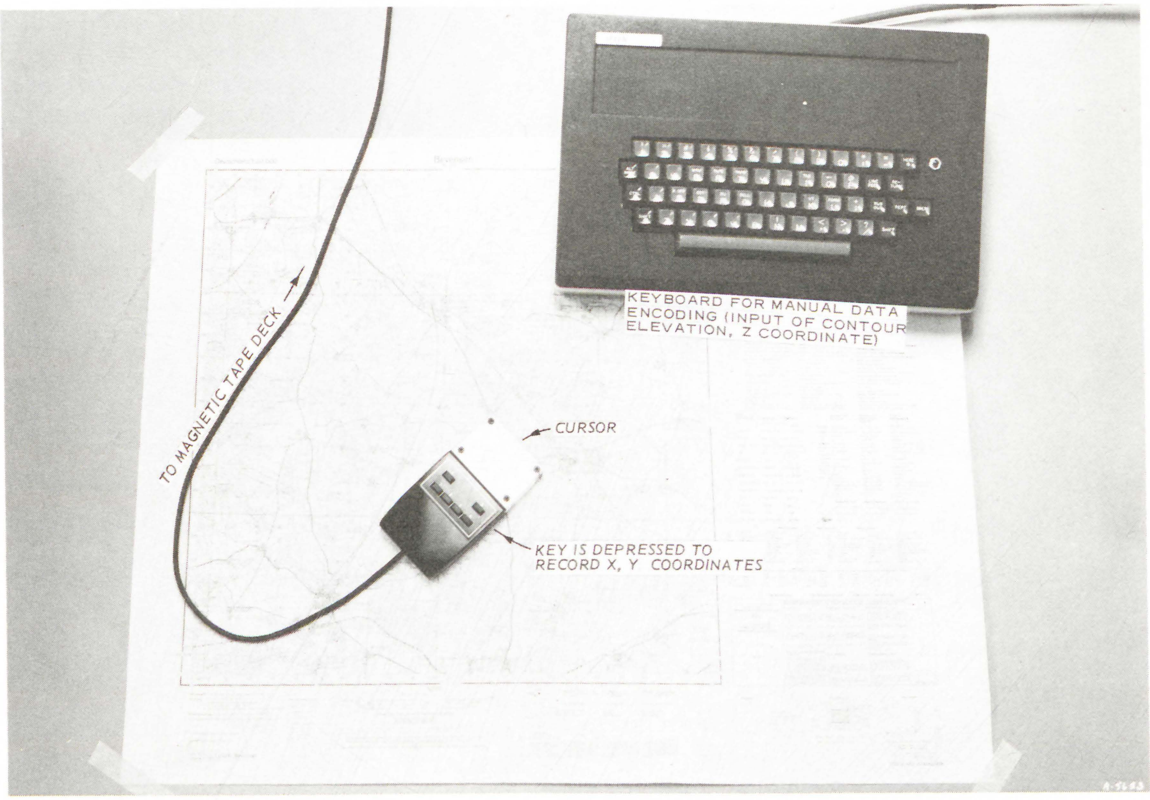

Figure C3. Illustration of equipment on digitizer table used as input to a computer program that generates an elevation grid array. In the grid array, the topographic surface is represented by a matrix (rows and columns), each element of which is the elevation of the topographic surface at that matrix (or grid) position (Figure C4). Also, in this figure, i indicates the number of rows, and j the number of columns of elevation data within the site.

$$
\begin{array}{cccccc}
Z_{1,1} & Z_{1,2} & Z_{1,3} & Z_{1,4} & \cdots & Z_{1,j} \\
Z_{2,1} & Z_{2,2} & Z_{2,3} & Z_{2,4} & \cdots & Z_{2,j} \\
Z_{3,1} & Z_{3,2} & Z_{3,3} & Z_{3,4} & \cdots & Z_{3,j} \\
Z_{4,1} & Z_{4,2} & Z_{4,3} & Z_{4,4} & \cdots & Z_{4,j} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
Z_{i,1} & Z_{i,2} & Z_{i,3} & Z_{i,4} & \cdots & Z_{i,j}
\end{array}
$$

Figure C4. Elevation grid array representing the topographic surface

4. To calculate the elevation values for each designated grid position within the array, an interpolation procedure was used. The procedure consists of first sorting the digitized data by distance and quadrant for each specified grid point in the array. The nearest neighbor within each of the four quadrants is then used in the following distance-weighed calculation to yield the elevation at the grid position:

$$
Z_{i,j} = \frac{\sum_{k=1}^{4} \frac{Z_k}{R_k^2}}{\sum_{k=1}^{4} \frac{1}{R_k^2}} \qquad \text{(C1)}
$$

where

$Z_{i,j}$ = elevation at the $(i,j)^{th}$ grid position

Z_k = elevations of the four different-quadrant nearest neighbors to the grid position (i,j)

R_k^2 = squared distance from each k^{th} data point to the $(i,j)^{th}$ grid position

5. The physical interpretation of the procedure is that in calculating the elevation at any given position, the data closest to that position is weighed most heavily in the calculation. Most interpolative procedures of this type in common use produce solutions (grid arrays) that are data-distribution dependent. That is, the grid array values depend not only on the values of the initial data points but also on the relative density of data points in one area of the site relative to that in another. The WES procedure successfully guards against this effect by selecting points to be used in the calculation from each quadrant about the point-of-interest.

Using SLOPEMAP to Compute Slope-Gradient

6. The third step in the procedure is to use the elevation grid array and the WES SLOPEMAP computer program[7] to determine the slope-gradient magnitude (and direction if desired) for each respective grid point. The procedure employs a quadratic polynomial, which uses the elevation values of the grid point in question and its nearest and next nearest neighbors. The quadratic used by the WES reduces to two closed-form equations, which provide for rapid calculation of the maximum slope from two fitted three-dimensional surfaces. The slope value assigned to the grid point is calculated from the maximum partial derivatives of $f(x,y)$ derived from both surfaces. The fitting procedure for each surface is accomplished by a second-order Taylor series expansion.

APPENDIX D: PROCEDURE FOR DETERMINING SEDIMENT BASIN VOLUME

1. Sediment basins have been constructed on a number of watercourses (e.g. watersheds 1, 2, and 5) and in other watersheds having no incised drainage networks (e.g. watersheds 2, 4, and 6) at Fort Carson. Although the majority of these impoundments were originally built for the purpose of intercepting water for livestock when the ownership of these areas was in private hands, they now are used for various purposes including erosion control, wildlife water supply, fire suppression, and recreation.

2. In order to determine the usefulness or effectiveness of these basins at any given time, it is necessary to be able to compute their volumes or capacities. Basin volume (V_c) is defined as that volume contained between the sediment surface and a plane projected horizontally across the spillway at the elevation of the spillway crest. Data necessary to compute V_c are collected by conventional survey methods. Using Automatic Data Processing (ADP) techniques, these data can be transformed to Cartesian coordinates and then converted to an elevation grid array.[7] From the gridded data, a calculation of V_c can be made. If desired, the original design volume of a basin (V_d) can also be computed with the use of sediment accumulation thickness data collected in conjunction with the field survey. A description of the field survey procedures and the software for coordinate transformation, gridding, and subsequent computation of volume are discussed below.

Field Survey Procedure

3. If possible, surveys should be conducted when the basin is empty and the surface is dry; with a water or snow cover, it is often difficult to determine the true surface, and the disturbance of the sediment is almost inevitable. A theodolite is recommended for use during the survey because of the accuracy it affords and the ease with which angular measurements can be read and documented. Although a number of options are normally available, the most commonly used

procedure for collecting basin topographic data includes the following steps:

- a. Selection of the origin of the coordinate system.
- b. Establishment of a baseline.
- c. Definition of the spillway parameters.
- d. Selection of a field grid interval.
- e. Use of vertical control.
- f. Location of magnetic north.

Furthermore, the field procedure should include accurate documentation of the numerical field data and any pertinent notes on a form that conforms to the specifications required for keypunching and processing by ADP techniques. Each of the steps in the field survey procedure and a form suitable for recording data are discussed below.

Selection of the coordinate system origin

4. Any point can be used as the origin of the coordinate system; however, this point should be selected on the basis of its visibility from other points in the basin. It is designated as turning point (TP)1 and sta 0+00 of cross section 1 (Figure D1). The exact location of TP1 should be marked with a fine-point punch if an iron rod is used, or a survey tack if a wooden stake is employed. Two temporary bench marks (TBM's) should be established near TP1 to provide vertical and horizontal control, in the event TP1 is lost and must be reestablished. These TBM's should be located at permanent locations, such as trees, massive rock formations, and hydraulic structures.

Establishment of a baseline

5. The purpose of a baseline is to define the orientation of the field grid and, therefore, the direction of the basin cross section. This line should be parallel to a major dimension of the sediment basin. At Fort Carson, the baseline was set along the crest of the dam. This location offers a good view of the basin surface, the spillway, and any other points that were needed to define the basin (Figure D1).

Definition of spillway parameters

6. The spillway must be surveyed to establish the elevation that

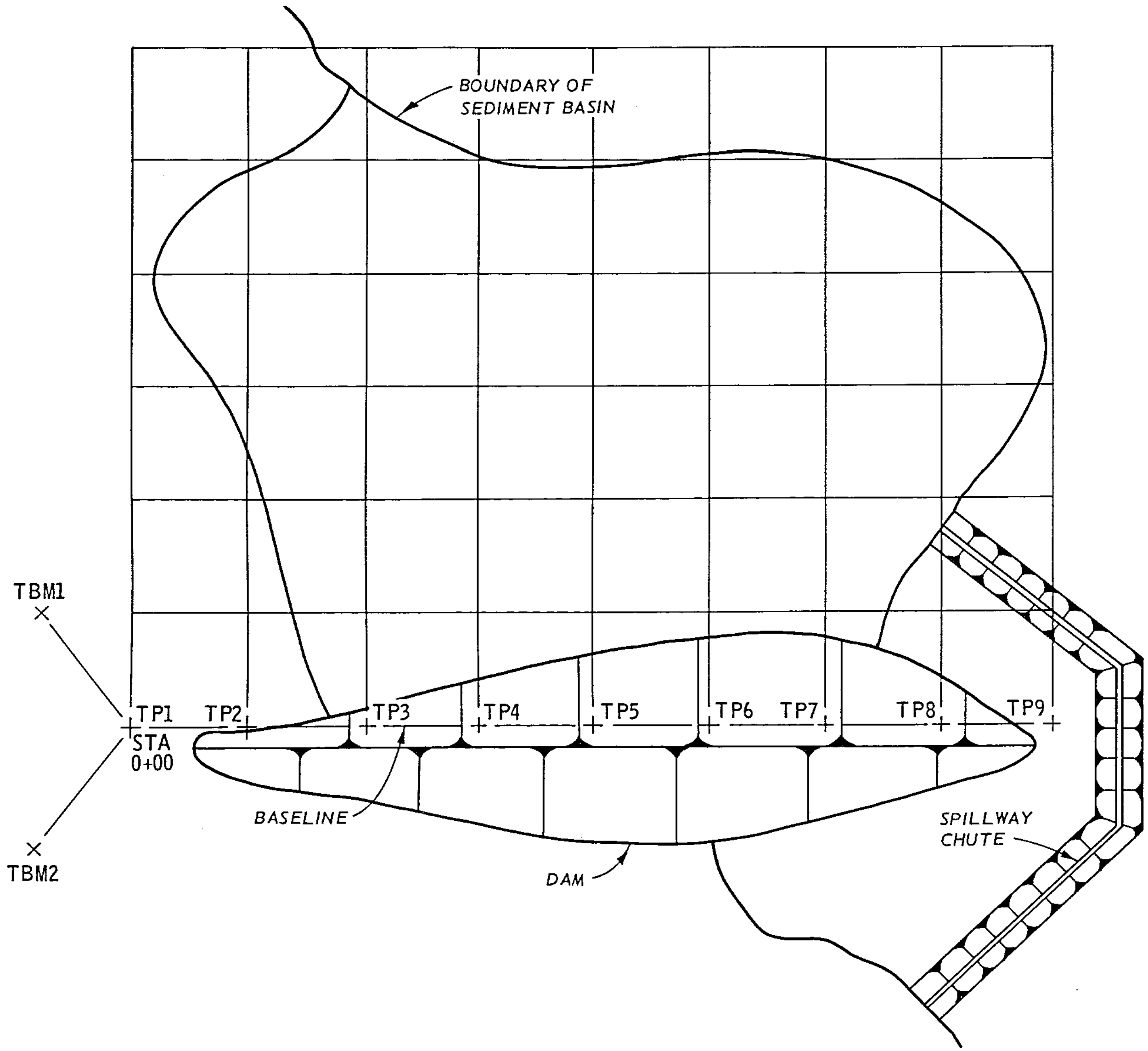

Figure D1. Layout of survey for basin volume determination will be used to define the boundary of the sediment basin (Figure D1). Additional spillway cross sections and a thalweg profile should also be taken if rigorous hydraulic and sediment regime studies are required.

Selection of cross-
section or field grid interval

7. The size and complexity of a basin, the degree of accuracy desired, the time and funds available, and prior survey controls collectively determine the cross-section interval. For example, if it is decided that a 10-m field grid interval should be used, then a series of TP's, 10 m apart, should be established along the baseline. Each TP is assigned a number and given a station number of 0+00. The TP is established with an iron rod (center-punched) or a survey stake (with tack). At each TP, a cross section is run perpendicular to the baseline. Direct rod readings are taken, and distances are measured at least every 10 m until an elevation greater than that of the spillway crest has been reached. If a direct rod reading cannot be taken, a vertical angle reading may be used. If needed, additional contour points can be taken at intervals less than 10 m along the cross section to define topographic features.

WES Form 1937

8. The WES has devised a data form, WES Form 1937 (Figure D2) for collecting and recording field survey data. This form has been extensively used for recording those data necessary to describe the topographic configuration of a basin. Data collected with this form can be punched on computer cards and handled by ADP techniques.

9. A brief description of WES Form 1937 follows in which the number in parentheses refer to column numbers on the data form:

a. Site and data identification (1-17). Alphanumeric information used to identify a site and a particular set of data.[18]

b. Height of instrument (18-20). Height in centimetres of the vertical distance from the horizontal axis of the instrument to the top of the TP beneath the instrument.

c. Instrument TP (21-24). The TP number assigned to the instrument location.

d. Backsight (25-28). The TP number assigned to the already

TOPOGRAPHIC DATA

MAP REF: ____________ MILITARY GRID: ____________

PAGE 1 OF 1 DATE: ____________

CREW:
ALLEN
PARKS
WEATHERSBY

REMARKS: TP1 = StA 0+00, XSECT1
BASE LINE = X AXIS ; 1000-CM GRID

COUNTRY	SITE NUMBER	SAMPLE NUMBER	FACTOR FAMILY	DATA FORM REFERENCE	DATA GROUP REFERENCE	LINE NUMBER	INSTRUMENT A H.I. (CM)	INSTRUMENT A AT T.P.	INSTRUMENT A B.S. T.P.	INSTRUMENT A F.S. T.P.	ROD READING (CM)	HORIZ DISTANCE (CM)	HORIZ ANGLE DEG	HORIZ ANGLE MIN	HORIZ ANGLE SEC	VERT ANGLE DEG	VERT ANGLE MIN	VERT ANGLE SEC	REMARKS	COM'T	REP'T
141	0001	01	3	11	02	001	150	0001	0002	0002	0149	01000	360	00	00	090	00	00	STA 0+00, XSECT2, MAG NØR		
				11	02	002				0003	0150	02000							STA 0+00, XSECT3		
				11	02	003				0004	0150	03000							STA 0+00, XSECT4		
				11	02	004				0005	0151	04000							STA 0+00, XSECT5		
				11	02	005				0006	0151	05000							STA 0+00, XSECT6		
				11	02	006				0007	0300	01500	180	00	00				STA 0+00, SPILLWAY XSECT		
				11	02	007				0008	0325	01550							SPILLWAY XSECT		
				11	02	008				0009	0350	01600							TØE=CREST OF SPILLWAY		
				11	02	009				0010	0325	01650							SPILLWAY XSECT		
				11	02	010				0011	0300	01700							STA 0+200 SPILLWAY XSECT		
				11	02	011				0012	0150	07500	090	00	00				TBM 1, NAIL IN PØST		
				11	02	012				0013	0150	08500	180	00	00				TBM 2, NØTCH ØN RØCK FM		
				11	02																
				11	02																
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WES FORM NO. 1937

Figure D2. Sample basin survey data on WES Form 1937 established turning point being used to reference the horizontal angle of 360°00'00". The first number recorded on the data form in this field is always 0002.

e. Foresight (29-32). The number assigned to the survey point being located. The first number in this field is always 0002, which establishes the positive X axis. All other foresights should follow 0002 in increasing numerical sequence on the data form.

f. Rod reading (33-36). A metric stadia rod is used to locate all foresights. It is held vertically at the point to be surveyed without disturbing the ground surface. The rod is then read, and the resulting value recorded.

g. Horizontal distance (37-41). The distance in centimetres from the instrument TP to the foresight.

h. Horizontal angle (deg (42-44), min (45-46), sec (47-48)). The clockwise angle between the backsight and the foresight. In the basin survey, foresight readings along the predesignated cross sections should be at right angles to the baseline with the exception of scattered shots necessary to describe a topographic feature.

i. Vertical angle (deg (49-51), min (52-53), sec (54-55)). The clockwise angle between the zenith and the foresight. A vertical angle of 90°00'00" is a horizontal reading and should always be used except when unavoidable (e.g., when vegetation blocks the view or when the topographic position of the foresight relative to that of the instrument TP is such that a horizontal reading is impossible due to the length of the rod).

j. Remarks (56-78). Any information pertinent to the foresight.

k. Control columns (79-80). Columns reserved for any future modifications to the software designed to read the field topographic data.

10. In the simplified example of Figure D3, the direction of magnetic north is identical with the positive X axis. The baseline, therefore, runs north-south, and TP 1-6 (Figure D2) are at sta 0+00 of cross-sections 1-6, each being 1000 cm apart along this baseline. From each of these six TP's, a cross section, consisting of contour points at least every 1000 cm apart, will be taken. Supplementary topographic data will be collected as needed. The cross sections will be run whatever distances are required to encounter elevations exceeding that of the spillway crest. Two TBM's have also been established for vertical

control. These data have been entered on Form 1937 (Figure D2) as an example of data acquired in the field and are used for discussion purposes in the remainder of this appendix.

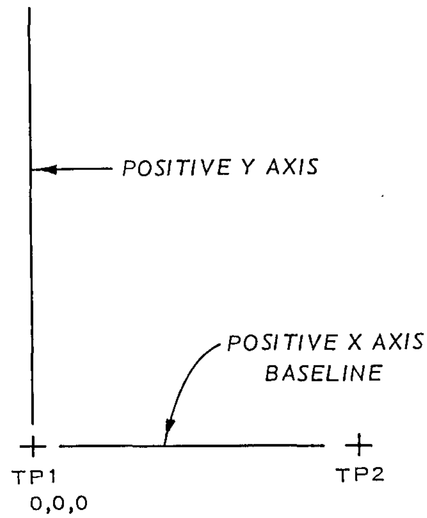

Figure D3. Layout of coordinate system for the basin survey

Cartesian Coordinate Transformation

11. Data collected by the field survey and recorded on WES Form 1937 can be punched on computer cards and processed by a Honeywell G-635 computer, Software Release 2H, with batch program CONXYZ written in FORTRAN IV. This program transforms the angles and distances collected in the field to Cartesian (XYZ) coordinates with TP1 being the origin of the coordinate system and the positive X axis coinciding with the line from TP1 to TP2. The positive Y axis is then set by the program 270 deg clockwise to the positive X axis. The baseline coincides with the X axis, and the XSECT's are parallel to the Y axis. Figure D3 shows the layout of the coordinate system for the field survey; Figure D4 is a computer printout of transformed Cartesian coordinates with the data of Figure D2 as input.

Calculation of an Elevation Grid Array

12. An elevation grid array can be constructed from the punched card output of CONXYZ. These data are loaded in a data file and

TOPOGRAPHIC DATA
SITE NUMBER

T.P.	X	Y	Z	
1	0.	0.	0.	
2	1000.00	0.	1.00	STA 0&00,XSECT2,MAG NOR
3	2000.00	0.01	0.00	STA 0&00,XSECT3
4	3000.00	0.01	0.00	STA 0&00,XSECT4
5	4000.00	0.01	-1.00	STA 0&00,XSECT5
6	5000.00	0.01	-1.00	STA 0&00,XSECT6
7	-1500.00	-0.00	-150.00	STA 0&00,SPILLWAY XSECT
8	-1550.00	-0.00	-175.00	SPILLWAY XSECT
9	-1600.00	-0.00	-200.00	TOE#CREST OF SPILLWAY
10	-1650.00	-0.00	-175.00	SPILLWAY XSECT
11	-1700.00	-0.00	-150.00	STA 0&200SPILLWAY XSECT
12	-0.01	7500.00	0.00	TBM1, NAIL IN POST
13	-8500.00	-0.01	0.00	TBM2 , NOTCH ON ROCK FM

Figure D4. Cartesian coordinate output of computer program CONXYZ with survey data of Figure D2 as input processed in three steps with a Honeywell G-635 computer, Software Release 2H. Timesharing programs TRANS and CONTEDIT and CARDIN program NGRID3 are used to read, sort, and translate the topographic data for a basin to produce the elevation grid array. Each step is discussed briefly.

TRANS

13. Program TRANS takes the Cartesian data that have been loaded into a file, sorts them into a form comparable to that of digitized topographic data, and translates the X and Y axis so that the lowest X and Y values of the input file are set as 0. All other X and Y values then become positive. The Z axis is not adjusted. The program writes these sorted and translated data onto an output file.

CONTEDIT

14. Program CONTEDIT takes the output of TRANS and prepares these data for input to NGRID3. CONTEDIT produces an output file that allows the user to write seven lines of descriptive information. On the eighth line of the file the user lists the variables necessary to: (a) convert the set of input data to metres (e.g., 0.01 if the input data are in centimetres), (b) assign the number of grid positions in both the X and Y directions, and (c) set the spacing between grid points. The remainder of the output consists of the translated X and Y coordinates and the Z coordinates.

NGRID3

15. Program NGRID3 reads the output file of CONTEDIT and converts a random distribution scalar field to an elevation grid array.[19] The elevation at each grid position is interpolated using a $1/d^2$ four-quadrant fit. The contour elevation data are searched for the nearest neighbor in each of the four quadrants about the grid position. The equation for calculating the elevations and distances from the grid position to those four nearest neighbors is expressed as

$$Z_s = \frac{\sum_{m=1}^{4} \frac{Z_m}{d_m^2}}{\sum_{m=1}^{4} \frac{1}{d_m^2}} \qquad \text{(D1)}$$

where

Z_s = elevation at the grid position

Z_m = elevation of the nearest neighbor in the m^{th} quadrant

d_m = distance of the nearest neighbor in the m^{th} quadrant from the grid position

The output of NGRID3 is a magnetic tape containing the descriptive information of the output file of CONTEDIT and the elevation grid array produced by the program.

Computation of Sediment Basin Volume

16. To calculate the sediment basin volume (V_c) between the spillway crest plane and the basin surface, the elevation grid array magnetic tape produced by NGRID3 is used. A volume is determined for each grid square, with a Honeywell G-635 computer, Software Release 2H and CARDIN program VOLUMN written in FORTRAN IV. Then V_c is computed by summing the individual volumes for all grid squares where the elevation of the spillway crest plane exceeds that of the basin surface. The equation for the calculation of V_c is

$$V_c = D^2 \sum_{s=1}^{s=t} \left(Z_{sp} - Z_s \text{ , for } Z_{sp} > Z_s \right) \qquad \text{(D2)}$$

where

D = grid spacing

Z_{sp} = elevation of the spillway crest plane

Z_s = elevation of the basin surface at the s^{th} location; t is the number of elevations computed with Equation D1

VOLUMN allows the user to select a series of spillway elevations at whatever interval he should choose.

Computation of Original Design Volume

17. If it is necessary to compute the original design volume (V_d)

of a basin, sediment borings must be taken and a determination of the accumulated sediment thickness made at the time of the basin survey. Depth of sediment is then added to the rod reading obtained on a level vertical angle reading from the instrument TP. Where no sediment is found, the vertical rod reading for the basin surface remains unchanged. Data processing is identical to that described in paragraphs 11-16. The equation for computation of V_d is

$$V_d = D^2 \sum_{s=1}^{s=t} \left(\left(Z_{sp} - Z_s \right) + d_s \text{ , for } Z_{sp} > Z_s \right) \tag{D3}$$

where d_s represents accumulated sediment thickness at the s^{th} location.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Keown, Malcolm Price

Environmental baseline descriptions for use in the management of Fort Carson natural resources; Report 4: Analysis and assessment of soil erosion in selected watersheds / by Malcolm P. Keown, Harold W. West. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

82, [38] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; M-77-4, Report 4)

Prepared for Directorate of Facilities and Engineering, Fort Carson, Colorado, and Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project 4A162121A896, Task 01, Work Unit 006.

References: p. 81-82.

1. Environmental impact. 2. Environmental management. 3. Fort Carson, Colo. 4. Military installations. 5. Natural resources. 6. Soil erosion. 7. Watersheds. I. West, Harold W., joint author. II. Fort Carson, Colo. Directorate of Facilities and Engineering. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; M-77-4, Report 4.

TA7.W34 no.M-77-4 Report 4