AN ABSTRACT OF THE THESIS OF

GERALD DENNIS KELLY for the MASTER OF SCIENCE
(Name) (Degree)

Forest Management
in (Forest Hydrology) presented on May 31, 1967
(Major) (Date)

Title: A COMPARISON OF SEVERAL METHODS FOR EROSION MEASUREMENT ON CUT AND FILL SLOPES OF A LOGGING ROAD IN THE OREGON COAST RANGE

Abstract approved: Signature redacted for privacy.
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The catchment-filter, soil erosion gage, macroprofile, and spike and washer techniques for erosion measurement were compared on six plots along a newly constructed logging road in the Oregon Coast Range during the winter of 1965-66. Three plots were located on a cut slope; three plots were on a fill slope. Erosion occurred uniformly over each plot. Any one technique could not be used to predict the results of any other. The catchment-filter technique was accepted as a standard. The data indicate that the soil erosion gage and macroprofile techniques may have application in studying the erosion process, but should not be used to measure amounts of erosion. In this study the spike and washer technique recorded deposition while the other techniques indicated erosion. The techniques were not affected by differences between the two slopes.

The steep cut slope eroded three times as much as the gentler fill slope during the study period. From limited data frost appeared to have an influence on erosion from steep cut slopes. No significant relation was found between rainfall and erosion. The first fall storm caused the greatest rate of erosion from the fill slope.

The erosion process is discussed briefly. The historic development and current status of erodibility indices are also presented.

A Comparison of Several Methods for Erosion Measurement on Cut and Fill Slopes of a Logging Road in the Oregon Coast Range

by

Gerald Dennis Kelly

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1968

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Date thesis is presented May 31, 1967

Typed by Clover Redfern for Gerald Dennis Kelly

ACKNOWLEDGEMENTS

A sincere thanks is extended to the Pacific Northwest Forest and Range Experiment Station of the U. S. Forest Service for the research grant that made this study possible.

Appreciation is extended to my major professor James T. Krygier for his suggestions and assistance throughout the course of this study.

Thanks also go to my fellow graduate students and office partners for the advice and encouragement that helped me to complete this thesis.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

APPENDIX II

APPENDIX III

LIST OF TABLES

APPENDIX I

APPENDIX III

A COMPARISON OF SEVERAL METHODS FOR EROSION MEASUREMENT ON CUT AND FILL SLOPES OF A LOGGING ROAD IN THE OREGON COAST RANGE

INTRODUCTION

The Alsea Watershed Study in the Oregon Coast Range was undertaken to determine the effect of logging on streams and stream biology. Eight watersheds had been located and gaged about 10 miles from the Pacific Ocean. Part of this study had as its purpose the determination of effects on streams of logging roads and road construction. Since roads are a major source of stream sediment, (BLM, n.d.; Dunford and Weitzman, 1955; Anderson, 1954) the roads in the Alsea Study area were expected to contribute sediment. The logging roads were constructed in the summer of 1965, one year prior to logging, to provide additional information for the Alsea Study about erosion and sedimentation. Cut and fill slopes along one of these roads were used to compare methods of erosion measurement.

Improved land and resource utilization has required an improved road system throughout the Oregon Coast Range. The U. S. Forest Service plans a final average road density of about four miles per section. The Siuslaw National Forest is working toward this goal at a rate of about 110 miles of road per year. Private road development is also extensive.

The natural vegetation of the Oregon Coast Range is very dense.

The rainfall is low in intensity, but long in duration. The land is steep. The potential for erosion in these mountains is undoubtedly very high. The nature of the precipitation and vegetative cover for most of the area has prevented erosion from becoming a major problem. However, current trends of intensifying land use and the resulting reduction of vegetative cover, may make erosion a major problem in this region. The amount of erosion control needed depends upon the amount of erosion expected. Prediction of erosion is, therefore, a necessity for management purposes.

Methods of erosion prediction have been developed, but these methods depend on quantitative values for factors that affect erosion. These values are determined from analysis of the erosion process and the conditions under which it operates. The values needed for erosion prediction are not available in the Oregon Coast Range. Erosion must be measured under Coast Range conditions before prediction studies can be approached.

Erosion measurement must be preceded by analysis of available methods. Several methods of measuring erosion have been developed, but the more common techniques have not been compared. The methods may not provide the same results when used under similar conditions. Comparisons of the results of erosion studies using different techniques would then be invalid.

Six plots were established on cut and fill slopes of a newly constructed logging road with the major objective of determining if each of three elevational differences techniques of measuring soil erosion were related to each other and to determine if they can be used to predict the results of a catchment technique. Subsidiary objectives were:

1. To determine if the amount and causes of erosion are different on cut and fill slopes.
2. To determine the relative precision of these four techniques.
3. To review the physical and theoretical problems inherent in each technique.

LITERATURE REVIEW

Since 1930 extensive research has been conducted to try to predict and control erosion. Several investigators applying different approaches to each phase of the erosion process have developed various measurement techniques. Each technique was developed to solve particular problems of measurement or to provide additional information about the erosion process. This study compared four of these techniques.

The Erosion Process

Erosion is the displacement of soil from a specified area. Baver (1940, p. 328) presented a general formula for erosion,

$$E = F(C, T, V, S, H),$$

which states that erosion is a function of climate (C), topography (T), vegetation (V), soils (S), and the human factor (H). This generalized formula includes all of the factors of the erosion process for any area.

Climate

All factors of climate, including wind, precipitation, frost, and drying forces, affect erosion. Climatic forces often initiate the erosion process. Rainfall impact has been identified as one of the major causes of particle detachment (Ellison, 1947; Neal, 1938; Bennett et al., 1951; and Stallings, 1957, p. 51). Surface runoff, the result of precipitation that exceeds soil infiltration capacity, is one of the major sources of energy for the movement of detached particles (Bennett et al., 1951). Frost heaving lifts and moves soil particles in relation to each other (Trimbel and Weitzman, 1953; BLM n.d., p. 152). On steep slopes the frost may lift particles and then, upon melting, allow them to roll under force of gravity to lower elevations (Sharpe, 1938). Wetting or drying soil causes the formation and disintegration of some soil and rock aggregates through changes in pore pressure and moisture tension within the soil mass (Baver, 1956, p. 236; BLM n.d., p. 150). Smaller soil particles are easier to transport. Wind may move soil particles if the soil and cover conditions are right (Stallings, 1957, p. 71). Wind erosion has not been observed as a major problem in the Alsea Study Area, although coastal dunes exist at the seaward edge of the coastal mountains.

Erosion measurements can be affected by climatic forces. Snow and ice may prevent accurate measurement of elevational changes that indicate erosion and affect the reliability of moisture content determinations of material caught at the base of a slope. Intense precipitation may wash out installations or exceed design capacities. Temperature extremes may affect the ability of measurement devices to perform as designed. Frost heaving may conceal actual soil losses. Windborn particles may damage or destroy mechanical devices or lead to inaccurate plot results.

Soil

Soil is the potential eroding material. Its properties cause the same soil mass to respond differently to different erosive forces and cause different soil masses to respond differently to the same forces. Size of the soil particles affects the amount of energy needed to move the particles after they have been detached (Osborn, 1955). The shape of the particles determine how well they may interlock and resist movement (Osborn, 1955). The arrangement of the soil particles affects the friction forces that resist the erosive forces. Interlocked particles, densely packed, are more difficult to move than loosely packed particles (U. S. Bureau of Reclamation, 1960, p. 51).

Water flowing over the soil surface provides an erosive force that can detach and transport many tons of soil per acre. Since runoff is the "complement" of infiltration, then infiltration rate could be an indication of the erodibility of the soil. The size, shape, and arrangement of the soil particles determines the size and number of pores available to transmit water (Buckman and Brady, 1960, p. 54; Taylor, 1948, Chap. 6). Cohesiveness of soil affects the efficiency of the soil pores to transmit water.

Permeability is the rate that water can move through the soil mass (PCA Soil Primer, 1962, p. 37). Since infiltration decreases with increasing moisture content (Musgrave, 1955; Neal 1938, Tisdall, 1951), the saturation permeability of the exposed layer of soil should be the lowest value for infiltration if moisture content is the only changing variable. Chorley (1959) found that erodibility was inversely proportional to the permeability of an undisturbed core sample of the soil surface.

Soil characteristics that vary from site to site also affect the measurement of erosion. Before selecting an erosion measurement technique, each of the identifiable soil characteristics should be studied to determine their effect on the proposed method.

Eroding material caught by catchments must be less than the capacity of the catchment. Accumulations of cohesive solid particles may prevent the proper operation of any mechanical device. Measurements of elevational changes at points must detect the movement of a range of particle sizes but not interfere with the erosion process.

Topography

The topographic factor, a combination of the surface characteristics of slope and location, modifies erosive forces. The volume of runoff increases with length of slope; as the degree of slope increases, the velocity of the runoff and the effect of gravity increases (Olsen and Wischmeier, 1963). On steep slopes the soils may be near or beyond the angle of repose and can easily be disturbed (Van Burkalow, 1945). Slope curvature, concave or convex, influences the friction within the soil mass (Van Burkalow, 1945).

Where topography is steep, attempts to measure erosion could easily disturb the soil. Extra care is needed in measurement so as not to conceal erosion losses.

Vegetation

Vegetative cover can dissipate or transmit erosive forces to the soil. Crown cover can reduce precipitation impact by interception (Dunford and Weitzman, 1955). Soil moisture is partially dependent upon vegetative cover (Wadleigh, 1955). The size and density of vegetative stems and roots affect soil permeability and runoff concentrations (Stallings, 1957, p. 160). Stems and roots may intercept, retard, and retain eroding material (Osborn, 1955). Forest litter and organic matter in the soil reduce erodibility by dispersing erosive forces, increasing permeability, decreasing bulk density and improving soil structure.

Erosion measurements under vegetative cover should detect changes at the soil surface without disturbing the vegetative cover. However, vegetation may conceal evidence of erosion that is present. Litter may prevent accurate measurements of elevational changes or may interfere with attempts to catch and/or retain eroding material.

Human Influences

The human factor (H) is concerned with man's use of the land. Changes due to roads, buildings, canals, dams, and agricultural practices including methods of tillage and erosion control are included here. Man's activities can cause a change in any of the other factors as well as possibly adding an independent erosive force that can obliterate the effects of all of the other factors of the erosion equation (Baver, 1956). The road used for this study was a human influence that modified many of the factors discussed above.

Soil Loss Equation

Olsen and Wischmeier (1963) compared the results of many studies made since 1930. Their universal soil loss equation was presented in 1963 to predict uniform soil loss from agricultural fields:

$$A = RKLSCP$$

where

A = average annual soil loss in tons per acre

R = rainfall energy-intensity factor

K = soil factor

L = length of slope factor

S = percent of slope factor

C = cropping factor

P = erosion control practices factor.

This equation is a specific case of Baver's (1940, p. 328) more general equation. Climate (C) of Baver's equation is reduced to a rainfall factor (R); topography (T) is accounted for in the length (L) and percent (S) of slope; vegetation (V) and the human factor (H) are combined in both the cropping (C) and erosion control practices (P) factors; the soil factor (S) remains the soil factor (K). The terms have been evaluated for some areas and have had some success where the variables are known (Olsen and Wischmeier, 1963; Smith and Wischmeier, 1962; Springer, 1963; Thoreson, 1963). All of the important variables in the rainfall erosion of agricultural fields are included although some refinement is still necessary. However, for the Oregon Coast Range the terms have not been evaluated, and until they are, the equation is unworkable for this area.

Erosion Indices

Because of the difficulty of predicting erosion, the inherent erodibility of soil has been the subject of much research. The first and perhaps best indices of erodibility were Middleton's (1930) dispersion and erosion ratios. The dispersion ratio is the ratio of non-dispersed silt plus clay to dispersed silt plus clay expressed as a percent. The erosion ratio is the dispersion ratio divided by the ratio of colloid percent to moisture equivalent. The dispersion ratio was found experimentally to have a higher correlation with the erodibility for nine widely scattered soils than the erosion ratio. However, these indices are not entirely satisfactory because soils of known high erodibility do not always have high ratios of dispersion or erosion.

Since 1930, many researchers have attempted to find a better index of soil erodibility. Most of the results indicate that Middleton's dispersion ratio to be the best index available. Baver and Rhoades (1932) developed a percent and degree of aggregation of water stable aggregates. Buoyoucos (1935) presented a clay ratio that he found to be better related to erosion than Middleton's erosion ratio. After extensive study, Peele, Latham, and Beale (1945) concluded that Middleton's dispersion ratio was at that time the best available index of erodibility. Bryant (1948) proposed aggregate stability as an index of erosion. Anderson (1951) studied erosion indices and decided that Middleton's dispersion ratio was a good expression of erodibility. Woodburn and Kozachyn (1956) studied Bryant's method of determining aggregate stability and also decided that Middleton's dispersion ratio was a better index of erodibility.

Adams (1958) concluded that the aggregate stability of the immediate surface was an important property of the soil affecting infiltration and erosion. In 1959, Chorley suggested an index using shearing resistance and permeability. Also, in 1959, Smerdon and Beasly proposed using the plasticity index as an index of erodibility in channels. The unified soil classification system which identifies soils according to their textural and plasticity qualities, also provides an erosion classification that has been used in culvert design and spacing on roads (BLM, n.d., p. 149-175).

At the conclusion of the last 35 years of erosion research there is apparently no reliable index of erosion. Middleton's dispersion ratio is the best available.

Erosion Measurement Techniques

A variety of methods for measuring erosion has been developed because of the different agencies and personnel engaged in erosion research. The methods discussed in this paper are only those applicable to surface erosion on hillside and field areas. Wind, stream, channel, gully, and mass movement types of erosion and methods of measuring these types of erosion are not considered here.

Techniques reviewed are placed into four categories: catchments, elevational differences, samplers, and tracers. This study included four techniques: one of the catchment type; and three utilizing elevational differences. All techniques considered for this study are listed below; four of these were used. The final selection was based on considerations of site conditions, information to be gained by the particular technique, cost, and operation of the technique.

Catchments

Techniques for catching all runoff and/or eroded material and retaining this material for evaluation are included in this category. Three catchment techniques are considered: the catchment-filter, the catchment-trough, and the sedimentation-tank. Only the catchment-filter-technique was used in this study.

Catchment-Filter. The catchment-filter technique, used in this study as a standard, was adapted from the description presented by Wilson (1963). All runoff and raveling are caught in a trough. The water is passed through a filter that retains the sediment. The following advantages are suggested: particles that would have passed a given point are retained; analysis of the sediment for chemical and physical properties is possible; weight measurements are made directly. The disadvantages include high cost for materials and construction, and no filter can remove all colloidal sized material from water (Dickey, 1961, p. 267)

Catchment-Trough. The catchment-trough, used extensively in erosion studies (Garcia, 1963; Hendrickson et al., 1963), catches and retains all runoff and eroded materials. The trough can be designed to the size and shape best suited to the site. The only requirement is that the capacity be sufficient to hold all of the eroding material as well as all of the runoff water. A distinct advantage over other methods is complete retention of sediment. Disadvantages include the large volume of water and solids that must be handled.

Sedimentation-Tank. The sedimentation-tank designed by Davis (1937) catches and retains runoff water long enough to add a flocculating agent and allow the sediment to settle out. The flocculating agent (three were discussed, the best being $Al_2(SO_4)_3$), is added automatically in proportion to rainfall. The tank as designed has a capacity of one cubic foot per minute. Davis claimed that his tank could be modified to handle larger flows. Advantages include retention of water-carried solids and ability to analyse the sample retained. The disadvantages include the small capacity, difficulty of maintenance and servicing, and high cost of construction.

Elevational Differences

Five techniques from this category were considered for use in this study, but only three--erosion gage, macroprofile, and spike and washer--were included in the final study design. Techniques in this category consist of various means of measuring periodically the elevation at points, along transects. Each change in elevation at a point is multiplied by the area represented by that point to yield the volume of erosion or deposition occurring in that area. Bulk density measurements allow conversion of the volume measurements to weight.

Spike and Washer. The spike and washer technique, used in this study, involves a spike with a loose fitting washer driven into the ground until the washer rests on the ground and the spike head just touches the washer. Both erosion (falling washer) and deposition (soil on top of washer) are measured with a carpenter's rule. This technique has been used by Gleason (1957) and Leupold (1966). Advantages are: low cost, ease of sampling, and simultaneous measurements of erosion and deposition at the same point. Disadvantages are: a need for a large number of sampling points, interference by forest litter, distortion of measurements by frost heaving, and prevention of raindrop splash erosion under the washer.

Macroprofile. The macroprofile technique used in this study is a modification of Sart's approach (1953) with some incorporation of Wilson's (1963) methods. A wire marked at one foot intervals is fastened at the road shoulder and at the opposite side of the slope, either cut or fill. The distances from the wire to the ground surface are measured periodically. The main advantage is easy measurement of actual changes in the slope profile, and the readings are easily taken. Disadvantages are: potential movement of reference points, sag in the wire, and difficulty of obtaining accurate measurements.

Soil Erosion Gage. The soil erosion gage used in this study was developed by Mesavage and Smith (1952). The gage is a $25\frac{1}{2}$ inch steel bar that is placed on two reference stakes and leveled. The distance from the top of the bar to the soil surface is measured at ten points along the bar. Measurements are made with a calibrated rod and vernier. "Accuracy tests between two operators showed a standard deviation of 0.0127 inch with a standard error of the mean of 0.00252 inch!" (Mesavage and Smith, 1952), showing a high degree of accuracy and reproductivity. A larger gage of this kind was used by Hudson (1964) to measure cross sections of a stream channel. Advantages are accuracy, small size of the instrument, speed and ease of reading. Disadvantages are potential loss or destruction of reference points; and the need for a large number of samples to determine the total soil movement.

Reference Stakes. This technique involves driving a stake deep enough into the ground to be anchored below the effect of the erosive forces. Any change in the exposed portions of the stake indicates erosion or deposition. Reference stakes of various types have been used extensively. Inman and Rusnak (1956) studying underwater beach erosion used brass rods; the measuring rod had a long broad base to damp out any local irregularities in the sand surface. Schumn (1956) studying hillslope erosion used wooden stakes buried flush with the surface of the soil. Diseker (1959) found that reference stakes worked well in roadside ditches, but a small number of points did not yield enough information for analysis of an irregular cut slope. The type of stake and the nature of the installation were not described. Schumn and Lusby (1963) used iron reference stakes driven at right angles to the surface of the soil. A pre-study evaluation of the reference stakes suggested that the spike and washer method would provide the same information, as well as additional information about deposition.

Bottlecaps. Bottlecaps were used by Gleason (1957). The method consists of placing bottlecaps at various locations in the field and allowing pedestals to form under them. The height of the pedestals indicates the depth of the layer of soil removed from the area. The only advantage is low cost. The disadvantages include small amount of information yielded, possibility of pedestal disintegration prior to remeasurement, and movement of the bottlecaps.

Samplers

Techniques for catching and retaining, for evaluation, a known portion of the runoff and/or eroded material are included in this category. The main difficulties are obtaining a representative sample and determining what proportion of the runoff and/or eroded material is being retained. Any device that gives a good estimate of runoff and erosion seems to require a larger amount of runoff for adequate operation than is expected from the Alsea area and the method has a high cost of construction and installation.

This category includes raindrop splash samplers, slot divisors, the Coshocton wheel, and tilting buckets. These methods are discussed below. All were finally rejected from the study design.

Raindrop Splash Samplers. Raindrop splash samplers are methods for sampling the amount of soil splashed into the air by raindrop impact. Ellison (1944) describes a shield that intercepts splashed particles; the amount of material that is caught on the shield is a sample of the amount of material eroding. Sreenivas (1947) describes another sampler that funnels splashed particles into a bottle. The advantages include low cost, and measurement of height and amount of material splashed. The principal disadvantage is that soil moved by factors other than raindrop splash is not sampled.

Slot Divisors. The slot divisor is a slot or a series of slots placed in a channel or at the toe of a runoff plot so that the water passing through one or more of these slots is diverted and retained for analysis. Geib (1933) presented a modification of earlier slot divisors; Kohnke (1943) discussed the problems of the Geib divisor and presented the Indiana runoff sampler as an improvement; Ellison (1944) describes a small portable shield with an attached slot divisor; Barns and Frevert (1954) describe a divisor for large streams; and ARS-41-79 (1963) discusses in detail a design for a small slot divisor.

However, for this study, the amount of runoff from the plots was not expected to be large enough to make a slot divisor practical.

Coshocton Wheel. The Coshocton wheel, described by Parsons (1954, 1955), collects and retains a sample of one half of one percent of the runoff and sediment. The wheel itself is a revolving disc which carries a runoff sampler through the entire stream flow once during each revolution of the disc. The wheel is driven by the force of the flowing water. A measurement is made of the volume of flow, a sample is taken of the sediment carried, and the sample is easily taken. The disadvantages are complex design, high cost of installation, potential for fouling moving parts of the apparatus, and for the Alsea area expectation of insufficient flow to drive the wheel.

Tilting Buckets. Tilting buckets consist of a trough to catch all runoff and sediment until a certain volume is reached. The trough is then automatically dumped. A counter records the number of times the trough is filled. A sample of the trough content is automatically taken at the time of dumping. Two types of tilting buckets have been described: one by Johnson (1942), and one by Russel (1945). However, Cook and Parsons (1953) studied all types of tilting buckets and found them unsatisfactory for erosion research because of the poor hydraulic characteristics, low capacity, and the need for large amounts of head room.

Tracers

The tracer category of erosion measurement includes methods of "salting" the ground with radio-active or other traceable material that will react to the erosion-causing processes in the same manner as the soil itself (Inman and Chamberlain, 1959). The progress of this material is followed down the slope. Tracer methods have been used by Leupold _et al._ (1966), Wooldridge (1965), Schumm and Lusby (1963), Inman and Chamberlain (1959), Smith and Eakins (1957), Putman and Smith (1956), and described by Kirkham and Kuntz (1962). Arlman, (1957) discussing the article by Smith and Eakins, suggests that if no size sorting takes place, tracer methods may be quantified. Some sorting nearly always occurs. At the present time no reliable tracer method has been developed to quantify erosion, and therefore, no tracer methods were considered for use in this study.

METHOD OF STUDY

Four techniques of measuring soil erosion were compared on each of six study plots in the Oregon Coast Range. The site was a cut and fill slope of a road on the upper slopes in the Deer Creek watershed of the Alsea Watershed Study. (Figure 1) Three plots were located on the cut slope and three on the fill slope (Figure 2); erosion measurements were made through the winter of 1965-1966.

Description of the Study Area and Plots

The study site has a marine climate with warm dry summers and mild wet winters. Most of the precipitation comes as low intensity, long duration, winter storms. This study was conducted from late October 1965 through early April 1966. At the study area 81 inches of precipitation were recorded for this period.

The soil series was a Bohannon sandy loam overlying a Tyee sandstond formation (Corliss, 1964). The natural slopes at the site were about 50 percent (27°). The aspect was due east; elevation was about 1500 feet. The erosion rate was classified as high (Corliss, 1964).

The slopes selected were as uniform as possible to reduce plot variability; however, the plots were spaced 33 feet apart to ensure minimum damage from slumping (Figure 2). The fill slope appeared to be a homogeneous mixture of soil and rock. The cut slope was layered--ranging from highly organic with low compaction on the top of the plots to exposed rock faces at the bottom. The cut face and the fill slope are shown in Figures 3 and 4.

Three plots were established on the cut slope and three on the fill slope. The cut slope plots averaged 22 feet long; the fill slope plots averaged 24 feet long (Table I). The average slopes were 109 and 60 percent for the cut and fill slopes respectively for the lower portions of the plots, and 35 and zero percent respectively of the upper (lip) portions of the plots. All plots were two feet wide.

The plots extended from about five feet above the break to the toe of the slope.(Figures 2 and 5). The break in the slope is the point of change from the natural slope to the slope of the cut face or the change from the road bed to the face of the fill. Wilson (1963) found that most of the material caught at the bottom of the cut face originated near the break in slope. An upper lip of five feet above the break in slope was included in each plot to be sure of enclosing the break within the plot throughout the study period.

The plots had wooden boundaries sealed against the slope with soil-cement mixture. The catchment-filter device formed the lower boundary on each plot. The plot boundaries prevented external flows and soil movements from influencing the measurements. All boundaries were installed with a minimum of plot disturbance.

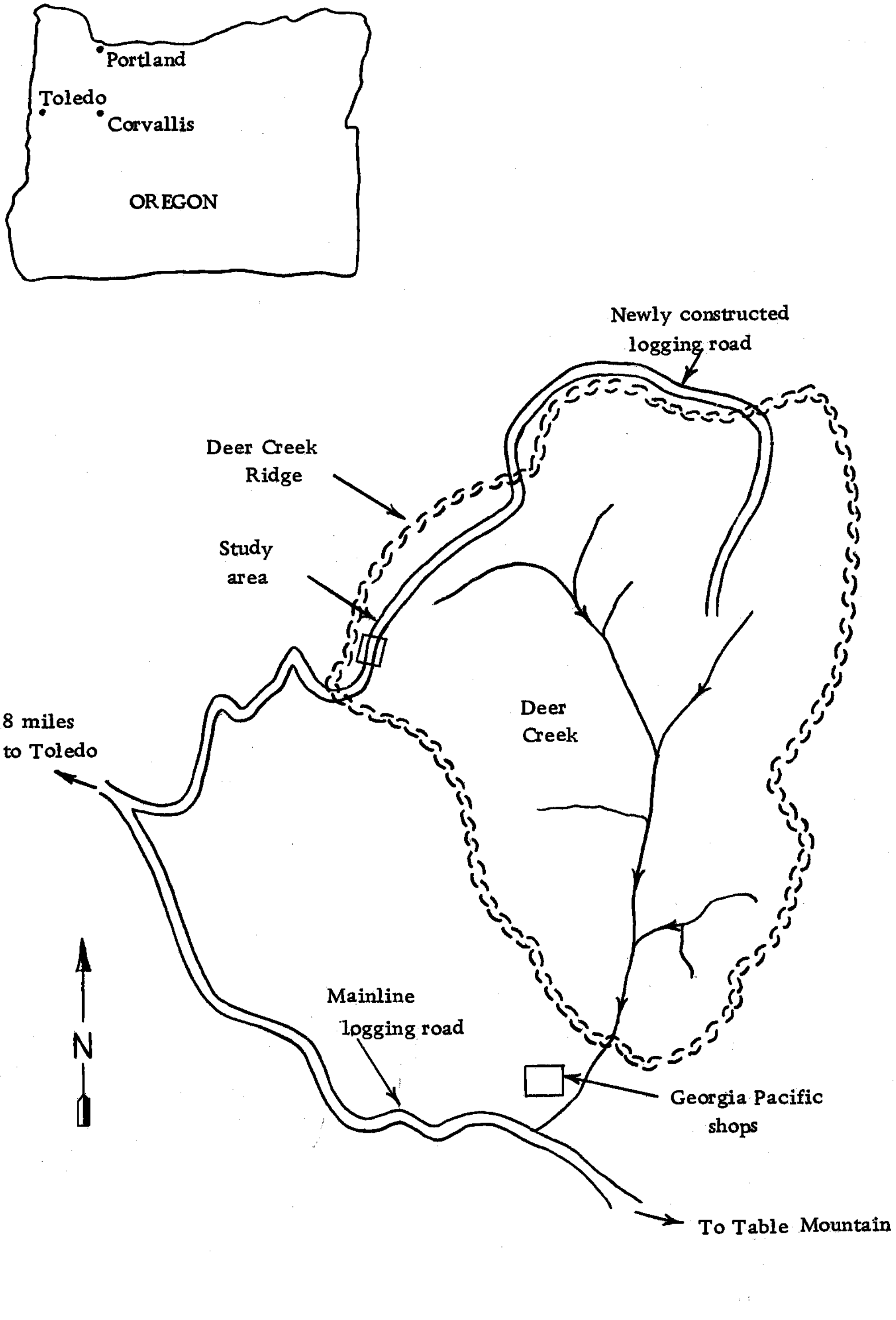

Figure 1. Location of the study area.

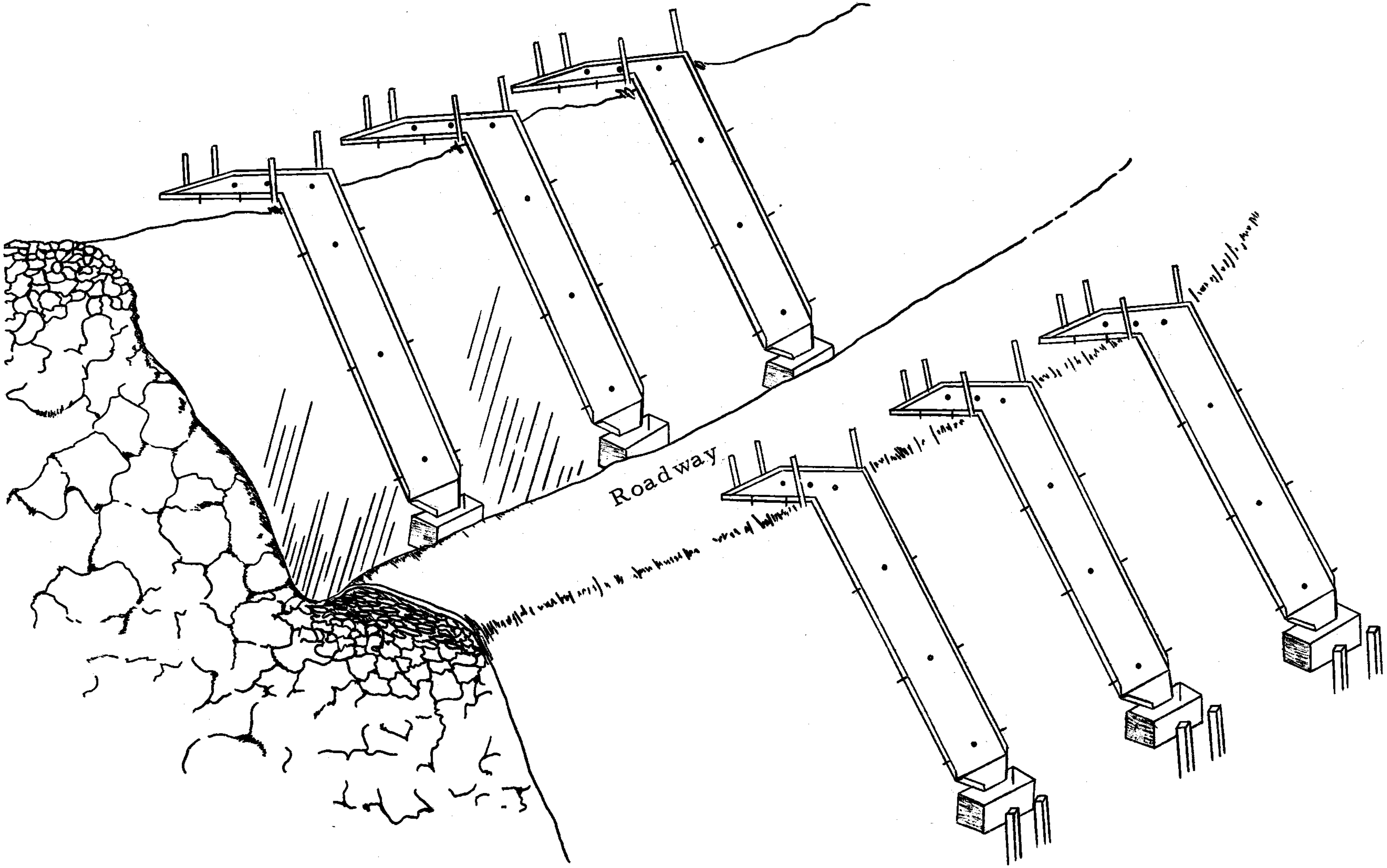

Figure 2. Six study plots showing plot location, boundaries and the catchment with respect to the logging road.

Figure 3. Photograph of downslope view of fill slope plot number 4.

Figure 4. Photograph of the cut slope and three cut slope plots.

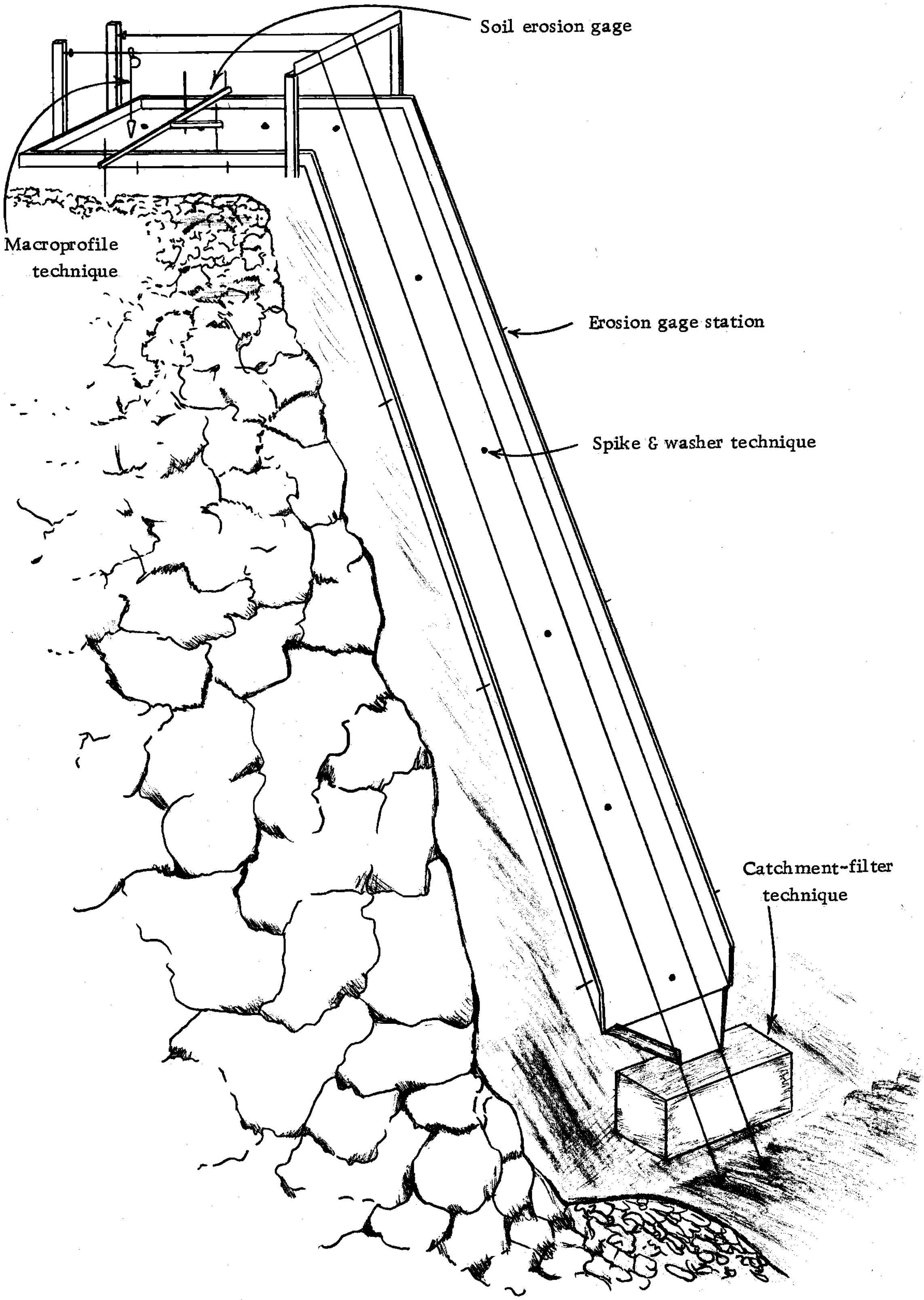

Figure 5. Study plot design.

Notes to Table I.

1. Dispersion ratio: The value for non-dispersed silt plus clay was the average of four samples. The value for dispersed silt plus clay was the average of three samples.

2. Bulk density top portion: The values for the top portions of cut slope plots were the average of three samples. The top portions of the fill slope plots were assummed to be the same as the lower portions.

3. Bulk density lower portion: The value for the lower portions of the cut slope plots was the average of three samples. The value for the fill slope plots was the average of three samples.

4. Permeability: Sample would not hold a one inch head of water.

Table I. Characteristics of the study plots.

Characteristic	Plot Number					
	1	2	3	4	5	6
	Cut Slope			Fill Slope		
Width (ft)	2	2	2	2	2	2
Overall length (ft)	23.15	20.51	21.23	24.70	24.40	23.65
Above break	4.65	5.31	5.30	5.35	5.65	6.55
Below break	18.50	15.20	15.93	19.35	18.75	17.10
Slope (%)						
Above break	42	33	29	0	0	0
Below break	114	100	114	65	60	55
Slope Area						
(ft^2)	46.30	41.02	42.46	49.40	48.80	47.30
Acres	0.001063	0.000942	0.000975	0.001134	0.001120	0.00109
Dispersion Ratio[1] (%)	23.6			34.4		
Bulk Density (gm/cc)						
Top Portion[2]	0.498	0.539	0.270			
Lower Portion[3]	1.308			1.178		
Permeability (in/hr)						
Top of plot	26.1 and 16.9	25.6	6.2	4	4	4
Top of face	15.5	22.8	4.8	17.8		
Bottom of plot	4.6	9.1	16.0		39.2	20.6

No vegetation was growing on the plots, although small amounts of litter were lying above the break in the cut slope. After road construction, the slopes had been sprayed with a straw mulch, but the small amount that was applied to this area was removed during plot construction. The slopes were essentially bare.

The inherent differences in the soils on the cut and fill slopes, even though they were both at the same location, were evaluated from limited samples of bulk density, permeability, and dispersion ratio. Table I lists these measured characteristics for each plot. The bulk density values were used to convert measured volumes to weights for elevational-difference techniques. The permeabilities and dispersion ratios were used to describe differences in erodibility of the cut and fill slopes. The average bulk density of the fill slope was 1.178; the cut face was 1.308. Bulk density of the natural slope near the cut slope plots varied enough to require individual values for the upper portions of these plots. The permeability of the cut slope ranged from 4.6 to greater than 26.1 inches per hour with a weighted average of 13.5 inches per hour; the fill slope ranged from 17.8 to greater than 39.2 inches per hour with a weighted average of 29.2 inches per hour. The average dispersion ratio was 23.6 percent and 24.4 percent for the cut and fill slopes respectively.

Erosion Measurement Techniques Used

The four techniques selected--catchment-filter, macroprofile, soil erosion gage, and spike and washer--seemed most suitable to the site and objectives of this study. All four techniques were used on each plot.

Catchment-Filter

A catchment-filter box, a box-type catchment with a nylon filter,[1] was placed at the toe of each plot.(Figure 5). The filter retains the soil but allows most of the water to pass through. The runoff and erosion were channeled from the plot into the box by a metal pan and funnel. A debris screen in the top portion of the box prevented damage to the filter by large rocks or branches; a window-screen in the lower portion of the box provided mechanical support for the filter.(Figure 6).

The dry weight of soil and rock retained was determined for each measurement period. When the device was checked, the entire contents, including filter, were weighed to the nearest tenth of a pound; a representative sample was taken to determine moisture content, and a clean filter installed. A detailed description of

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[1] Schwarzenbach-Huber Co. Nylon filter fabric quality 5044F. Thread count 220 x 123, 70 denier.

computational procedures is presented in Appendix III.

Macroprofile

Two transects of macroprofile points ran the length of each plot. The transects were placed six inches from each side, or one foot apart, and ran parallel to the side of the plot (Figure 5); thus each plot was divided lengthwise in half, and one cable ran down the center of each half.

Each transect gave measured elevational changes at 18 to 23 points along the slope profile. For each transect the ground and a cable strung over the plot was measured to the nearest hundredth of a foot at points spaced one foot apart along the cable (Figure 5 and 7). To prevent the cable from resting on the ground at the break in slope, a support bar was installed near this point. The cable was strung and removed each time the transect was measured. A spring scale and turnbuckle kept the tension the same at each restringing. Since the same cable was used on all plots, a link chain allowed adjustments in length. An engineer's tape on a reel was used for the measurements. The tape was hung at marked points and kept plumb by a free swinging hanger and plumb bob (Figure 8).

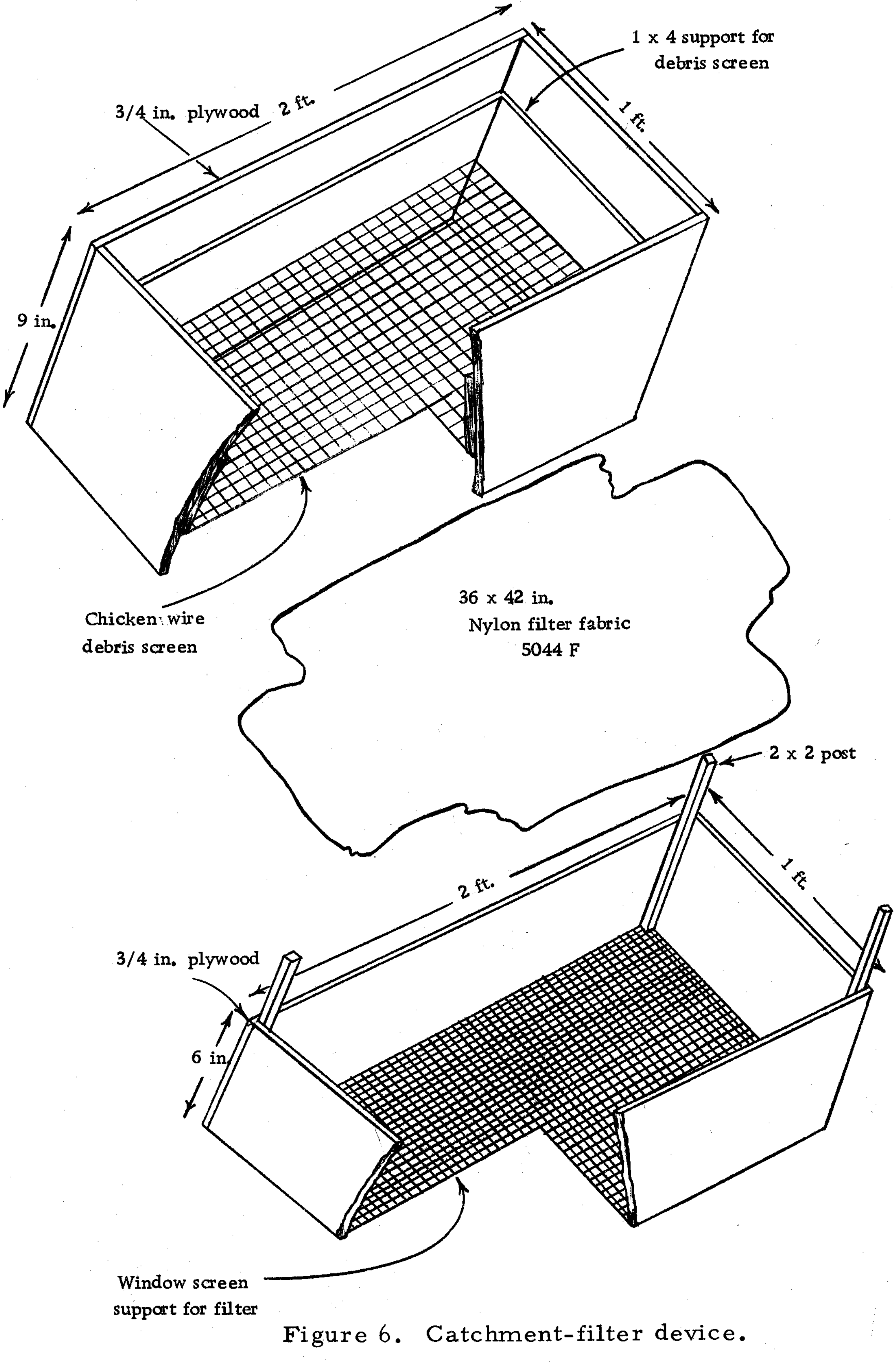

Figure 6. Catchment-filter device.

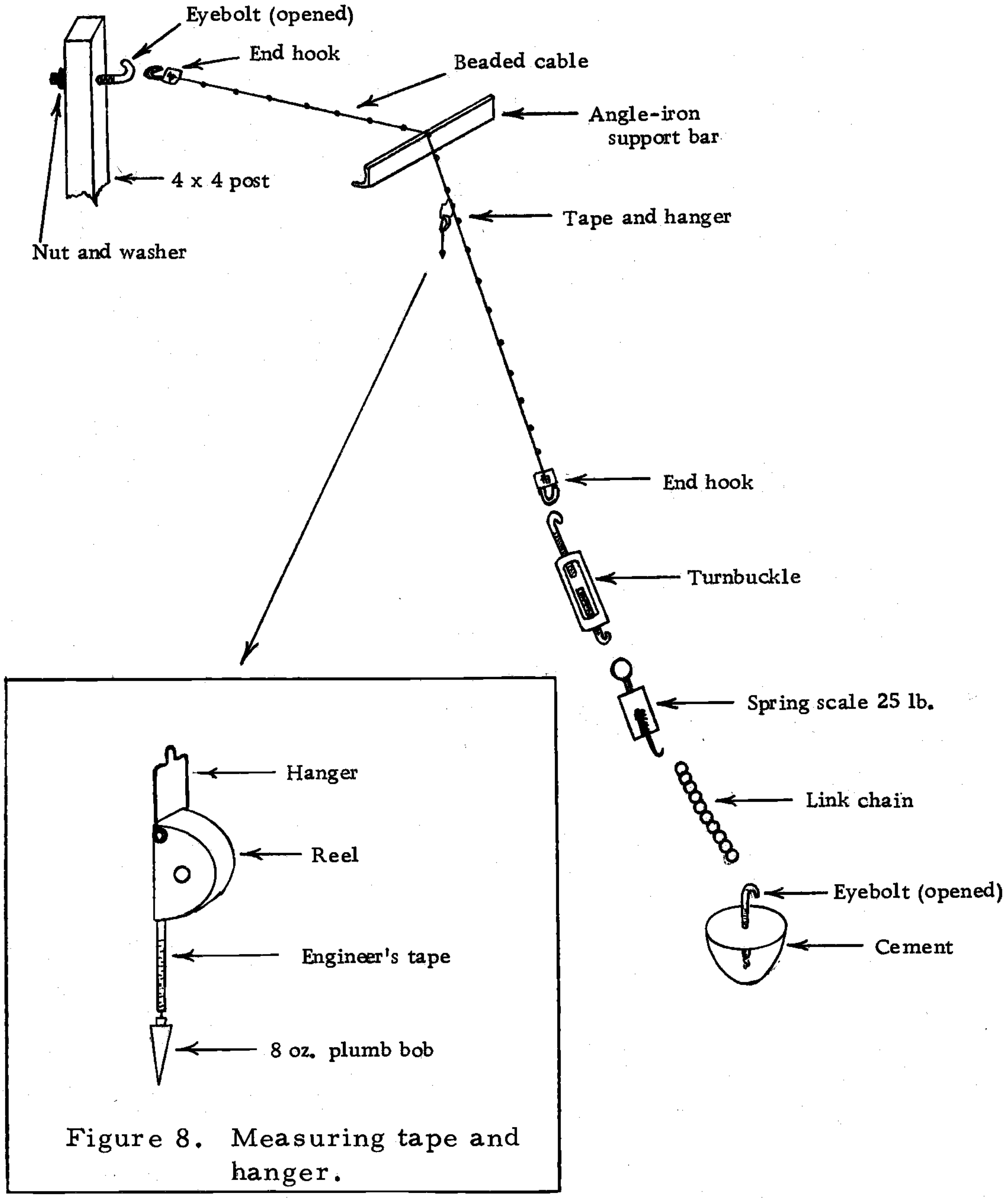

Figure 8. Measuring tape and hanger.

Figure 7. Apparatus used for the macroprofile technique.

The weight of material moved from the plot for each measurement period was computed. The changes in elevation multiplied by the area provided the volume; and volume multiplied by the bulk density gave the weight of soil moved. A detailed description of computational procedures is presented in Appendix III.

Soil Erosion Gage

Six soil erosion gage stations were established on each plot (Figure 5). The maximum amount of erosion was expected at the break in slope. The lower boundary of the plot was expected to have an effect on the amount of erosion near that boundary; therefore, one erosion gage station was allotted to each of these zones. Two of the remaining four stations were allotted to the upper portion of the plot, and two to the lower portion. These were spaced to provide uniform coverage. The mechanical division of the areas into thirds was altered slightly to avoid installation problems. The exact distances between stations are presented in Table XIX in Appendix III.

At each station ten points of elevational change were read. The gage is a rod and a vernier that measures the distance between a bar and the soil surface to the nearest hundredth of an inch (Figure 9). The bar is 30 inches long, to reach across the plot, with the ten points spaced 1.33 inches apart and centered on the bar. The bar was set up and leveled each time a station was measured. About ten minutes were required to set up the gage and read a station.

The weight of material moved off of the plot for each measurement period is the product of elevational change, area, and bulk density. A detailed description of the computational procedures is presented in Appendix III.

Spike and Washer

Six spike and washer stations spaced similar to erosion gage stations were established on each plot (Figure 5). To avoid mutual interference between the spike and washer and erosion gage techniques, the two stations were offset slightly from each other. The exact distances between the spike and washer stations are presented in Table XX, Appendix III.

At each station, the depth of erosion and the depth of deposition were measured independently. Each station consisted of a 12 inch spike driven into the soil and a loose fitting washer (Figure 10). Erosion was measured by the changing distance between the spike head and the washer; deposition by the changing depth of the soil on top of the washer. The two measurements were recorded to the nearest hundredth of a foot. Six stations were read in about ten minutes.

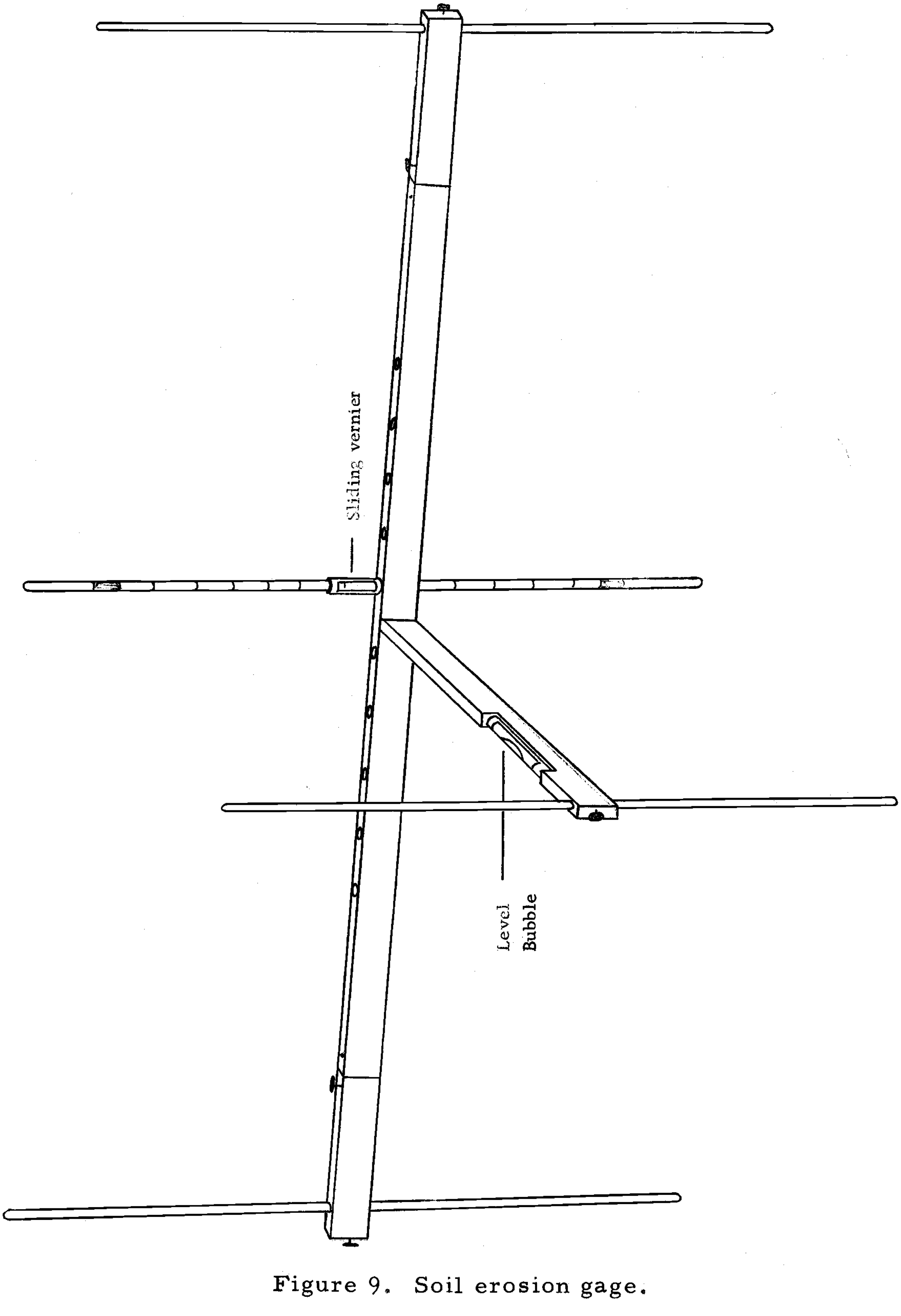

Figure 9. Soil erosion gage.

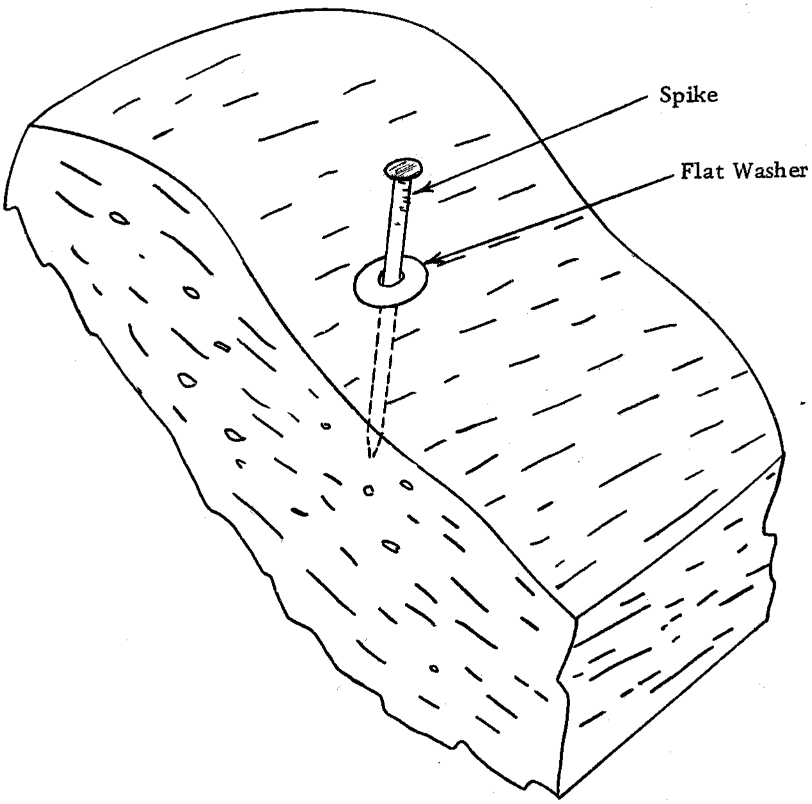

Figure 10. Spike and washer technique.

The weight of material moved from the plot for each measurement period was computed. The change in distance between the spike head and the washer and the change in deposition on the washer were each multiplied by area to provide the volume of change. Each of these volumes was multiplied by bulk density to provide the weight of soil moved away by erosion and the weight of soil deposited in the area. The two weights were combined to give the weight of material moved off of the plot. The computational procedures are presented in Appendix III.

Periods of Measurement

All catchment-filter devices were checked weekly[2]. The cut and fill slopes were measured on alternate weeks by the three elevational differences techniques. Only one slope (cut or fill) could be measured on any one day. If the ground was covered by snow or hail, the elevational difference measurements were delayed until the following week. The dates and measurements taken on those dates are listed in Table II. The relative amounts of erosion recorded for these periods are presented in Appendix I. The catchment-filter devices were checked on 21 dates on both the cut and fill slopes. The changes in elevation were measured by all of the elevational-difference techniques six times on the cut slope and seven times on the fill slope.

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[2] The period ending January 1 was two weeks long.

Table II. Sampling dates of four techniques on cut and fill slopes.

	Cut slope				Fill slope		
Date	Macroprofile	Erosion gage	Spike & washer	All plots catchment filter	Macroprofile	Erosion gage	Spike & washer
1965							
10-24		x					
10-31		x					
11- 6				x		x	
11-13	x	x		x			
11-20				x	x	x	x
11-28	x	x	x	x			
12- 4				x	x	x	x
12-11	x	x	x	x			
12-18				x	x	x	x
1966							
1- 1				x			
1- 8	x	x	x	x			
1-15				x	x	x	x
1-22	x	x	x	x			
1-29				x	x	x	x
2- 5	x	x	x	x			
2-12				x			
2-19				x	x	x	x
2-26	x	x	x	x			
3- 5				x			
3-12				x	x	x	x
3-19				x			
3-26	x	x	x	x			
4- 2				x	x	x	x

RESULTS

Comparison of Measurement Techniques

The principal objective of this study was to determine if four techniques--catchment-filter, soil erosion gage, macroprofile, and spike and washer--would yield the same results. All comparable readings of relative amounts of erosion for all intermediate periods between November 20, 1965 and April 2, 1966 were used in a correlation analysis. An analysis of variance was applied to the total erosion from six plots for the entire study period as measured by the four techniques.

Correlation Analysis

Four techniques were used to measure relative amounts of erosion from the same plot during the same time period. Erosion in pounts per square foot of slope area, as computed for each technique, was determined for 39 plot-periods (13 periods, or dates, x 3 plots = 39 plot-periods) between November 20, 1965 and April 2, 1966. This data is presented in Appendix I. If the techniques are related, the results of one technique can be predicted from the results of another.

A correlation analysis, using 39 plot-periods and all possible combinations of two techniques, provided the correlation coefficients

(r) presented in Table III. The largest coefficient is 0.66126. The macroprofile technique will provide reasonable predictions of the soil erosion gage technique only 43.7 percent ($r^2 \times 100$) of the time. No regression equations were formulated. The results of the elevational differences techniques cannot be predicted from one another, nor can they predict the amounts of material caught by the standard method (catchment-filter).

Table III. Results of correlation analyses using all possible combinations of two of the four techniques and data from 39 plot-periods.

Comparison	Correlation Coefficients (r)		
	All Plots	Cut Slope[1]	Fill Slope[2]
Catchment-Filter vs. macroprofile	0.18808	0.11992	0.48495
Catchment-Filter vs. erosion gage	0.23566	0.45776	0.27522
Catchment-Filter vs. spike & washer	0.08025	0.18018	-0.05525
Macroprofile vs. erosion gage	0.44581	0.13133	0.66126[3]
Macroprofile vs. spike & washer	-0.05934	0.11358	-0.14114
Erosion gage vs. spike & washer	-0.00713	0.05564	-0.03920

[1] 18 plot-periods

[2] 21 plot-periods

[3] Highest correlation coefficent of all possible combinations of erosion measurement techniques.

Analysis of Variance

The total relative amounts of erosion measured by the catchment-filter, macroprofile, soil erosion gage, and spike and washer techniques between November 28, 1965 and March 26, 1966 on the cut slope and between November 20, 1965 and April 2, 1966 on the fill slope were compared by analysis of variance. The values used in this comparison are presented in Table IV. Table V shows the results of the analysis of variance.

Table IV. Total relative amounts of erosion (lbs/ft^2) between November 20 and April 2 as measured on six plots by four techniques.

Techniques	Cut slope Plot			Means	Fill slope Plot			Means	Grand Means
	1	2	3		4	5	6		
Catchment-filter	-0.4942	-0.8131	-0.5792	-0.6288	-0.2491	-0.2906	-0.0647	-0.2015	-0.4152
Macroprofile	-1.8084	-3.4517	+3.3443	-0.6386	-0.3485	+0.3312	-0.1368	-0.0514	-0.3450
Soil erosion gage	-3.5830	-2.7313	-2.3487	-2.8877	+0.5279	-0.3540	-1.7819	-0.5360	-1.7118
Spike and washer	+8.1983	+0.3362	+2.6013	+3.7119	+14.4276	+4.1303	+1.1625	+6.5735	+5.1427
Means		-0.1108				+1.4462			

Table V. Analysis of variance of total relative amounts of erosion from six plots between November 20 and April 2 as measured by four techniques.

Source	Degrees of freedom	F	Conclusion
Technique	3	5.8271	significant at 95%
Cut vs. fill	1	1.6417	N.S.(not significant)
Cut-fill x technique	3	0.255	N.S.
Plot within cut and fill	4	1.1614	N.S.
Error	12		
Total	23		

The analysis of variance indicated a significant difference among the results of the techniques. Additional analysis by individual degrees of freedom indicated that the spike and washer gave results that were different but the results of the other three methods were the same. Table IV shows that the total relative amounts of erosion for the spike and washer method indicated that deposition (positive values) had occurred when erosion had actually taken place. The spike and washer technique, as used in this study, gave invalid results. On the cut slope the range of values for the macroprofile technique, one positive and two negative, overlaps the entire ranges of values of the catchment-filter and erosion gage techniques. On the fill slope the range of values for the erosion gage, one positive and two negative, overlaps the entire ranges of the macroprofile and catchment-filter techniques. This overlap explains the lack of significance among these three techniques even though the ranges of values may be very different.

The similarity of the catchment-filter, macroprofile, and erosion gage found in the above analysis of variance is a contradiction of the results of the correlation analysis. The correlation analysis compares the individual values for many short periods while the analysis of variance compares the means of six plots for a long period. The similarity of the means is due to the overlap of the values of the techniques. The variability of the amounts of erosion recorded from plot to plot masks the differences that are apparent in the correlation analysis. A graph of the individual plot values used in the analysis of variance showed the lack of meaningful relationships indicated by the correlation analysis. Any one technique cannot be used to predict the results of any other technique.

The same analysis of variance (Table V) was used for additional information. No difference was found between cut and fill slopes. Since the catchment-filter method (standard) recorded three times as much erosion from the cut slope as from the fill slope, it is concluded that for this analysis differences between techniques and the variation within techniques were sufficient to mask differences between the slopes. The cut-slope plots were not different from each other, nor were the fill-slope plots different from each other. No interaction was found between the two slopes and the techniques. The relative accuracy and precision of these techniques were unaffected by the differences between cut and fill slopes.

Standard Deviations of Relative Amounts of Erosion

The relative order of magnitude of the mean standard deviation of the amounts of erosion (Table VI) for the techniques do not vary between cut and fill slopes. The mean standard deviation of the catchment-filter is least, the soil erosion gage is second and the macroprofile is third. (The mean standard deviation of the spike and washer varies from second largest to largest, but the preceding analyses have shown that the spike and washer technique yields invalid measurements of relative amounts of erosion.) This order of magnitude is generally consistent for all intermediate periods, and confirms the lack of interaction between techniques and slope indicated by the analysis of variance.

Location of Erosion Along the Slope

Efforts to control erosion from cut and fill slopes should be concentrated where erosion is most severe. The erosion gage and the macroprofile techniques provided measurements of changes in elevation at about 100 points on each plot. If the slope were eroding more rapidly at one zone than another, then analysis of these measurements should indicate areas of concentrated erosion.

The erosion gage provided elevational changes at ten points across each plot at six different locations on the slope profile (Figures 5 and 9). An analysis of variance indicated no significant difference in vertical elevational changes across the plots. Erosion was uniform horizontally and no apparent channeling occurred.

Table VI. Standard deviation and means of relative amounts of erosion from plots for all techniques by date on cut and fill slopes (lb/ft^2).

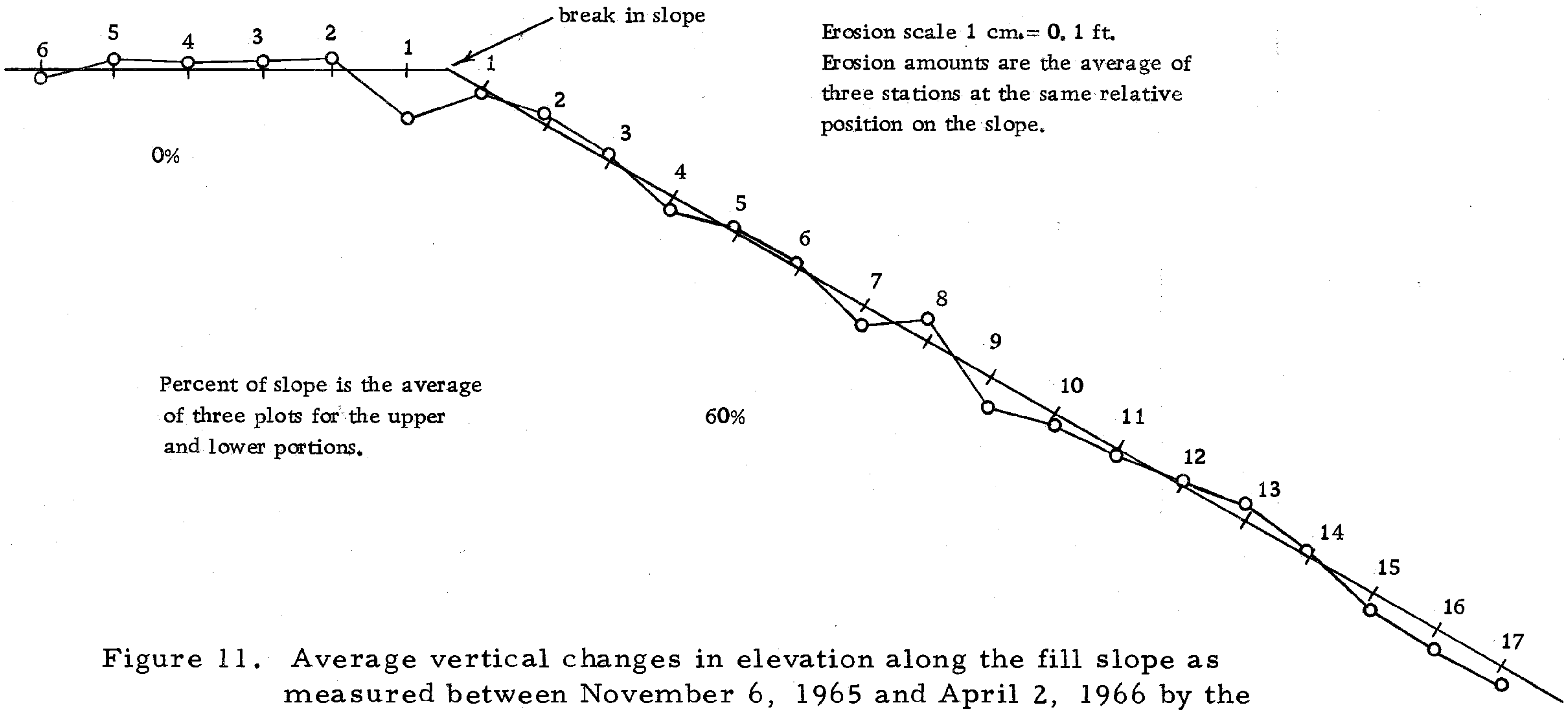
		Cut Slope						
	Catchment-filter		Macroprofile		Soil erosion gage		Spike and washer	
Date	Standard deviation of amounts of erosion	Mean amount of erosion	Standard deviation of amounts of erosion	Mean amount of erosion	Standard deviation of amounts of erosion	Mean amount of erosion	Standard deviation of amounts of erosion	Mean amount of erosion
Nov. 13	±0.1032[1]	-0.1925			±1.6317	+0.1337		
Nov. 28	±0.0172	-0.0570	±0.6976[1]	+0.3768	±0.5174	-0.0165		
Dec. 11	±0.0506	-0.0617	±0.8033	-0.5612	±0.3328	-0.3502	±0.1121	+0.2445
Jan. 8	±0.1328	-0.3282	±0.5857	-0.6268	±0.1802	-1.3096	±0.5385	+0.1502
Jan. 22	±0.0286	-0.1014	±0.4410	+1.2109	±1.1674	-0.3946	±0.0612[1]	+0.6105
Feb. 5	±0.0191	-0.0370	±2.2598	-2.0720	±0.3284	-0.6816	±0.4087[1]	+0.0299
Feb. 26	±0.0046	-0.0311	±3.4394	+2.2518	±0.1149	+0.0635	±0.8735[1]	+0.2887
March 26	±0.1021	-0.1040	±0.7315	-0.8904	±0.1301	-0.2153	±1.5218	-0.5443
Mean	±0.0573		±1.2798		±0.5504		±0.5860	
		Fill Slope						
Nov. 20	±0.0842	-0.0730			±0.6516	-0.5958		
Dec. 4	±0.0011	-0.0056	±0.8118	-1.4043	±0.1184	+0.0510	±0.2177	+0.7612
Dec. 18	±0.0025	-0.0026	±1.1085	+2.8484	±0.8061	+2.4107	±0.3134	0.4229
Jan. 15	±0.0556	-0.0899	±0.8681	-3.0404	±0.2542	-2.2033	±1.7682	+0.8046
Jan. 29	±0.0006	-0.0060	±0.7652	+1.3624	±0.3326	-0.0281	±1.3602	-0.8498
Feb. 19	±0.0023	-0.0068	±0.1626	+0.0921	±0.3653	-0.0481	±5.8417	+3.8657
March 12	±0.0481	-0.0465	±0.4852	-0.1660	±0.1054	-0.0494	±3.5592	+4.2882
April 2	±0.0019	-0.0060	±0.0963	+0.2554	±0.5152	-0.4401	±1.9029	-2.7193
Mean	±0.0245		±0.6140		±0.3936		±2.1376	

[1] Only two values.

The macroprofile technique provided readings at 18 to 23 positions (depending upon the plot) down the slope profile. The average total vertical elevational changes for the macroprofile stations are plotted in Figures 11 and 12. The common point in all plots is the break in slope, and the station positions are plotted relative to that point. An analysis of variance of the total elevational changes at the end of the study period indicated no significant difference between the stations on either the cut or fill slopes. Individual degrees of freedom tests indicated that while erosion was essentially uniform, the lower portions of the cut slope received more deposition than the rest of the slope. The slopes were expected to erode severely at the break in slope, and although it was insignificant in the statistical analysis, Figures 11 and 12 indicate erosion at the break in slope for both cut and fill slopes.

Comparison of Cut Slope Versus Fill Slope

A higher dispersion ratio and a longer slope (Table I) indicate that the fill slope should erode more than the cut slope. Higher bulk density, lower permeability and steeper slope indicate that the cut slope should erode more than the fill slope.

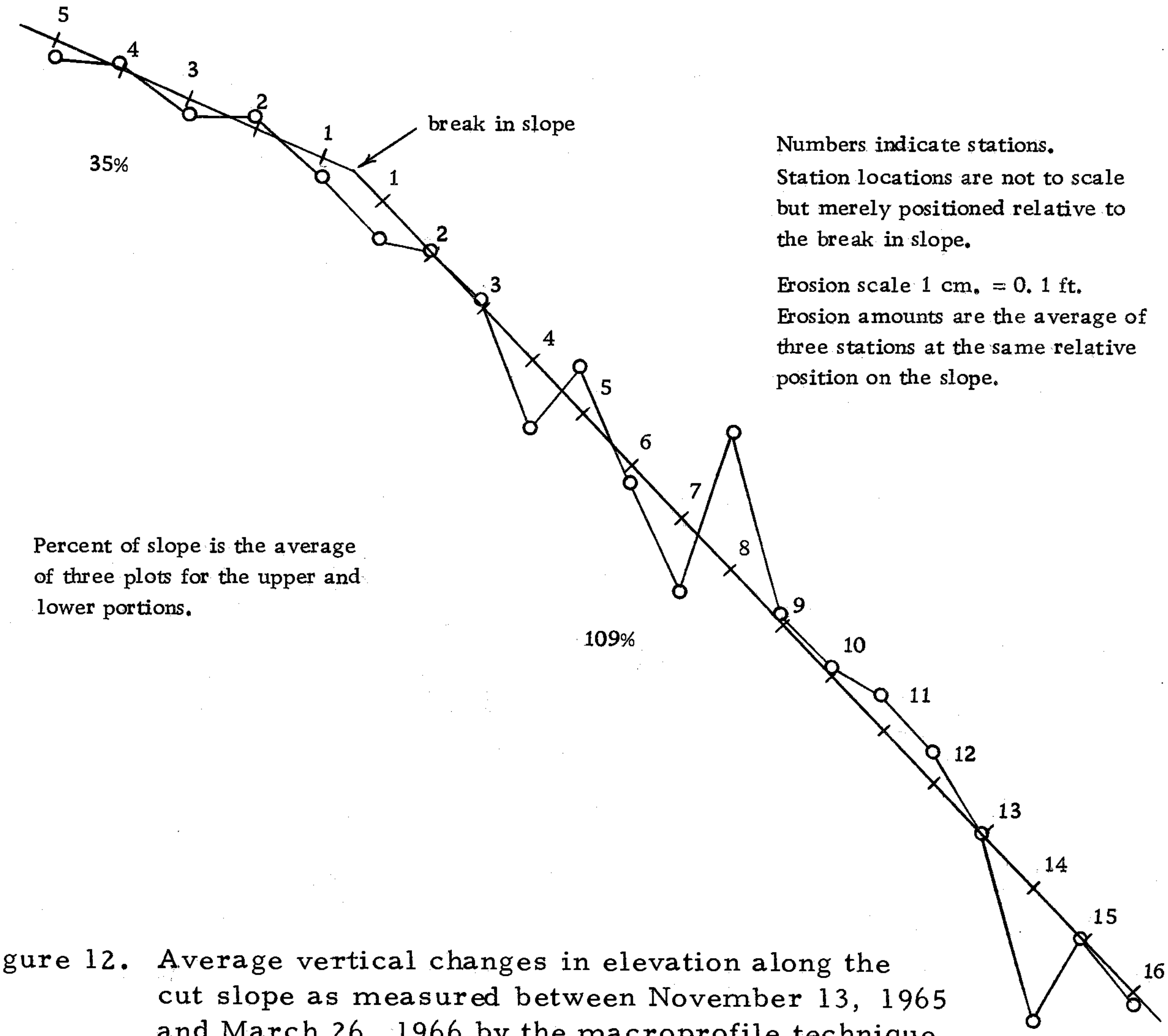


Numbers indicate stations.
Station locations are not to scale but merely positioned relative to the break in slope.

Erosion scale 1 cm.= 0.1 ft.
Erosion amounts are the average of three stations at the same relative position on the slope.

Percent of slope is the average of three plots for the upper and lower portions.

Figure 11. Average vertical changes in elevation along the fill slope as measured between November 6, 1965 and April 2, 1966 by the macroprofile technique.



Numbers indicate stations.
Station locations are not to scale but merely positioned relative to the break in slope.

Erosion scale 1 cm. = 0. 1 ft.
Erosion amounts are the average of three stations at the same relative position on the slope.

Percent of slope is the average of three plots for the upper and lower portions.

Figure 12. Average vertical changes in elevation along the cut slope as measured between November 13, 1965 and March 26, 1966 by the macroprofile technique.

Only the standard, catchment-filter technique, was used to measure erosion from both cut and fill slopes for identical periods (Table VII). Between October 31, 1965 and April 2, 1966, the catchment-filter technique recorded a total of 18.2 tons per acre of material eroding from the cut slope, while the fill slope lost only 5.5 tons per acre. This, in agreement with Wilson's (1963) conclusions, indicates that the cut slope erodes more than the fill slope. Table VII shows only one intermediate period (March 5) where the fill slope eroded more than the cut slope.

Causes of Erosion

The catchment-filter technique was used to measure erosion at weekly intervals[3] on both cut and fill slopes. Total rainfall for these periods was measured at the study area. Rainfall intensities were recorded at the mouth of the Deer Creek drainage one-quarter mile away and about 800 feet lower in elevation. Field notes were made of occurrences of snow and frost. These data are presented in Tables VIII and IX.

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[3] Period ending January 1, was two weeks long.

Table VII. Average amounts of erosion from cut and fill slopes as measured by the catchment-filter technique.

		Average catch of three cut slope plots			Average catch of three fill slope plots		
		Pounds of catch	Erosion in tons/acre[1]	Percentage of total	Pounds of catch	Erosion in tons/acre[2]	Percentage of total
1965							
October	31	---------- catchments installed ----------					
November	6	3.64	1.84[3]	10.13	0.61	0.27	4.88
	13	4.11	2.07	11.38	3.42	1.54	27.85
	20	2.07	1.04	5.72	0.13	0.06	1.08
	28	0.37	0.19	1.04	0.17	0.08	1.45
December	4	0.26	0.13	0.72	0.10	0.04	0.72
	11	0.23	0.12	0.66	0.06	0.03	0.54
	18	4.09	2.06	11.33	0.08	0.04	0.72
1966							
January	1	4.71	2.37	13.03	1.26	0.57	10.31
	8	4.36	2.20	12.09	3.03	1.36	24.59
	15	0.23	0.12	0.66	0.12	0.05	0.91
	22	4.17	2.10	11.54	0.15	0.07	1.27
	29	1.13	0.57	3.13	0.14	0.06	1.08
February	5	0.51	0.26	1.43	0.22	0.10	1.81
	12	0.22	0.11	0.60	0.01	0.01	0.18
	19	0.72	0.36	1.98	0.11	0.05	0.91
	26	0.39	0.20	1.10	0.33	0.15	2.71
March	5	1.42	0.72	3.96	1.78	0.80	14.47
	12	1.15	0.58	3.19	0.17	0.08	1.45
	19	0.75	0.39	2.14	0.09	0.04	0.72
	26	1.13	0.57	3.13	0.09	0.04	0.72
April	2	0.38	0.19	1.04	0.20	0.09	1.63
Totals		36.04	18.19	100.00	12.27	5.53	100.00

[1] Average size of cut slope plots = 43.2 ft^2 = 0.0099 A.

[2] Average size of fill slope plots = 48.5 ft^2 = 0.0111 A.

[3] Average of two plots--value from plot 3 was invalid.

Table VIII. Average amounts of erosion from the cut slope as measured by the catchment-filter in descending order of magnitude for periods of one week.[1]

	Ending date of measurement period	Erosion	Percent of total erosion	Total rainfall	Maximum rainfall intensity	Frost	Snow depth
	(date)	(tons/acre)	(%)	(inches)	(inches/hour)	(occurrence)	(inches)
1	Jan. 1	2.37	13.03	16.98	0.50	x	14
2	Jan. 8	2.20	12.09	9.00	0.33	x	
3	Jan. 22	2.10	11.54	0.14	0.04	x	
4	Nov. 13	2.07	11.38	6.50	0.35		
5	Dec. 18	2.06	11.33	0.24	0.02	x	
6	Nov. 6	1.84	10.13	2.97	0.80		
7	Nov. 20	1.04	5.72	3.08	0.25		
8	Mar. 5	0.72	3.96	2.71	0.20		3
9	Mar. 12	0.58	3.19	8.87	0.37		
10	Jan. 29	0.57	3.13	2.41	0.12		
11	Mar. 26	0.57	3.13	1.87	0.50		
12	Mar. 19	0.39	2.14	4.93	0.30		0.5
13	Feb. 19	0.36	1.98	0.69	0.25		
14	Feb. 5	0.26	1.43	2.22	0.02		
15	Feb. 26	0.20	1.10	1.75	0.19		
16	Nov. 28	0.19	1.04	3.54	0.25		
17	Apr. 2	0.19	1.04	0.14	0.03		
18	Dec. 4	0.13	0.72	2.88	0.27		
19	Jan. 15	0.12	0.66	4.96	0.25		
20	Dec. 11	0.12	0.66	1.47	0.05		
21	Feb. 12	0.11	0.60	3.68	0.20		
	Total	18.19	100.00	81.03			

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[1] Period ending January 1 is two weeks long.

Table IX. Average amounts of erosion from the fill slope as measured by the catchment-filter in descending order of magnitude for periods of one week.[1]

	Ending date of measurement period	Erosion	Percent of total erosion	Total rainfall	Maximum rainfall intensity	Frost	Snow depth
	(date)	(tons/acre)	(%)	(inches)	(inches/hour)	(occurrence)	(inches)
1	Nov. 13	1.54	27.85	6.50	0.35		
2	Jan. 8	1.36	24.59	9.00	0.33	x	
3	Mar. 5	0.80	14.47	2.71	0.20		3
4	Jan. 1	0.57	10.31	16.98	0.50	x	14
5	Nov. 6	0.27	4.88	2.97	0.80		
6	Feb. 26	0.15	2.71	1.75	0.19		
7	Feb. 5	0.10	1.81	2.22	0.02		
8	Apr. 2	0.09	1.63	0.14	0.03		
9	Nov. 28	0.08	1.45	3.54	0.25		
10	Mar. 12	0.08	1.45	8.87	0.37		
11	Jan. 22	0.07	1.27	0.14	0.04	x	
12	Nov. 20	0.06	1.08	3.08	0.25		
13	Jan. 29	0.06	1.08	2.41	0.12		
14	Feb. 19	0.05	0.91	0.69	0.25		
15	Jan. 15	0.05	0.91	4.96	0.25		
16	Mar. 19	0.04	0.72	4.93	0.30		0.5
17	Dec. 4	0.04	0.72	2.88	0.27		
18	Mar. 26	0.04	0.72	1.87	0.50		
19	Dec. 18	0.04	0.72	0.24	0.02	x	
20	Dec. 11	0.03	0.54	1.47	0.05		
21	Feb. 12	0.01	0.18	3.68	0.20		
	Totals	5.53	100.00	81.03			

[1] Period ending January 1 is two weeks long.

Data from this study indicated no relation between erosion and rainfall. Graphs of erosion versus total rainfall, maximum rainfall intensity, and the product of total rainfall and maximum 30 minute rainfall intensity (in/hr.) all indicated no relation on either cut or fill slopes. Smith and Wischmeier (1962) found a high correlation of erosion with rainfall factors. The seeming lack of correlation of erosion with amount and intensity of rainfall may be due to low amounts and low intensities of rainfall in most storms. The effects of other factors in the erosion process may have been great enough to mask the effects of rainfall. The high permeability rates in relation to the intensities of rainfall probably reduced the effect of rainfall. Little erosion was recorded during some periods of relatively high intensity rains. The permeability of the exposed layers of soil (Table I) were found to be greatly in excess of the highest recorded rainfall intensity.

Frost was apparently a major cause of erosion on steep cut slopes, but on the gentler fill slopes, frost was not directly related to erosion. The data will not support a definite conclusion, but the significance of frost as a cause of erosion on steep cut banks is supported by Sharpe (1938) and Diseker (1959b). The four periods that are known to have included occurrences of frost (Tables VIII and IX) were associated with 48 percent of the erosion from the cut slope, and the rates of erosion during these four periods rank among the six largest rates of erosion from this slope. These same four periods, although they are associated with 40 percent of the erosion from the fill slope, are scattered throughout the fill slope data. It appears from this data that where topography is steep (45 degrees or greater), a particle detached by frost is moved to the base of the slope by the force of gravity, but on gentler slopes other factors have a greater influence on the amounts of erosion.

With external surface runoff excluded by plot boundaries, the most important difference in factors of erosion for these two slopes is percent of slope. Particles detached from the cut slope fell to the base of the slope. Gravity alone usually did not move detached particles to the base of the fill slope. Additional forces were not usually available.

The effect of snow cannot be determined from these data. Snow fell on three known occasions (Tables VIII and IX). Although some inferences might be drawn, none are attempted.

Frost, snow-melt, and high total precipitation seem to have interacted and caused higher rates of erosion than any of these factors working independently. January 8 was associated with the second largest total amount of precipitation, frost occurrence, and the melting of 14 inches of snow. The maximum rate of erosion ($lb/ft^2/day$) from the cut slope, and the second largest rate of erosion from the fill slope occurred during this period.

The week ending November 13 accounted for the highest rate ($lb/ft^2/day$) of erosion from the fill slope and the third highest rate of erosion from the cut slope. Krammes (1965) indicates that dry raveling is a major source of erosion on some slopes in California. Dry raveling followed by rain may be the cause of the high erosion rates for this period. The disturbance caused by road building may have left loose material on the slopes, and the first fall storm may have washed this material into the catchments. In any case, the rates of erosion for the period ending November 13 are not entirely explained.

DISCUSSION

Comparison of Techniques

One method of erosion measurement cannot be used to predict the results of another because of the extreme variability within the elevational differences techniques. The catchment-filter method measures the amount of soil moving off of the plot. The elevational difference techniques record changes in elevation at points. Any change in elevation must be accounted for either in a change in elevation at another point, increases in the catchment, or changes in bulk density.

Material caught by the catchment-filter technique may not have originated at a point measured by an elevational difference method. Likewise, material moving away from an elevational measurement point will not necessarily be deposited in the catchment or come to rest at another point where elevational change is measured. Intensive sampling might solve the problem, but the sampling intensity is already nearly one point of elevational change for every square foot of surface. A more intensive sample would be impractical and is statistically unnecessary. The variation must be caused by problems within the techniques.

The elevational difference techniques include changes in bulk density. Changes in bulk density may cause changes in elevation. The surface soil may swell or compact depending upon frost action, moisture content, clay content, raindrop impacts, and other factors. A measured change in elevation may be due to loss or deposits of soil, or it may be due to a change in the nature of the soil through one of the factors mentioned above while no actual change in the amount of soil present has occurred. Bulk density measurements taken during this study were limited, but the range of values obtained for bulk density, when applied to the measurements as they would have been applied, would account for a difference of 0.01 pound per square foot. A change of this amount would not explain the variation within nor between the methods.

The sensitivity of measurement of each technique may be a source of variation. The sensitivity of four techniques, ignoring operational errors, is presented in Table X. The catchment-filter provides measurements to the nearest tenth of a pound, the macroprofile and spike and washer techniques provide measurements to the nearest hundredth of a foot, and the soil erosion gage reads to the nearest hundredth of an inch. The changes in elevation times the weighted (by area) average bulk density over the plots, 1.10, times the density of water, 62.4 pounds per cubic foot, provided the weights listed in Table X.

The variation caused within a technique by difficulties in the field has not been quantified. Each technique has unique problems that can contribute to errors. In general, an individual working on a steep cut slope is more likely to make measurement mistakes than when working on the gentler fill slopes. Bad weather can increase the likelihood of errors in the field on either slope.

Table X. Sensitivity of the four measurement techniques.

Technique	Elevational Change		Weight (lb/ft^2)
catchment-filter			0.027
soil erosion gage	0.01 0.00083	in. ft.	0.057
macroprofile	0.01	ft.	0.686
spike and washer	0.01	ft.	0.686

The most significant problem that would cause variation of the catchment-filter technique is obtaining a representative sample of the soil and water retained by the filter for moisture content determinations. The proportions of soil and water to include in the sample were difficult to determine, and large volumes of water retained by a clogged filter often confounded the problem. The low standard deviation for this technique listed in Table VI indicates that the sampling procedure was consistent. The catchment capacity was never exceeded during the study, but the filter clogging would have caused such a problem if runoff and erosion had been more severe. The metal funnel that was used to channel the runoff and sediment from the plot to the catchment was sealed against the slope. The seals occasionally failed during the course of the study, but the leaks were small and promptly patched so that only a small amount of material could have been lost in this manner. On the cut slopes, some of the material retained in the catchments had bounded over the plot boundaries. The effect appeared to be random, and undoubtedly the material introduced from outside the plot equaled the amount moving off the plot to locations outside the catchment.

The difficulties of use of the macroprofile technique include proper stringing and location of the cable, and weight changes in the cable and tape due to accumulations of soil and moisture. Use of the erosion gage includes problems of instrument location, movement of reference points, slippage of set screws on the instrument, and incorrect reading of the vernier. The spike and washer method suffered from problems of sediment deposits that buried installations, pedestalling under the washer, adherence of soil particles to the spike between the spike head and the washer, and prevention of erosion by the presence of a barrier spike. Measurements for all three elevational differences techniques were made vertically. The variation within and between these methods is so large that even if correction for slope, which is about 15 percent, were applied, the final conclusions would remain the same. However, since vertical elevational differences were used in the computations, the values obtained for the three elevational differences techniques are relative amounts of erosion rather than actual amounts.

If reasonable care is exercised, the field problems of the erosion gage and the macroprofile techniques probably are insignificant. Except for the problem of obtaining a sample of the moisture content, the problems of use of the catchment-filter technique are probably also insignificant. However, the problems inherent in using the spike and washer technique are sufficient to make the results meaningless.

The factors causing elevational changes cannot be held constant, and it would be impractical to increase sampling intensity. Therefore, the macroprofile and erosion gage techniques cannot be used to measure amounts or erosion. However, elevational differences techniques may have limited application in qualitative studies of the erosion process, if the limitations of precision are acceptable.

The Erosion Process

This study was designed to compare techniques for measuring erosion, and this objective had been accomplished. However, the data has also been used to draw conclusions about erosion and the erosion process. The study area was visited only on weekends. Frost and/or snow may have occurred during the week, for which no data is available. If the data were complete, some of the relationships might become clear. Conclusions about the erosion process based upon the limited data can only be accepted with reservations.

The establishment of plot boundaries on these slopes introduced an artificial condition where the measurements were being made. The study plots were designed to exclude external surface runoff. How these slopes would have eroded under concentrations of surface runoff is unknown. The permeabilities recorded for surface soil (Table 1) are greater than any recorded rainfall intensity. Perhaps no surface runoff would have occurred even if plot boundaries had not been installed. However, concentrated surface runoff has caused extensive rill and gully erosion as it flowed across the fill slope at other locations. Rill and gully erosion have not been observed on the cut slopes. Additional work needs to be done to determine the rainfall intensity and duration necessary before surface runoff will occur and to determine the effect of concentrated runoff on erosion from cut and fill slopes.

The catchment-filter technique recorded 18.2 and 5.5 tons of erosion from cut and fill slopes respectively for a 22 week period. Wilson (1963) in the Cascade Mountains of Oregon recorded 60.5 tons per acre from cut slopes for an average six month period. Diseker (1959a) caught 27 tons per acre from road banks in Georgia. The erosion amounts recorded by the catchment-filter may be low, but they are not entirely unrealistic. However, in light of the study objectives and the artificial conditions imposed, these values should be considered as valid only for these plots.

Future Work

This study ran through a typical winter in the Oregon Coast Range. Most of the precipitation for the year fell during this period. How significant dry ravel may be for this area is still unknown. Additional work should be done to determine the significance of this type of erosion.

Further studies should include the use of elevational difference techniques to measure the response of the soil surface to the erosive forces. Any measurements of erosion rates, however, should be done with a catchment or sampler technique. Additional studies should also be made of the amounts of erosion originating from logging roads, under various conditions of soil and slope.

SUMMARY OF CONCLUSIONS

Four methods of erosion measurement--catchment-filter, macroprofile, soil erosion gage, and spike and washer--were compared on cut and fill slopes of a newly constructed logging road in the Oregon Coast Range. Data from this study indicate that

1. The results of any one of these four techniques cannot be used to predict the results of any other.
2. In this study the spike and washer technique gave results far different from the other methods indicating major amounts of deposition while the other techniques indicated erosion.
3. The soil erosion gage and macroprofile methods may have application for studying the erosion process, but the catchment-filter method should be used to measure amounts of erosion.
4. The total amount of erosion was essentially uniform over each of the slopes studied--both up and down slopes and across the plots.
5. Under the artificial conditions imposed on the study area, the cut slope eroded three times as much as the fill slope.
6. From these limited data frost appeared to have some influence on erosion from steep cut slopes.

7. The first fall storm caused the greatest rate of erosion from the fill slope.
8. No relations were found in this data between rainfall--as an independent causitive agent--and erosion.

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APPENDICES

APPENDIX I

Relative amounts of erosion--listed by plot for each technique and all measurement periods.

Table XI. Cut Slope Plot 1. Relative amounts of erosion as determined by four techniques for all measurement periods.

Date	Catchment - Filter			Macroprofile	Soil Erosion Gage	Spike & Washer
	(total lbs.)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)
Oct. 31 '65	installed	installed	installed		initial reading	
Nov. 6, '65	-3.79	-0.0819				
13	-0.34	-0.0073	-0.0892	initial reading	-1.5587	
20	-1.48	-0.0320				
28	-0.58	-0.0125	-0.0445		+0.6674	initial reading
Dec. 4, '65	-0.15	-0.0032				
11	-0.31	-0.0067	-0.0099	-1.1190	+0.0914	+0.7962
18	-3.21	-0.0693				
Jan. 1, '66	-3.88	-0.0838				
8	-3.38	-0.0731	-0.2262	-0.2613	-1.0559	+0.8901
15	-0.10	-0.0022				
22	-4.27	-0.0923	-0.0945	+1.8343	-2.0190	+0.8712
29	-1.93	-0.0417				
Feb. 5, '66	-1.03	-0.0222	-0.0639	-0.3607	-0.4503	-0.7577
12	-0.18	-0.0039				
19	-0.61	-0.0132				
26	-0.61	-0.0132	-0.0303	-0.5546	+0.1482	+3.2445
March 5, '66	-2.07	-0.0447				
12	-0.53	-0.0114				
19	-0.17	-0.0036				
26	-0.45	-0.0097	-0.0694	-1.3471	-0.2974	+3.1540
April 2, '66	-0.27	-0.0058				
Totals	-29.34	-0.6337	-0.6279	-1.8084	-4.4743	+8.1983

Table XII. Cut Slope Plot 2. Relative amounts of erosion as determined by four techniques for all measurement periods.

Date	Catchment - Filter (total lbs.)	(lbs/ft^2)	(lbs/ft^2)	Macroprofile (lbs/ft^2)	Soil Erosion Gage (lbs/ft^2)	Spike & Washer (lbs/ft^2)
Oct. 31, '65	installed	installed	installed		initial reading	
Nov. 6, '65	-3.49	-0.0851				
13	-8.82	-0.2150	-0.3001	initial reading	+2.3384	
20	-3.12	-0.0761				
28	-0.22	-0.0053	-0.0814	-0.3208	-0.1333	initial reading
Dec. 4, '65	-0.09	-0.0022				
11	-0.20	-0.0049	-0.0071	-1.1394	-0.7118	+0.2679
18	-5.99	-0.1460				
Jan. 1, '66	-10.26	-0.2501				
8	-4.91	-0.1197	-0.5158	-1.4532	-1.4155	-1.2104
15	-0.28	-0.0068				
22	-2.61	-0.0637	-0.0705	+0.9166	+0.6726	+1.5709
29	-0.59	-0.0144				
Feb. 5, '66	-0.30	-0.0074	-0.0218	-0.5902	-1.1460	+0.8773
12	-0.33	-0.0080				
19	-0.78	-0.0190				
26	-0.41	-0.0100	-0.0370	+0.2145	-0.0990	-1.1695
March 5, '66	-1.79	-0.0436				
12	-1.33	-0.0325				
19	-1.17	-0.0285				
26	-2.31	-0.0563	-0.1609	-1.400	-0.0316	0.0000
April 2, '66	-0.78	-0.0190				
Totals	-49.78	-1.2136	-1.1946	-3.7725	-0.5262	+0.3362

Table XIII. Cut Slope Plot 3. Relative amounts of erosion as determined by four techniques for all measurement periods.

Date			Catchment - Filter			Macroprofile	Soil Erosion Gage	Spike & Washer
			(total lbs.)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)
Oct.	31	'65	installed	installed	installed		initial reading	
Nov.	6,	'65	no reading	no reading				
	13		-3.18	-0.0749	-0.0749	initial reading	-0.3787	
	20		-1.61	-0.0379				
	28		-0.31	-0.0073	-0.0452	+1.0744	-0.5836	initial reading
Dec.	4,	'65	-0.54	-0.0127				
	11		-0.19	-0.0045	-0.0172	+0.6217	-0.4303	+0.4030
	18		-3.08	-0.0725				
Jan.	1,	'66	-2.51	-0.0591				
	8		-4.71	-0.1109	-0.2425	-0.1658	-1.4571	+1.2216
	15		-0.30	-0.0071				
	22		-5.62	-0.1324	-0.1395	+0.8818	+0.1628	no reading
	29		-0.87	-0.0205				
Feb.	5,	'66	-0.21	-0.0049	-0.0254	-5.2650	-0.4485	no reading
	12		-0.16	-0.0038				
	19		-0.79	-0.0186				
	26		-0.15	-0.0035	-0.0259	+7.0956	+0.1412	no reading
March	5,	'66	-0.39	-0.0092				
	12		-1.59	-0.0374				
	19		-0.92	-0.0216				
	26		-0.65	-0.0153	-0.0835	+0.1760	-0.3168	+0.9767
April	2,	'66	-0.09	-0.0021				
Totals			-27.87	-0.6562	-0.6541	+4.4187	-3.3110	+2.6013

Table XIV. Fill Slope Plot 4. Relative amounts of erosion as determined by four techniques for all measurement periods.

Date	Catchment - Filter			Macroprofile	Soil Erosion Gage	Spike & Washer
	(total lbs.)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)
Oct. 31 '65	installed	installed	installed			
Nov. 6, '65	-0.23	-0.0047	-0.0047		initial reading	
13	-0.71	-0.0144				
20	-0.08	-0.0016	-0.0160	initial reading	-1.3255	initial reading
28	-0.33	-0.0067				
Dec. 4, '65	-0.02	-0.0004	-0.0071	-0.8486	+0.0117	+0.7352
11	-0.18	-0.0036				
18	-0.12	-0.0024	-0.0060	+2.6708	+3.5123	+0.6818
Jan. 1, '66	-1.02	-0.0206				
8	-3.74	-0.0757				
15	-0.10	-0.0020	-0.0983	-3.9578	-2.3500	+3.2915
22	-0.18	-0.0036				
29	-0.11	-0.0023	-0.0059	+2.4191	-0.2583	-2.7599
Feb. 5, '66	-0.07	-0.0014				
12	-0.01	-0.0002				
19	-0.10	-0.0020	-0.0036	-0.1233	-0.5358	+12.1174
26	-0.18	-0.0036				
March 5, '66	-5.21	-0.1055				
12	-0.24	-0.0049	-0.1140	-0.8508	-0.0180	+3.1126
19	-0.07	-0.0014				
26	-0.21	-0.0043				
April 2, '66	-0.42	-0.0085	-0.0142	+0.3421	+0.1660	-2.7510
Totals	-13.33	-0.2698	-0.2698	-0.3485	-0.7976	+14.4276

Table XV. Fill Slope Plot 5. Relative amounts of erosion as determined by four techniques for all measurement periods.

Date	Catchment - Filter			Macroprofile	Soil Erosion Gage	Spike & Washer
	(total lbs.)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)
Oct. 31 '65	installed	installed	installed			
Nov. 6, '65	-1.42	-0.0291	-0.0291		initial reading	
13	-9.09	-0.1863				
20	-0.28	-0.0057	-0.1920	initial reading	-0.1984	initial reading
28	-0.10	-0.0020				
Dec. 4, '65	-0.13	-0.0027	-0.0047	-0.8121	-0.0703	+1.0398
11	-0.00	-0.0000				
18	-0.04	-0.0008	-0.0008	+1.5883	+2.1138	-0.0180
Jan. 1, '66	-2.51	-0.0514				
8	-4.82	-0.0988				
15	-0.16	-0.0033	-0.1535	-1.8752	-1.8457	-0.6668
22	-0.12	-0.0025				
29	-0.14	-0.0029	-0.0054	+1.0361	-0.2682	+0.3020
Feb. 5, '66	-0.25	-0.0051				
12	-0.00	-0.0000				
19	-0.13	-0.0027	-0.0078	+0.1299	+0.0483	-0.6073
26	-0.09	-0.0018				
March 5, '66	-0.05	-0.0010				
12	-0.14	-0.0029	-0.0057	+0.1390	+0.0611	+9.1146
19	-0.08	-0.0016				
26	-0.04	-0.0008				
April 2, '66	-0.07	-0.0014	-0.0038	+0.1252	-0.3930	-5.0340
Totals	-19.66	-0.4028	-0.4028	+0.3312	-0.5524	+4.1303

Table XVI. Fill Slope Plot 6. Relative amounts of erosion as determined by four techniques for all measurement periods.

Date	Catchment - Filter			Macroprofile	Soil Erosion Gage	Spike & Washer
	(total lbs.)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)	(lbs/ft^2)
Oct. 31 '65	installed	installed	installed			
Nov. 6, '65	-0.19	-0.0040	-0.0040		initial reading	
13	-0.47	-0.0099				
20	-0.05	-0.0011	-0.0110	initial reading	-0.2634	initial reading
28	-0.09	-0.0019				
Dec. 4, '65	-0.14	-0.0030	-0.0049	-2.5521	+0.2116	+0.5084
11	-0.00	-0.0000				
18	-0.04	-0.0008	-0.0008	+4.2860	+1.6060	+0.6048
Jan. 1, '66	-0.24	-0.0051				
8	-0.52	-0.0110				
15	-0.09	-0.0019	-0.0180	-3.2882	-2.4142	-0.2106
22	-0.14	-0.0030				
29	-0.18	-0.0038	-0.0068	+0.6320	+0.4423	-0.0917
Feb. 5, '66	-0.33	-0.0070				
12	-0.01	-0.0002				
19	-0.09	-0.0019	-0.0091	+0.2696	-0.3433	+0.0871
26	-0.72	-0.0153				
March 5, '66	-0.08	-0.0017				
12	-0.13	-0.0027	-0.0197	+0.2138	-0.1911	+0.6376
19	-0.12	-0.0025				
26	-0.04	-0.0008				
April 2, '66	-0.10	-0.0021	-0.0054	+0.3021	-1.0932	-0.3731
Totals	-3.77	-0.0797	-0.0797	-0.1368	-2.0453	+1.1625

APPENDIX II

Final profile of erosion and deposition on each plot of the cut and fill slope.

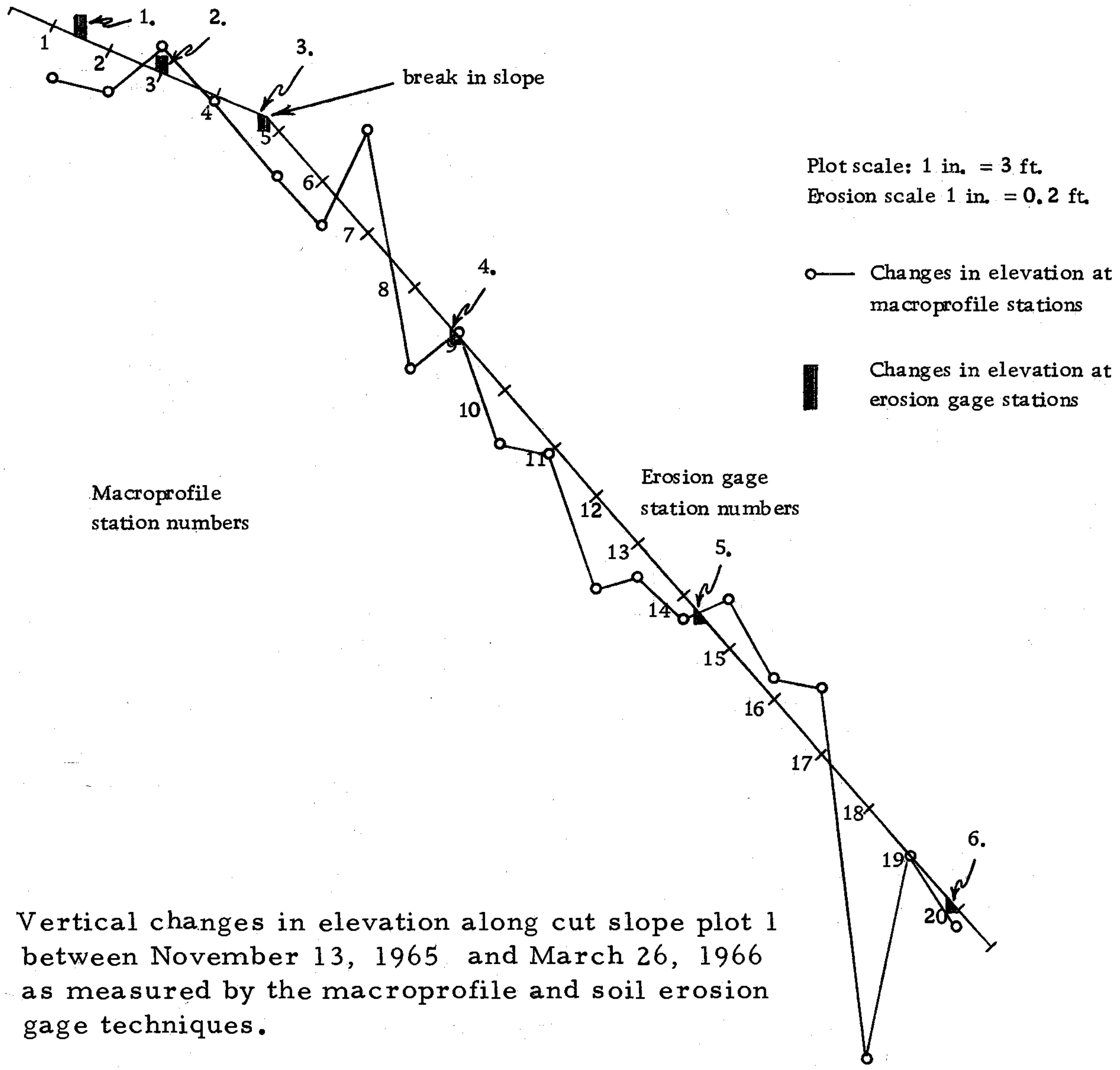

Figure 13. Vertical changes in elevation along cut slope plot 1 between November 13, 1965 and March 26, 1966 as measured by the macroprofile and soil erosion gage techniques.

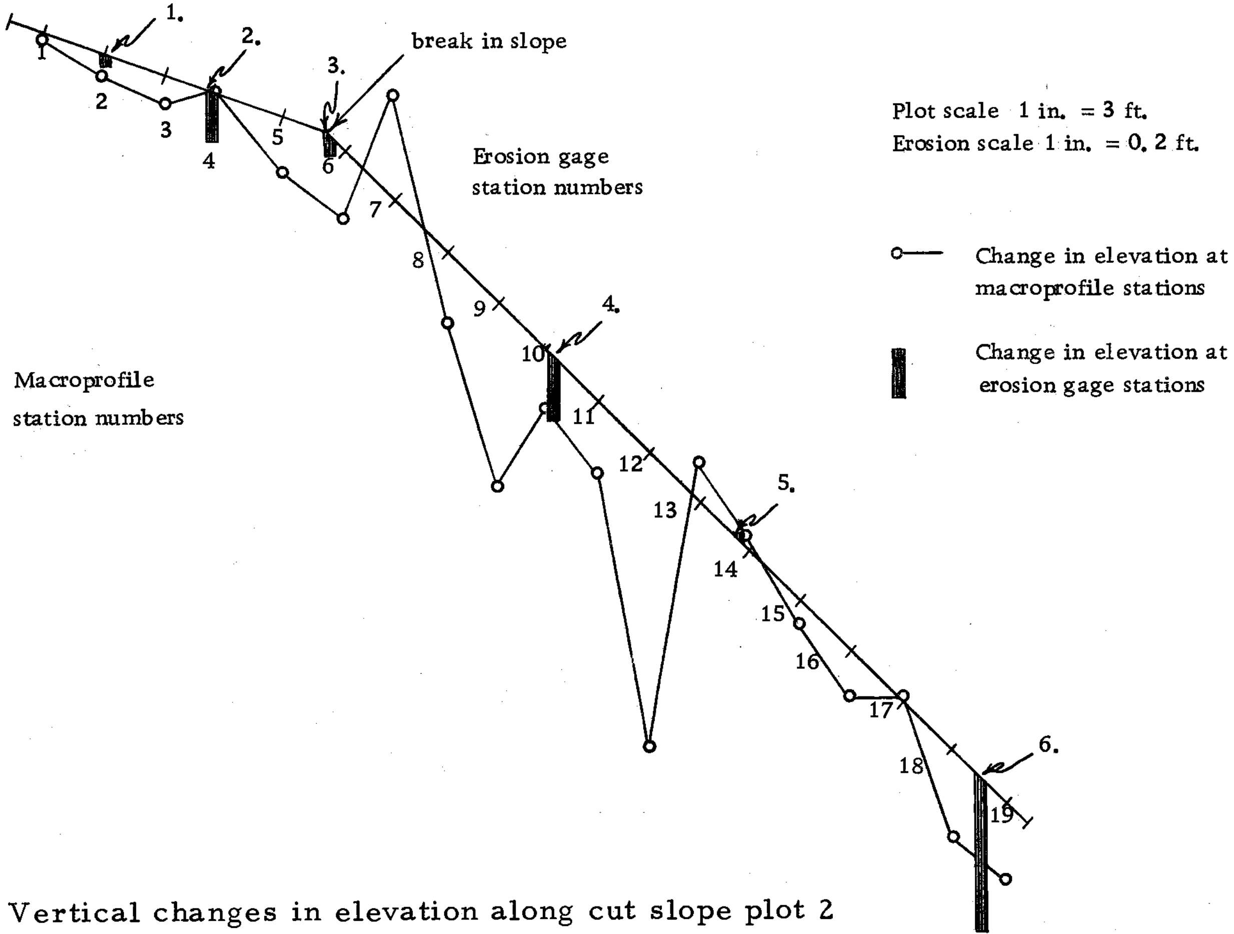

Figure 14. Vertical changes in elevation along cut slope plot 2 between November 13, 1965 and March 26, 1966 as measured by the macroprofile and soil erosion gage techniques.

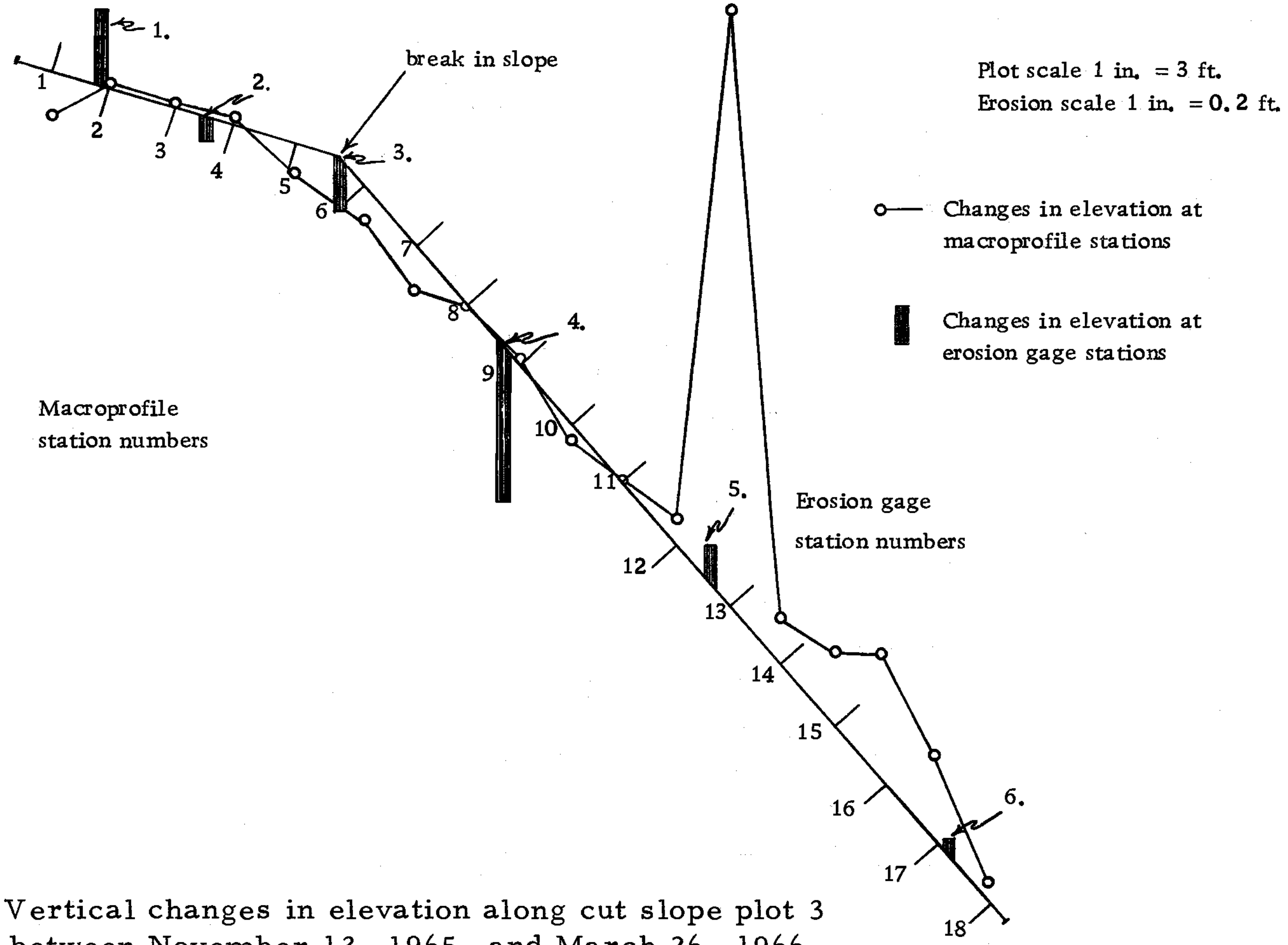

Figure 15. Vertical changes in elevation along cut slope plot 3 between November 13, 1965 and March 26, 1966 as measured by the macroprofile and soil erosion gage techniques.

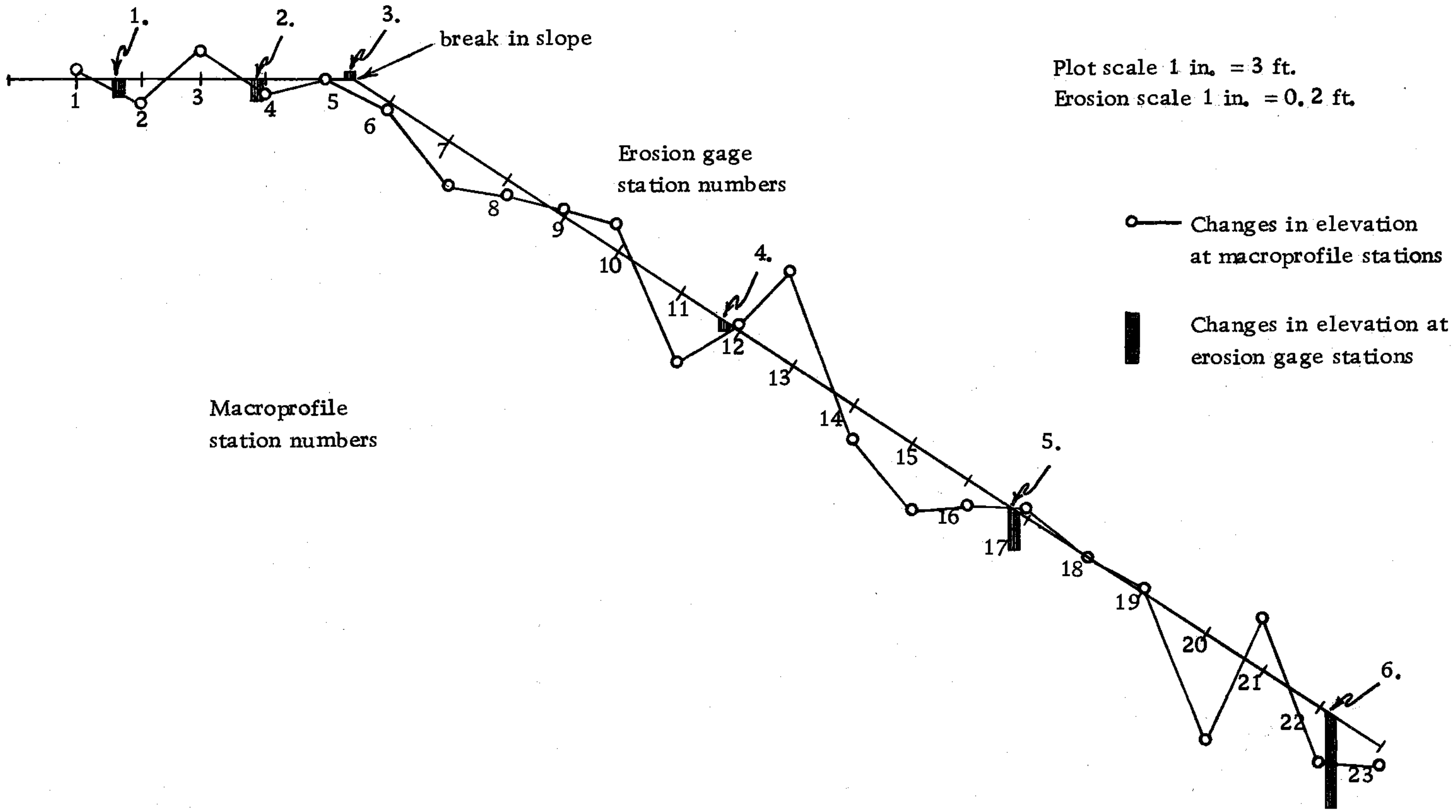

Figure 16. Vertical changes in elevation along fill slope plot 4 between November 6, 1965 and April 2, 1966 as measured by the macroprofile and soil erosion gage techniques.

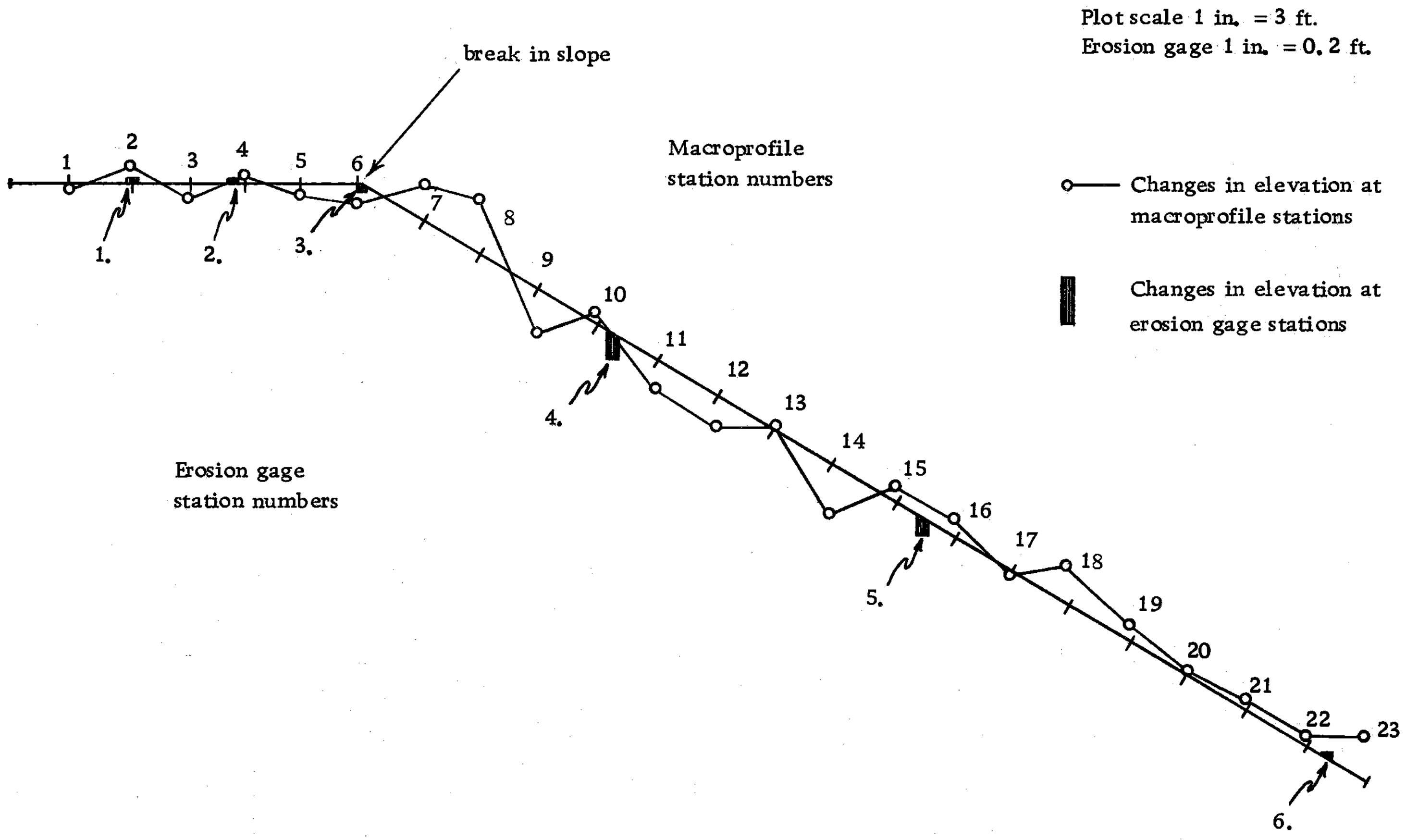

Figure 17. Vertical changes in elevation along fill slope plot 5 between November 6, 1965 and April 2, 1966 as measured by the macroprofile and soil erosion gage techniques.

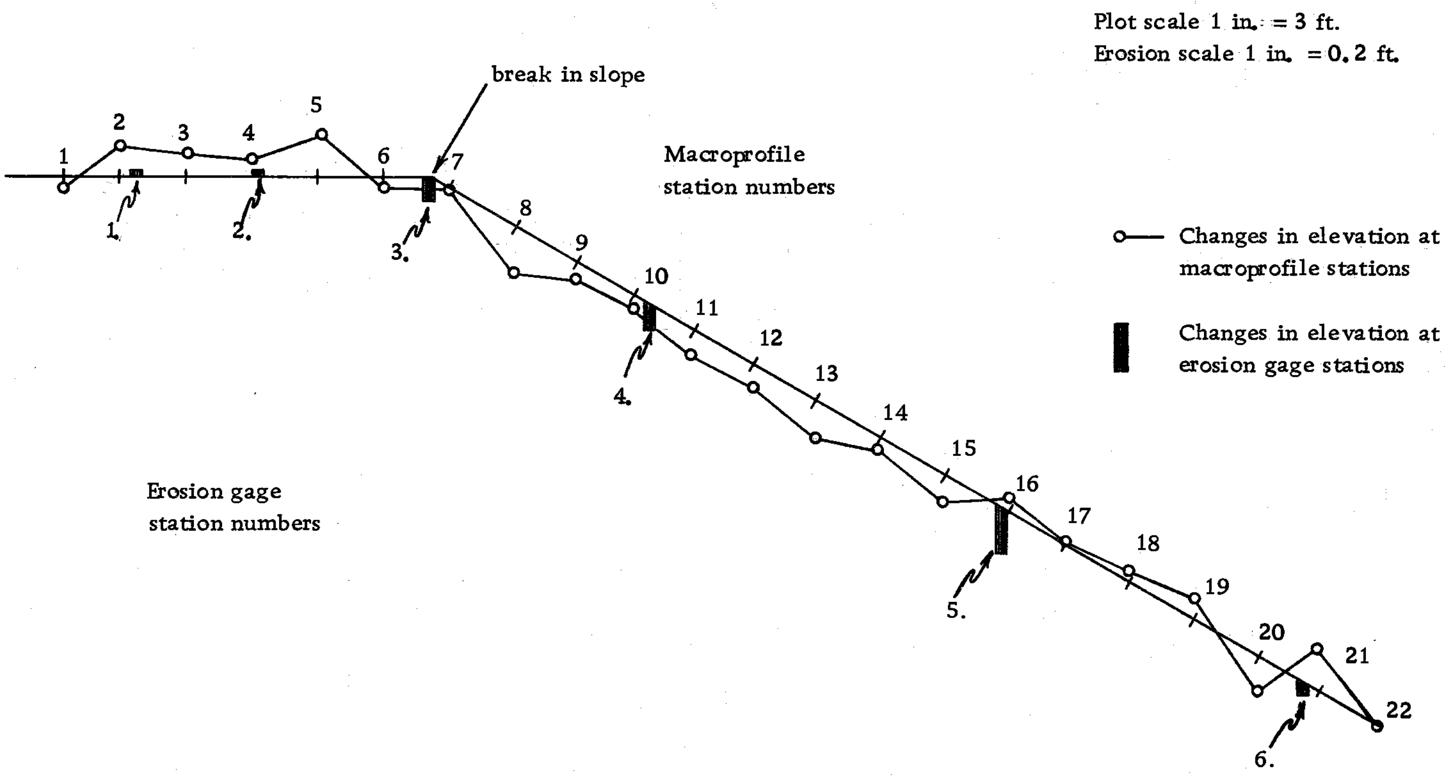

Figure 18. Vertical changes in elevation along fill slope plot 6 between November 6, 1965 and April 2, 1966 as measured by the macroprofile and soil erosion gage techniques.

APPENDIX III

Procedures to compute the weights of erosion for the catchment-filter-erosion measurement technique, and the volumes and weights of erosion for the macroprofile, soil erosion gage, and spike and washer techniques of erosion measurement.

Methods of the Catchment-Filter Technique

In this section the procedure for computing the dry weight of the catch and the procedure for obtaining the values needed for this computation are presented.

Constants Used and Method of Determination

All rock was assumed saturated at 13.8 percent moisture content by weight. This value was determined from a laboratory wetting and oven drying of a rock sample.

Field Measurements

The field measurements were made with a scale reading to the nearest 0.1 pound. (0.1 pound spread over the average plot size of 45.9 square feet at a bulk density of 1.09 will form a layer 3×10^{-5} feet deep.) The following measurements were made in the field for each installation of the catchment-filter technique each time the installations were checked.

tare = the weight of the bucket.

tare + rock + filter + soil + water = bucket + entire contents of the catchment-filter device.

tare + rock = bucket + rock fraction of catch.

Rock was considered to be all particles (greater than 1.22 inches in diameter) retained on the debris screen of the catchment-box. (See Text)

Laboratory Determinations

The following measurements were made in the laboratory on samples from each catchment box:

wet weight of soil moisture sample can and sample--nearest 0.01 g.

dry weight of soil moisture sample can and sample--nearest 0.01 g.

after 24 hours of drying at 105° Centigrade.

clean dry weight of soil moisture sample can--nearest 0.01 g.

clean dry weight of the filter--nearest 0.01 g. This value was converted to pounds by dividing by 454 g/lb.

Values Computed

$$\text{Dry weight of catch (lbs)} = \frac{\text{soil + water}}{1 + \dfrac{\text{water sample}}{\text{soil sample}}} + \frac{\text{(tare + rock) - (tare)}}{\text{1 + moisture content of rock}} \qquad (1)$$

soil + water = (tare + soil + filter + water) - (tare) - (filter)

filter = clean dry weight of filter in pounds

water sample = (wet weight of soil moisture can and sample) - (dry weight of soil moisture can and sample) soil sample = (dry weight of soil moisture sample can and sample)

- (clean dry weight of soil moisture sample can)

moisture content of rock = 0.138

Methods of the Macroprofile Technique

In this section the procedure for computing the weight of material moved off of the plots and the procedure for obtaining the values needed for this computation are presented for the macroprofile technique.

Constants Used and Method of Determination

Cable Spacing. The cables were placed six inches from each side of the plots, or one foot apart, and ran parallel to the sides of the plot. The plots were two feet wide. Therefore, the plots were divided lengthwise in half and one cable ran down the center of each half.

Slope. The slope of each plot was determined with a hand abney and level rod. Two values were determined for each plot--one for the upper portion of the plot and one for the lower portion of the plot. The lengths and numbers of stations included in each portion of each plot are listed in Table XVIII.

Bulk Density. The fill slope plots were considered to be a uniform mixture of soil and rock. For that reason, one bulk density value was taken from the fill slope near each plot. The average of these values was assumed to be the bulk density of the fill slope, and was used in all conversions of volume of soil to weight of soil for this slope.

The cut slope plots were considered to have two values for bulk density--one for the upper portions of the plots and one for the lower portion of the plots. One measurement of the bulk density of the lower portion of the cut face was taken near each of the three cut slope plots. The three values thus determined were averaged to provide a conversion factor for the lower portion of the cut slope plots. One measurement of the bulk density near the upper portion of each cut slope plot revealed great variation between plots. Additional measurements were taken near each plot and the average of three values provided the conversion factor for the top portion of the cut slope plot. The values thus determined are listed in Table XVII.

Figure 4 in the text illustrates the stratification of the cut face. The soil grades from highly organic to bed rock. The bulk density values were assumed to change at the transition zone between soil and bedrock. The station numbers included in each zone are listed in Table XVII.

Table XVII. Bulk density values used to convert volumes to weight.

Plot	Zone	Bulk Density	Macroprofile Stations (t)[1] Included	Soil Erosion Gage Stations (t) Included	Spike & Washer Stations (t) Included
1	Upper Portion	0.498	1-8	1-3	1-3
	Lower Portion	1.308	9-20	4-6	4-6
2	Upper Portion	0.539	1-8	1-3	1-3
	Lower Portion	1.308	9-19	4-6	4-6
3	Upper Portion	0.270	1-8	1-3	1-3
	Lower Portion	1.308	9-18	4-6	4-6
4	Entire Plot	1.178	1-23	1-6	1-6
5	Entire Plot	1.178	1-23	1-6	1-6
6	Entire Plot	1.178	1-22	1-6	1-6

[1] (t) is the station number used in all volume computations, Equations 2 through 21.

Data Gathered in the Field

The change in the distance between the cable and the ground surface was determined by subtracting the most recent reading from the previous reading. The readings were the distance that the tape (Figures 7, 8, and 19) had to be extended so that the tip of the plumb bob just touched the ground. Two readings were taken at each station--one from each cable. (Figure 20)

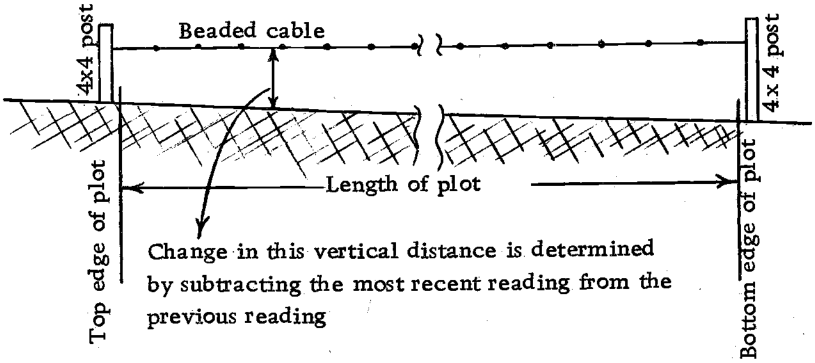

Figure 19. Distance measured by the macroprofile technique.

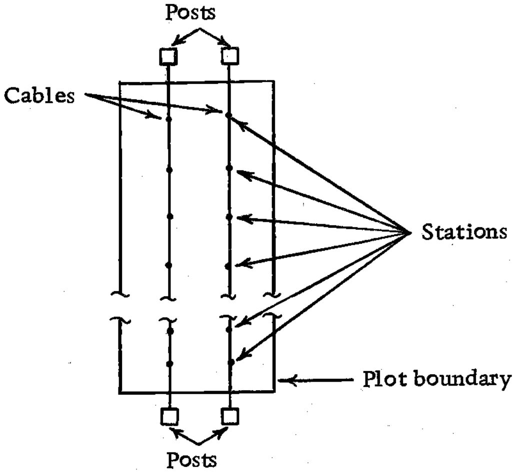

Figure 20. Macroprofile station positions on the plots.

Computational Procedures

For the purposes of calculation, the slope was considered to be uniform with the exception of the change at the break in the slope. Since the points on the cable were uniformly spaced, each point represents an equal area of ground surface. (Proof is not presented) Therefore, the average of the two readings at each station was multiplied by the area represented by that station--which was twice that represented by each point--to provide the volume of change in the slope at that station. The sum of the values for all stations gave the volume of change over the entire plot. The volume at each station was multiplied by the bulk density that was representative of that station to provide the weight of change at the station. The weights were summed to provide the weight of change over the entire plot. The formulas listed show how the values were determined.

Where $t \leq n_u$

$$V_t = \left[\frac{L_u}{n_u}\right]\left[R_{P_tL_1} - R_{C_tL_1} + R_{P_tL_2} - R_{C_tL_2}\right] \qquad (2)$$

and

V = volume of change at station t in ft^3

t = station number

R = reading

$R_{P_tL_1}$ = previous (P) reading at station t cable or line (L) 1

L_u = length of upper portion of plot (see Table XVIII)

n_u = number of stations included in the upper portion of the plot (see Table XVIII)

$R_{C_tL_2}$ = current or most recent (C) reading at station (t) cable or line (L) 2

Where $t > n_u$

$$V_t = \left[\frac{L_B}{n_B}\right]\left[R_{P_t L_1} - R_{C_t L_1} + R_{P_t L_2} - R_{C_t L_2}\right] \tag{3}$$

and

V_t = volume of change at station t

t = station number

R = reading

$R_{P_t L_1}$ = previous (P) reading at station t cable or line (L) 1

$R_{C_t L_2}$ = current or most recent (c) reading at station t cable or line (L) 2

L_B = length of the lower portion of the plot (see Table XVIII)

n_B = number of stations included in the lower portion of the plot (see Table XVIII)

To account for the plot width of two feet, the volume in Equations (1) and (2) should be multiplied by 2. To get the average change in elevation the reading term should be multiplied by 1/2.

$$2 \times 1/2 = 1$$

Table XVIII. Lengths and macroprofile stations included in each portion of each plot.

Plot	Length (L_u) of the upper portion of the plot (ft)	Station numbers (t) inclusive in upper portion of plot	Number of stations (N_u) in the upper portion of the plot	Length (L_g) of the lower portion of the plot	Station numbers (t) inclusive in upper portion of plot	Number of stations (N_B) in the lower portion of the plot
1	4.50	1-4	4	18.65	5-20	16
2	5.00	1-4	5	15.51	6-19	14
3	5.00	1-5	5	16.23	6-18	13
4	5.00	1-5	5	19.70	6-23	18
5	5.50	1-6	6	18.90	7-23	17
6	6.00	1-6	6	17.65	7-23	17

$$W_t = V_t(BD)(62.4) \tag{4}$$

W_t = weight (lb) of the soil eroded or deposited at station t

V_t = volume of soil moved at station t

BD = bulk density of soil at station t according to Table XVII

62.4 = density of water (lb/ft^3)

The volume of material eroded or deposited over the entire plot (V_p) can be computed according to the following Equation (5).

$$V_p = \sum_{t=1}^{b} V_t \tag{5}$$

Where b = number of stations on plot

The weight of material (lb) eroded or deposited over the entire plot (W_p) can be computed according to the following Equation (6).

$$W_p = \sum_{t=1}^{b} W_t \qquad (6)$$

Methods of the Soil Erosion Gage Technique

In this section the procedures are presented for computing the weight of material moved off of the plots and for obtaining the values for this computation for the soil erosion gage techniques.

Constants Used and Method of Determination

Station Spacing. The criteria for spacing the erosion-gage stations are presented in the text. Table XIX presents the actual distances between stations. The code L_t is used in the computations of volume. The distances recorded in this table are slope distances between stations measured along the plot boundaries.

Table XIX. Distances (ft.) between erosion gage stations and L_t values for erosion gage volume computations.

L_t	Station	Plot					
		1	2	3	4	5	6
	Edge of Plot						
L_1		1.35	1.66	1.42	1.63	1.65	1.75
	1						
L_2		1.40	1.68	1.66	1.96	1.87	2.15
	2						
L_3		1.90	1.97	2.22	1.76	2.13	2.65
	3						
L_4		4.93	4.60	3.75	7.02	4.90	5.00
	4						
L_5		6.22	4.40	5.05	5.68	5.85	5.59
	5						
L_6		6.55	5.20	5.68	6.10	7.60	5.53
	6						
L_7		0.80	1.00	1.45	0.55	0.40	0.98
	Edge of Plot						
	Length of Plot	23.15	20.51	21.23	24.70	24.40	23.65

Point Spacing. The instrument specifications space the reading points 1.33 inches, center to center, from each other. (Figure 21) The plot width is 24 inches. The ten points taken at each erosion gage station were centered on the plot. The center eight reading points account for 10.64 inches in the center of the plot. The two readings nearest the edge of the plot each represent 6.68 inches, to total plot width. Each point represented its particular portion of the plot width.

Bulk Density. The bulk density values used for this technique are the same as the values used for the macroprofile technique. The values are presented in Table XVII.

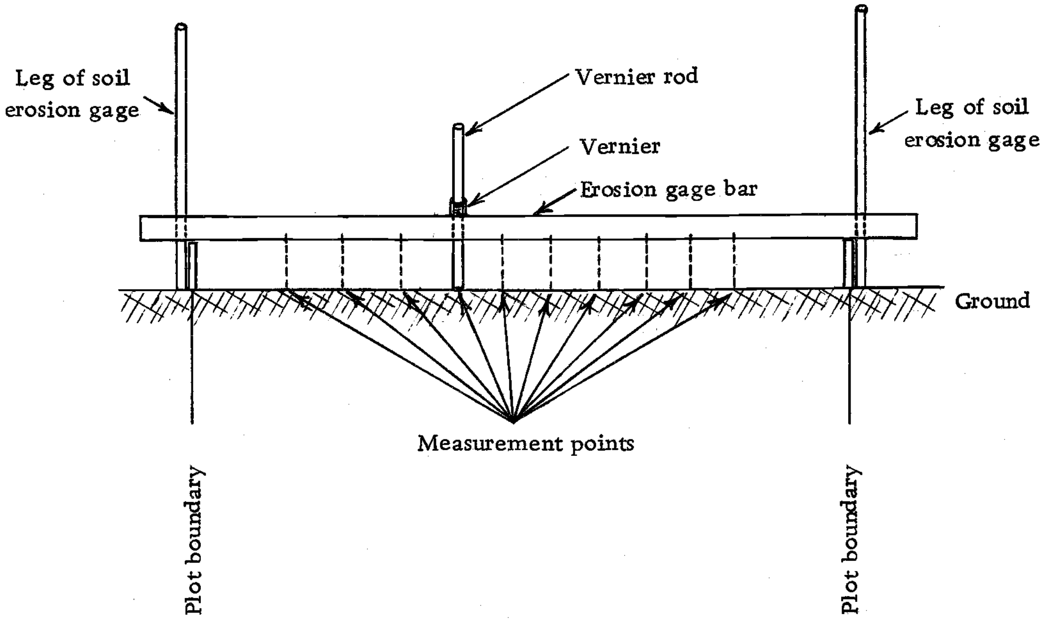

Figure 21. Measurement points at a soil erosion gage station.

Data Gathered From the Field

The change in distance between the bar and the ground was determined by subtracting the most recent reading at any given point from the previous reading at that point. The readings are the vernier readings (Figures 9 and 21) when the vernier is resting on the top of the bar and the rod is extended to touch the ground surface. The distances were measured and recorded to the nearest 0.01 inch.

Computational Procedure

In anticipation of an edge effect, and understanding that the result will be valid even if no edge effect exists, the volumes were computed using the weighted sum of the vertical elevational changes. Where h_t represents the weighted sum of the vertical elevational changes in feet^2 at the station (t).

$$h_t = \frac{1.33 \sum_{i=2}^{9} (R_{P_i} - R_{C_i}) + 6.680(R_{P_1} - R_{C_1} + R_{P_{10}} - R_{C_{10}})}{144} \qquad (7)$$

and

R_{P_i} = previous reading at point i of station t

i = number of the reading point across the plot. There are 10 such points beginning at point 1 on the left of the gage and extending to point 10 at the right of the gage

R_{C_i} = current reading at point i of station t

R_{P_1} = previous reading at point 1 of station t

$R_{P_{10}}$ = previous reading at point 10 of station t

R_{C_1} = current reading at point 1 of station t

$R_{C_{10}}$ = current reading at point 10 of station t

To compute the volume of erosion or deposition, an h_t value (ft^2) is computed for each erosion gage station. If these values are plotted over their respective positions on the plot diagram and the points are connected by a line, the volume of erosion or deposition is represented by the sum of the areas between this line and the zero change ($h_t = 0$) line. The signs of the h_t values determine the sign of the result. (Figure 22)

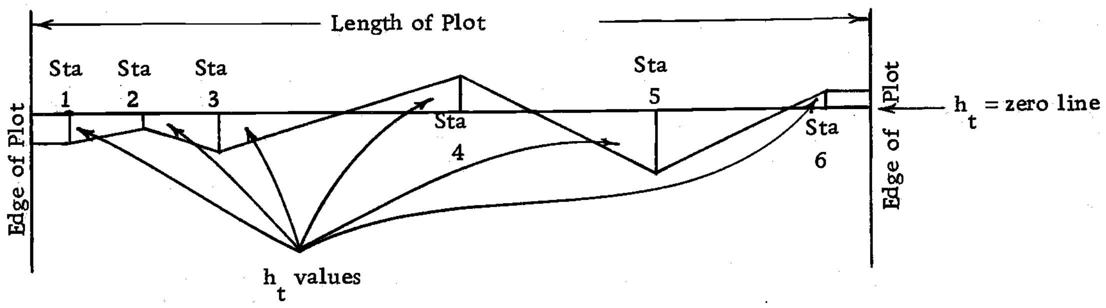

Figure 22. Schematic diagram used to compute volumes of change on total plots from soil erosion gage readings.

The volume of erosion or deposition at each station was computed independently and the results were summed over the plots to provide the plot totals. The procedure used for this operation was to sum the areas of triangles and trapezoids. The formulas needed (Equations 5, and 8 through 21) are presented below.

$$V_p = \sum_{t=1}^{b} V_t \qquad \text{see Eq. (5)}$$

Where

V_p = total volume of erosion or deposition over the entire plot

V_t = volume of erosion or deposition at station t

and

$$V_t = Q_1 + Q_2 \tag{8}$$

Where

Q_1 = the area under the curve extending from station t to halfway to station (t-1) (Figures 22 and 23).

Q_2 = the area under the curve extending from station t to halfway to station (t+1) (Figures 22 and 23).

The following symbols are used in Equations (9) through (20). The symbols are defined below and their physical meaning is illustrated in the figures that will accompany the equations for each case.

$$\left.\begin{array}{r} h_t = \\ h_{(t-1)} = \\ h_{(t+1)} = \end{array}\right\} \text{the weighted sum of the elevational changes in } ft^2 \text{ at stations (t), (t-1) and (t+1)} \qquad \text{see Eq. (7)}$$

Since there are only six soil erosion gage stations

when

$$t = 1$$

$$h_t = h_{(t-1)}$$

and when

$$t = 6$$

$$h_{(t)} = h_{(t+1)}$$

L_t = the distance in ft. between stations (t-1) and (t). See Table XIX

$L_{(t+1)}$ = the distance in ft. between stations (t) and (t+1). See Table XIX

except when

$L_t = L_1$ then the value in Table XIX $= \frac{L_t}{2}$

and when

$L_{(t+1)} = L_7$ then the value in Table XIX $= \frac{L_{(t+1)}}{2}$

Case I.

When $h_{(t-1)}$, h_t, and $h_{(t+1)}$ have the same sign, then

$$V_t = Q_1 + Q_2 = \frac{h_{(t-1)}(L_t) + 3h_t(L_t + L_{(t+1)}) + [h_{(t+1)}][L_{(t+1)}]}{8} \tag{9}$$

where

$$Q_1 = [h_{(t-1)} + 3h_t][\frac{L_t}{8}] \tag{10}$$

and

$$Q_2 = [3h_t + h_{(t+1)}][\frac{L_{(t+1)}}{8}] \tag{11}$$

Q_1 and Q_2 are trapezoids. Unit is ft^3.

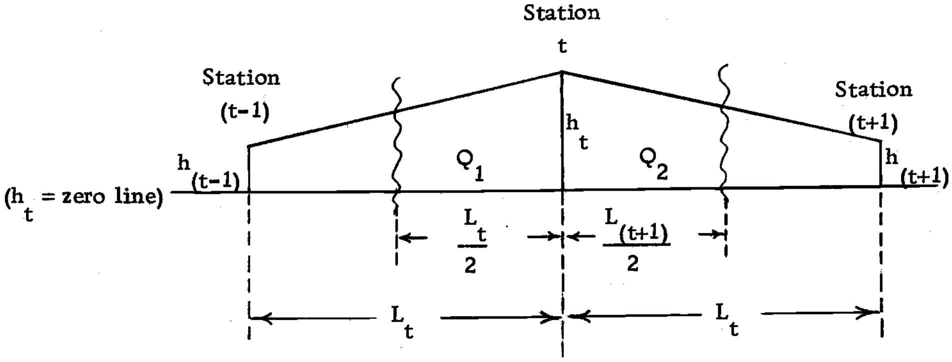

Figure 23. Volume computations. Case I.

Case II.

When $h_{(t-1)}$ and $h_{(t+1)}$ have the same sign but h_t has the opposite sign then:

$$V_t = Q_1 + Q_2 \qquad \text{see Eq. (8)}$$

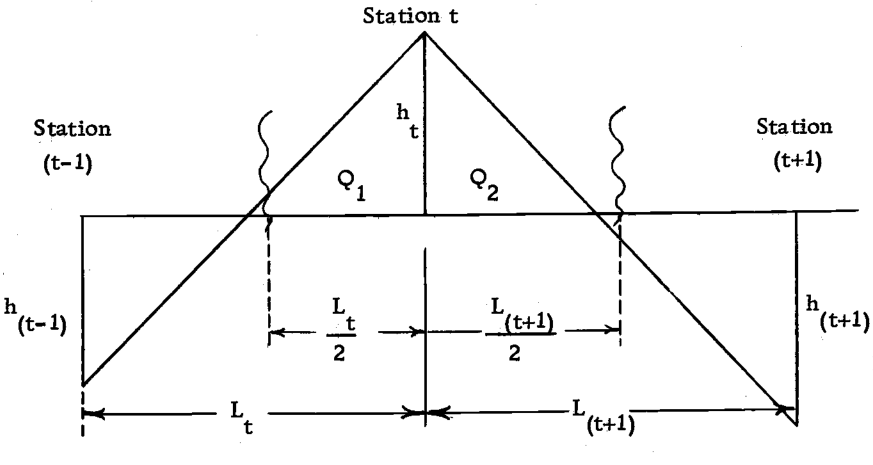

Figure 24. Volume computations. Case II.

where,

$$|h_{(t-1)}| > |h_t|$$

$$Q_1 = (\tfrac{1}{2})(h_t)\left[\frac{|h_t|(L_t)}{|h_{(t-1)}| + |h_t|}\right] - \left[\frac{L_t}{2} - \frac{|h_t|(L_t)}{h_{(t-1)} + |h_t|}\right]\left[\frac{h_t(|h_{(t-1)}| - |h_t|)}{2|h_t|}\right](\tfrac{1}{2}) \qquad (12)$$

Q_1 is the area of a trapezoid. Unit is ft^3.

when

$$|h_{(t-1)}| < |h_t|$$

$$Q_1 = \left[h_t + \frac{h_t}{2|h_t|}(|h_t| - |h_{(t-1)}|)\right]\left[\frac{L_t}{4}\right] \qquad (13)$$

Q_1 is the area of a triangle minus the area of another triangle. Unit is ft^3.

when

$$|h_t| < |h_{(t+1)}|$$

$$Q_2 = (\tfrac{1}{2})(h_t)\left[\frac{|h_t|L_{(t+1)}}{|h_t| + |h_{(t+1)}|}\right] - \left[\frac{L_{(t+1)}}{2} - \frac{|h_t|L_{(t+1)}}{|h_t| + |h_{(t+1)}|}\right]\left[\frac{h_t(|h_{(t+1)}| - |h_t|)}{2|h_t|}\right](\tfrac{1}{2}) \qquad (14)$$

Q_2 is the area of a triangle minus the area of another triangle. Unit is ft^3.

when

$$|h_t| > |h_{(t+1)}|$$

$$Q_2 = \left[h_t + \frac{h_t}{2|h_t|}(|h_t| - |h_{(t+1)}|)\right]\left[\frac{L_{(t+1)}}{4}\right] \qquad (15)$$

Q_2 is the area of a trapezoid. Unit is ft^3.

when

$$|h_t| = |h_{(t-1)}|$$

$$Q_1 = \frac{L_t h_t}{4} \qquad (16)$$

Q_1 is the area of a triangle. Unit is ft^3.

and when

$$|h_t| = |h_{(t+1)}|$$

$$Q_2 = \frac{L_{(t+1)} h_t}{4} \qquad (17)$$

Q_2 is the area of a triangle. Unit is ft^3.

Case III.

When $h_{(t-1)}$ and h_t have the same sign but $h_{(t+1)}$ has the opposite sign:

$$V_t = Q_1 + Q_2 \qquad \text{see Eq. (8)}$$

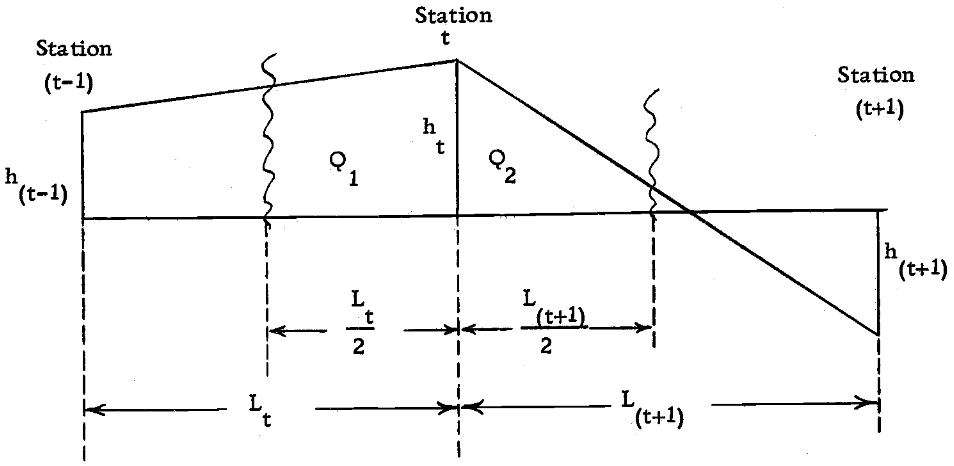

Figure 25. Volume computations. Case III.

Equation (10) holds for Q_1

when

$$|h_t| = |h_{(t+1)}|$$

then Equation (17) holds for Q_2

when

$$|h_t| > |h_{(t+1)}|$$

then Equation (15) holds for Q_2

when

$$|h_t| < |h_{(t+1)}|$$

then Equation (14) holds for Q_2

Case IV.

When h_t and $h_{(t+1)}$ have the same sign but $h_{(t-1)}$ has the opposite sign:

$V_t = Q_1$ and Q_2 see Eq. (8)

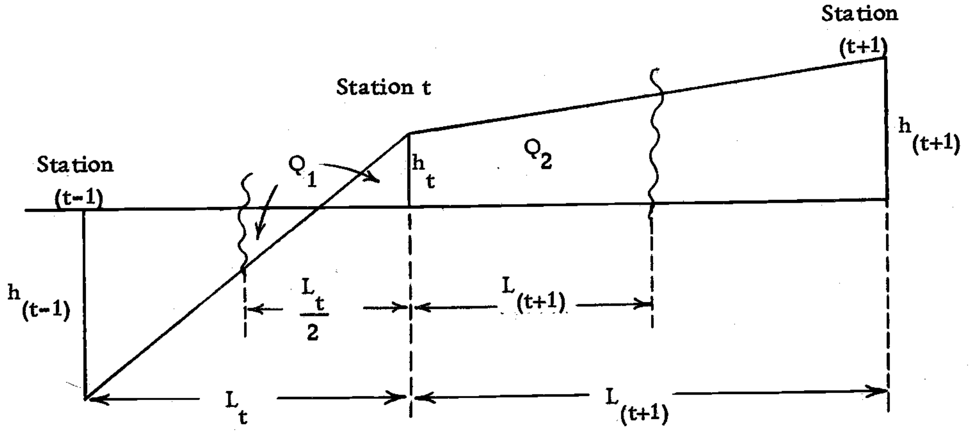

Figure 26. Volume computations. Case IV.

Equation (11)holds for Q_2

when

$$|h_t| = |h_{(t-1)}|$$

Equation (16) holds for Q_1

when

$$|h_t| > |h_{(t-1)}|$$

then Equation (13) holds for Q_1

when

$$|h_t| < |h_{(t-1)}|$$

then Equation (12) holds for Q_1

Case V.

When h_t = zero and $h_{(t-1)}$ and $h_{(t+1)}$ have the same sign then treat as though all three have the same sign, Case I.

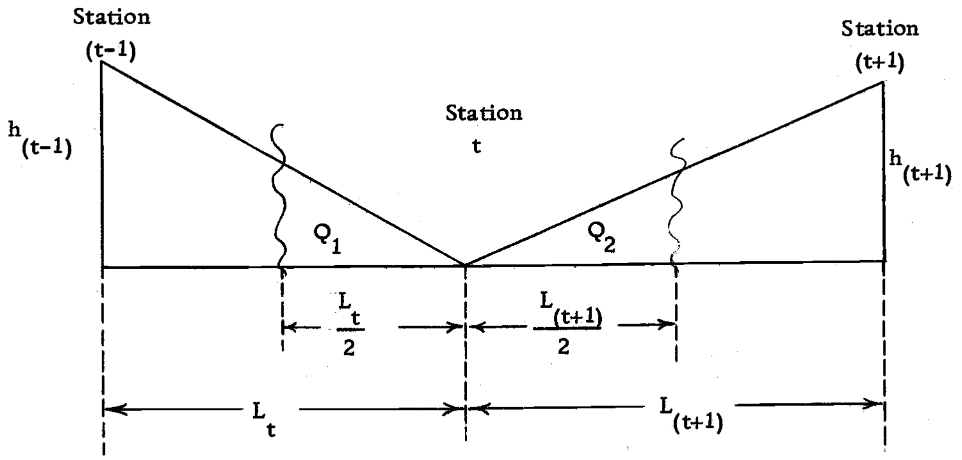

Figure 27. Volume computations. Case V.

Case VI.

When h_t = zero but $h_{(t-1)}$ and $h_{(t+1)}$ have opposite signs:

$$V_t = Q_1 + Q_2 \qquad \text{see Eg. (8)}$$

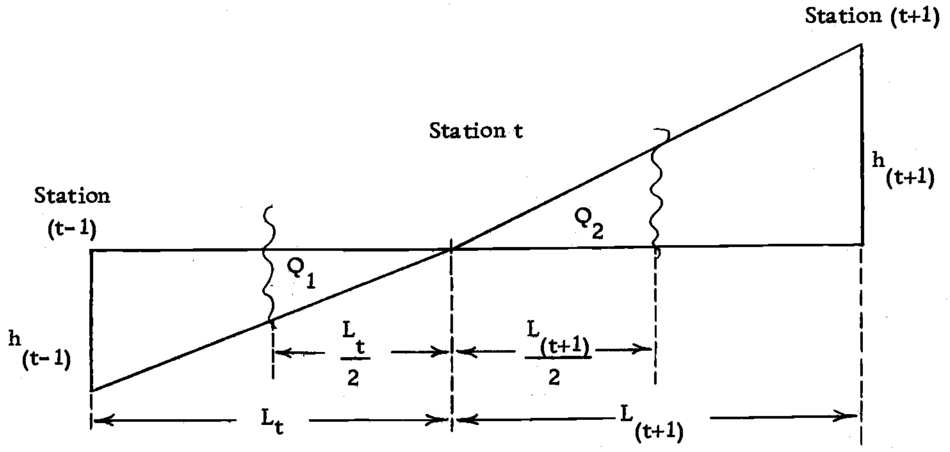

Figure 28. Volume computations. Case VI.

where

$$Q_1 = \frac{(h_{(t-1)})(L_t)}{8} \tag{18}$$

and

$$Q_2 = \frac{(h_{(t+1)})(L_{(t+1)})}{8} \qquad (19)$$

Q_1 and Q_2 are the areas of triangles. The unit is ft^3.

Case VII.

When $h_{(t+1)}$ = zero but h_t and $h_{(t-1)}$ have opposite signs, treat as though h_t and $h_{(t+1)}$ have the same sign, Case IV.

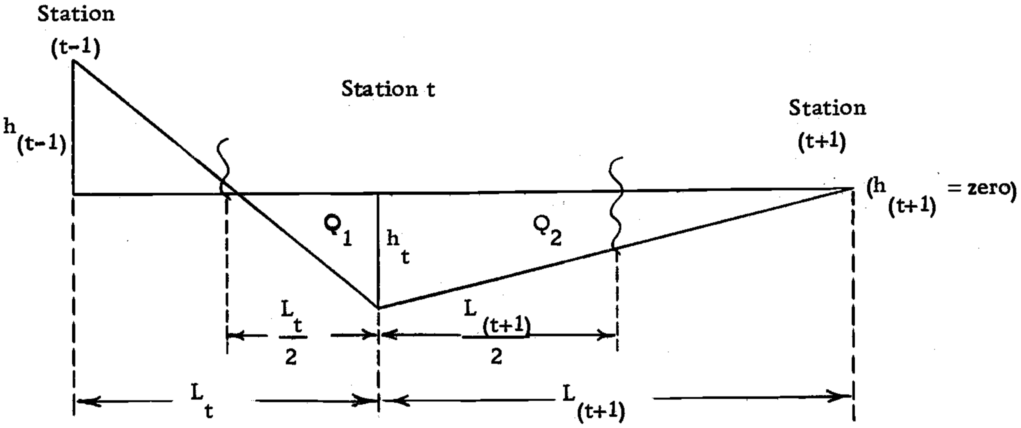

Figure 29. Volume computations. Case VII.

Case VIII.

When $h_{(t+1)}$ = zero but h_t and $h_{(t-1)}$ have the same signs, treat as though all three have the same sign, Case I.

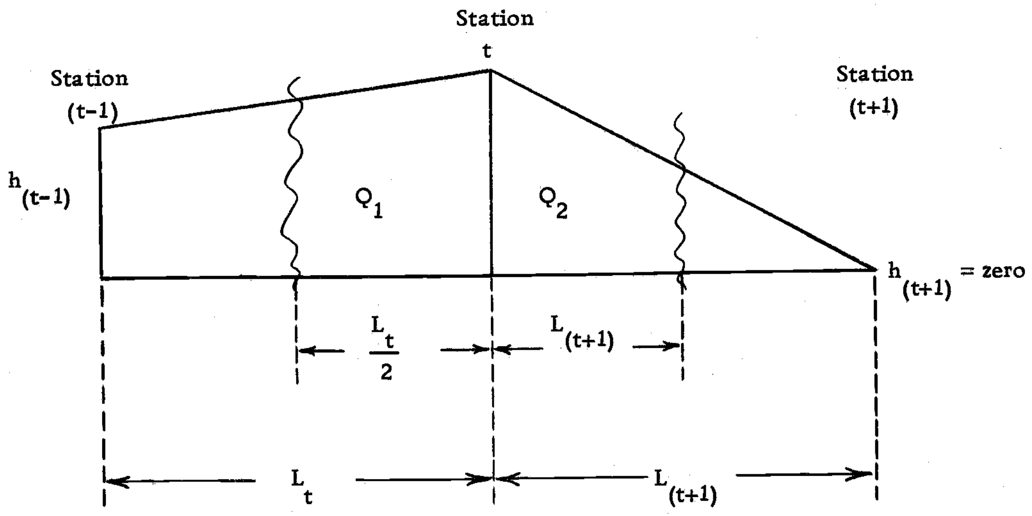

Figure 30. Volume computations. Case VIII.

Case IX.

When $h_{(t-1)}$ = zero and h_t and $h_{(t+1)}$ have the opposite signs, treat as though $h_{(t-1)}$ and h_t have the same sign, Case III.

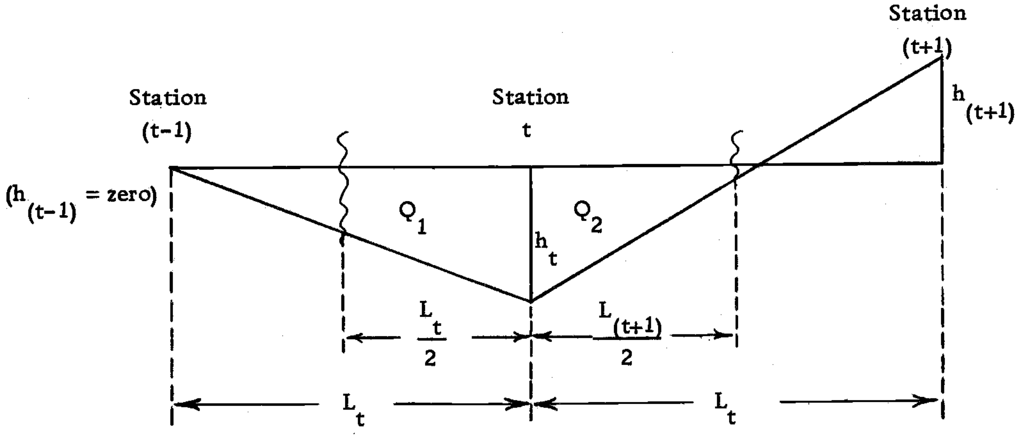

Figure 31. Volume computations. Case IX.

Case X.

When $h_{(t-1)}$ = zero and h_t and $h_{(t+1)}$ have the same sign, treat as though all three have the same sign, Case I.

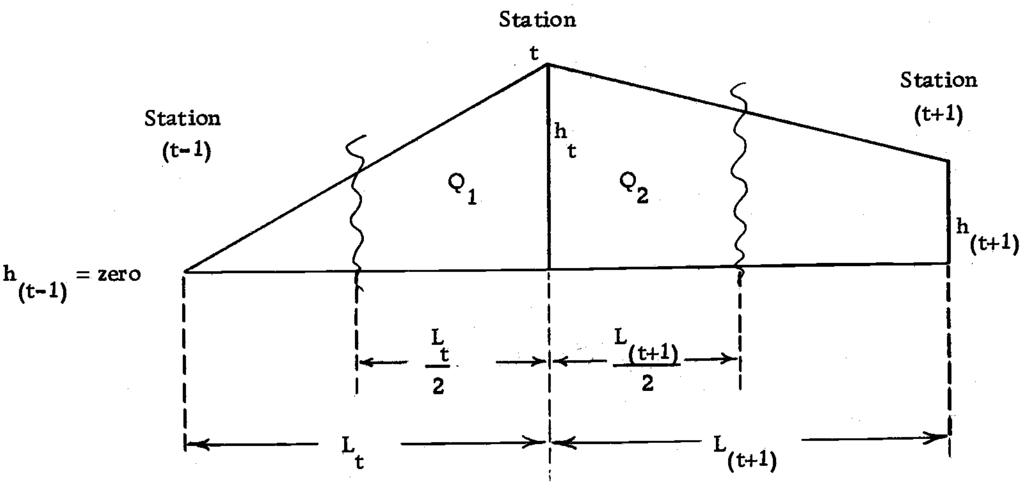

Figure 32. Volume computations. Case X.

Case XI.

When two of the three $(h_{(t-1)}, h_t, h_{(t+1)})$ = zero, treat as though all three have the same sign, Case I.

Case XII.

When all three $h_{(t-1)}, h_t, h_{(t+1)}$ equal zero then

$$V_t = \text{zero} \tag{20}$$

The V_t values computed from Equation (8) provide the volume of erosion at the stations. These volumes can be converted to weight (W_t) according to Equation (4). The volume of erosion or deposition over the entire plot (V_p) is computed according to Equation (5). The weight of erosion or deposition over the entire plot (W_p) can be computed according to Equation (6).

Methods of the Spike and Washer Technique

Constants Used and Method of Determination

Station Spacing. The station spacing for this technique was approximately the same as for the soil erosion gage and for the same reasons. (see text) The actual installations were offset slightly from the erosion gage stations to prevent mutual interference. The station locations are given in Table XX.

Table XX. Distances (ft.) between the spike and washer stations and L_t values for spike and washer volume compurations.

L_t	Station	Plot					
		1	2	3	4	5	6
	Edge of Plot						
L_1		0.95	1.11	0.70	1.05	1.20	1.35
	1						
L_2		1.45	1.80	2.20	1.80	2.10	3.20
	2						
L_3		0.85	1.90	1.70	1.90	1.90	1.60
	3						
L_4		4.90	4.60	4.25	8.20	5.95	5.00
	4						
L_5		9.10	10.45	5.05	5.50	6.45	5.10
	5						
L_6		4.70	L_5[1]	5.38	3.20	5.90	5.30
	6						
L_7		1.20	0.65	1.95	3.05	0.90	2.10
	Edge of Plot						
Length of Plot		23.15	20.51	21.23	24.70	24.40	23.65

[1] Station 5 improperly established, L_5 = distance between stations 4 and 6.

Bulk Density. Bulk densities used for the spike and washer method are the same as those for the macroprofile technique. The bulk density determinations for the top of the cut slope plots were used for stations 1, 2, and 3. The determinations for the lower portions were used for stations 4, 5, and 6. The fill slope plots used the same determinations of bulk density for all stations. All bulk density values are listed in Table XVII.

Data Gathered in the Field

Two measurements were made at each station--the distance between the spike head and the washer, and the depth of soil accumulated on top of the washer. These values were recorded to the nearest 0.01 foot.

Computational Procedures

Since two independent measurements were made at each station, the two values were worked up independently to provide the volumes (V_t, V_p) and weights (W_t, W_p) of soil movement for each station and plot. The h_t values in square feet were computed for each measurement according to the following formula.

$$h_t = 2(R_{P_t} - R_{C_t}) \qquad (21)$$

where

R_{P_t} = previous (P) reading at station t

R_{C_t} = current (C) reading at station t.

The constant, 2 feet, is the plot width. The h_t values thus computed are used in the formulas listed under the soil erosion gage section of the Appendix to provide the volume and weight of material eroded or deposited. The L_t and $L_{(t+1)}$ values for the spike and washer technique are listed in Table XX. These values are used in the same manner as those listed for the soil erosion gage. The V_t and W_t values computed for each of the two measurements of the spike and washer technique were combined to provide the final volume and weights of erosion or deposition recorded at each station for this technique.