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A Comparison of Highway Slope Erosion Estimates By The Mechanical Slope Template, Sediment Collection Trough, and Slope Erosion Transect Survey Methods

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16. ABSTRACT
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This report discusses a comparison of measuring slope erosion by the Mechanical Slope Template, Sediment Collection Trough, and Slope Erosion Transect Survey Methods for a highway slope on Route 50 at Camino (03-ED-50, P.M. 23.8). The study was conducted during a portion of the 1977-78 winter. The data show that the Mechanical Slope Template method produced unusually high estimates compared to the other two methods.

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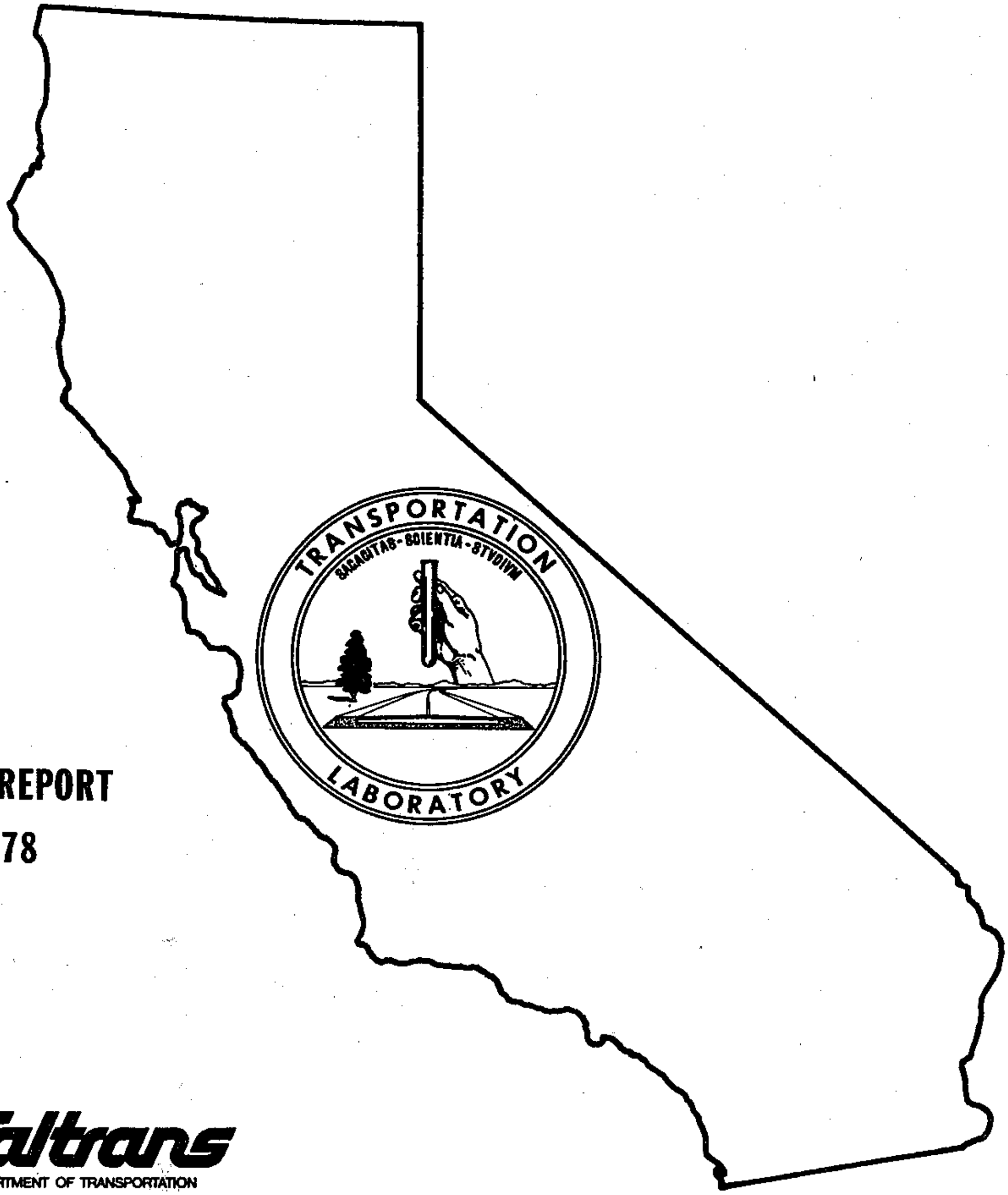
A COMPARISON OF HIGHWAY SLOPE EROSION ESTIMATES BY THE MECHANICAL SLOPE TEMPLATE, SEDIMENT COLLECTION TROUGH AND SLOPE EROSION TRANSECT SURVEY METHODS



INTERIM REPORT

AUG. 1978

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

August 1978

TL No. 657108

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this interim research project report titled:

A COMPARISON OF HIGHWAY SLOPE EROSION ESTIMATES BY THE MECHANICAL SLOPE TEMPLATE, SEDIMENT COLLECTION TROUGH, AND SLOPE EROSION TRANSECT SURVEY METHODS

Study made by . . . . Enviro-Chemical Branch

Under the Supervision of . . . . Earl C. Shirley, P.E.

Principal Investigator . . . . . Richard B. Howell, P.E.

Co-Investigator . . . . Richard J. Spring, P.E.

Report Prepared by . . . . Richard B. Howell, P.E.

Assisted by . . . . James A. Racin

Very truly yours,

NEAL ANDERSEN
Chief, Office of Transportation Laboratory

Attachment

RBH:caj

ACKNOWLEDGEMENTS

The following people provided assistance in the field study: James Racin, Martin Nolan, Don Nakao, Jeffrey Gidley, and Richard Spring of the TransLab Water Quality Section, and Patrick Monahan of the Cement and Concrete Testing Section. The mechanical slope template was designed by Richard Howell and fabricated by Robert Breazile (deceased). The graphs and maps were delineated by Elmer Wigginton and the report was typed by Carol Johnson.

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INTRODUCTION

Part of the environmental assessment of highway impact on water quality includes an analysis of potential slope erosion for each proposed alternative. The California Department of Transportation (Caltrans) commonly uses the Slope Erosion Transect Survey method for determining potential quantities of slope erosion for new construction(1). The method uses subjective evaluation techniques in observing various erosion signatures on existing slopes near the proposed project such as tree root exposure, overhang near the top of the slope, rill and gully erosion, etc. The method is fairly rapid and can usually be completed within a few weeks depending on the number of slopes to be surveyed.

Another technique that is used less frequently is the Sediment Collection Trough method(1). This method requires the installation of a metal trough on a slope that traps sediment as it erodes from the slope. The sediment is periodically removed, dried, and weighed. The accumulated sediment is plotted relative to the amount of rainfall that fell during the monitoring period. The resulting curve is then used to estimate potential erosion quantities for various rainfall amounts for slopes having characteristics similar to the monitored slope. This technique usually requires monitoring through at least one winter season and possibly more, depending on the accuracy desired. The Sediment Collection Trough method is also used to evaluate the effectiveness of erosion control treatments that are applied to highway slopes(2).

A third method that has not been utilized to any extent by Caltrans involves the use of a device called a mechanical slope template to measure changes in the configuration of the slope as erosion occurs(1). To use this technique, reference points are established on a slope. An initial set of readings is obtained by placing the mechanical slope template between two of the points and measuring the distance between the template and the slope surface at one foot (.305 m) intervals. The process is repeated at several places on the slope. After a series of storms, measurements are again taken and the difference between these and the initial readings is used to calculate the volume of sediment that was eroded. An in-place soil density reading is taken to convert the soil volume to a weight. Measurements must be taken over a minimum of one winter season. The results are highly dependent on antecedent moisture and the characteristics of the rainfall (rainfall intensity, amount, frequency, and duration). For this reason, accurate results are usually obtained by monitoring over several winter seasons. This method may be useful in cases where the difference in erosion rates at various locations on a slope needs to be identified; information is desired on the rate of sediment transport in the downslope direction as the soil erodes; erosion is so rapid that the capacity of sediment collection trough would be exceeded using normal monitoring procedures; or where there is limited space at the base of a slope to install a sediment collection trough. TransLab used this method on a limited basis during some erosion studies in the Lake Tahoe Basin in 1973(3).

Sediment Collection Trough

Mechanical Slope Template

To compare the results obtained from using these three slope erosion measuring methods, a study was undertaken during the 1977-78 winter on a highway slope located near Camino on Route 50 (03-ED-50, P.M. 23.8). The location is shown in Figure 1.

This site was selected because another TransLab research study, "Control of Slope Erosion Using Fiberglass Roving with Vegetation", was being conducted at this same location(4). Consequently, manpower was effectively used in obtaining data for both studies.

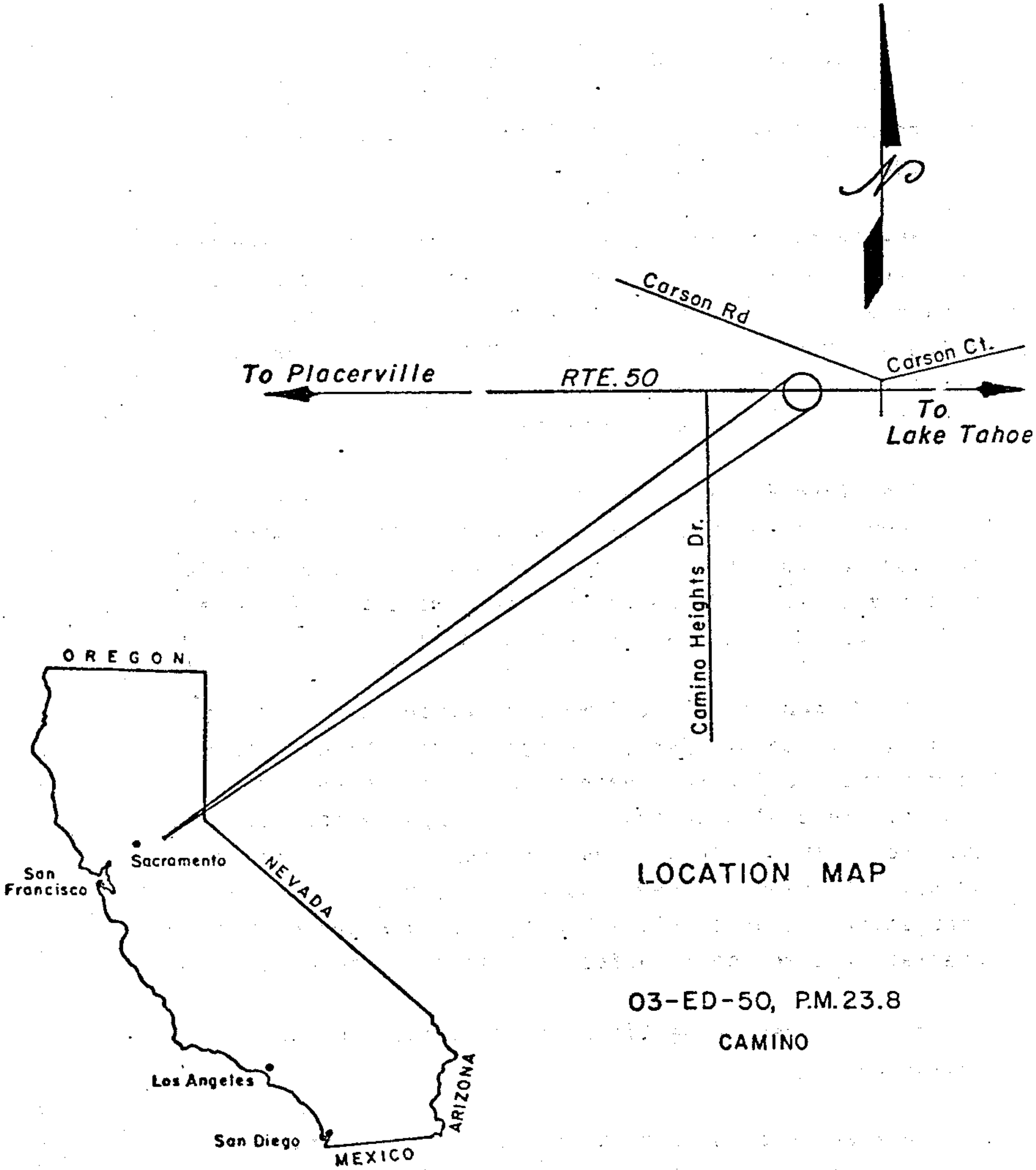

N
Carson Rd
Carson Ct.
To Placerville
RTE. 50
To
Lake Tahoe
Camino Heights Dr.
OREGON
NEVADA
ARIZONA
MEXICO
Sacramento
San
Francisco
Los Angeles
San Diego
LOCATION MAP
03-ED-50, P.M. 23.8
CAMINO

Figure 1

CONCLUSIONS AND RECOMMENDATIONS

As a result of this study, the following conclusions are made:

1. The Sediment Collection Trough method of determining slope erosion is easy to use and provides very accurate results of current erosion rates because it traps the eroded sediment which can then be measured. The average annual rate on the slope studied was 17.4 tons/ac/yr (3.9 $kg/m^2/yr$) using this method.

2. The Slope Erosion Transect Survey method gives good long term average annual erosion rates that represent the average erosion from the construction of the slope to the present time. The average annual rate on the slope studied was 18.7 tons/ac/yr (4.2 $kg/m^2/yr$).

3. The Mechanical Slope Template method gave very high results, 87.1 tons/ac/yr (19.6 $kg/m^2/yr$), which is about 5 times the erosion rate determined by the other two methods. Several problems were also experienced with the template in the field such as difficulty in climbing up and down the slope to get measurements, rods would sometimes stick in the template holes, the rods would sometimes penetrate the wet soil surface giving false readings, etc.

The following recommendations are made based on these conclusions:

1. Caltrans should continue to use the Sediment Collection Trough method as the preferred method to study erosion rates for environmental investigations and to monitor the effectiveness of erosion control treatments.

2. The Slope Erosion Transect Survey method should continue to be used for estimating slope erosion for various route alternatives during the environmental investigation. The erosion rate determined by this method will reflect the average long term erosion from specific slopes which can be used to estimate erosion from other similiar slopes that are to be constructed.

3. The Mechanical Slope Template method should not be used on erosion studies for road slopes. Although the method is useful for determining characteristics of erosion on a slope, more refined and detailed analysis would be required for its accurate use. This is not warranted at this time.

4. The TransLab report "Methods of Measuring Erosion from Road Slopes", CA-DOT-TL-7108-76-17, dated January 1976, should be updated to reflect the findings of this study.

IMPLEMENTATION

Copies of this report were distributed to Caltrans district and Headquarters offices for their information and future use. The findings of this study will be used to advise others on erosion investigations, analysis, interpreting, and reporting of data. This information will also serve as a useful base to which future studies on erosion can be referenced.

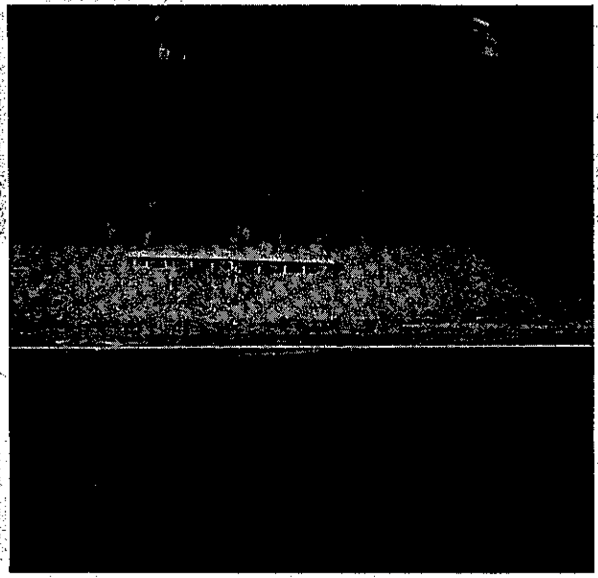
The erosion rate determined by the Sediment Collection Trough method was used by the Resource Conservation District and U.S. Soil Conservation Service for the 208 Nonpoint Source Sediment Study for the Camino-Fruitridge Pilot Study Area. This information will become part of the State's Non-Designated Area 208 Plan (Public Law 92-500).

FIELD STUDY

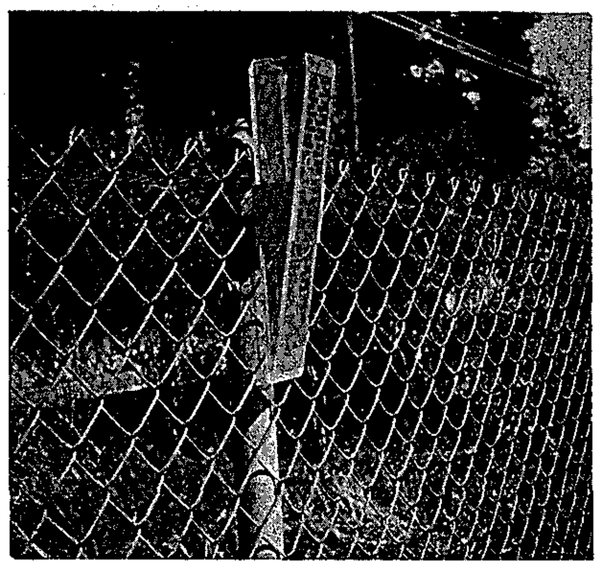
The slope that was used for the field study is located near Camino on Route 50 about 6 miles (9.6 km) east of Placerville (03-ED-50, P.M. 23.8). The elevation in this vicinity is about 3,500' (1,067 m) and the climate is typical of the lower regions of the western portion of the Sierra Nevada Mountains. Rainfall averages about 45 inches/year (1.14 m) and mainly falls in the October-May period. Some snow falls at the site but typically melts within a few days. The surrounding vegetation consists of some hardwood and pine trees, and manzanita bushes.

The south facing slope is approximately 20 feet (6.1 m) high and was constructed on a 31° angle (about a 1.7:1 slope) in 1963. The soil consists of a clay. A grading analysis of the sediment collected in the sediment trough showed a mean diameter of 10 microns. There is a high iron component which gives the soil a reddish appearance. Sheet erosion is the predominate type of erosion on the slope, although there is some slight rilling from concentrated surface flows.

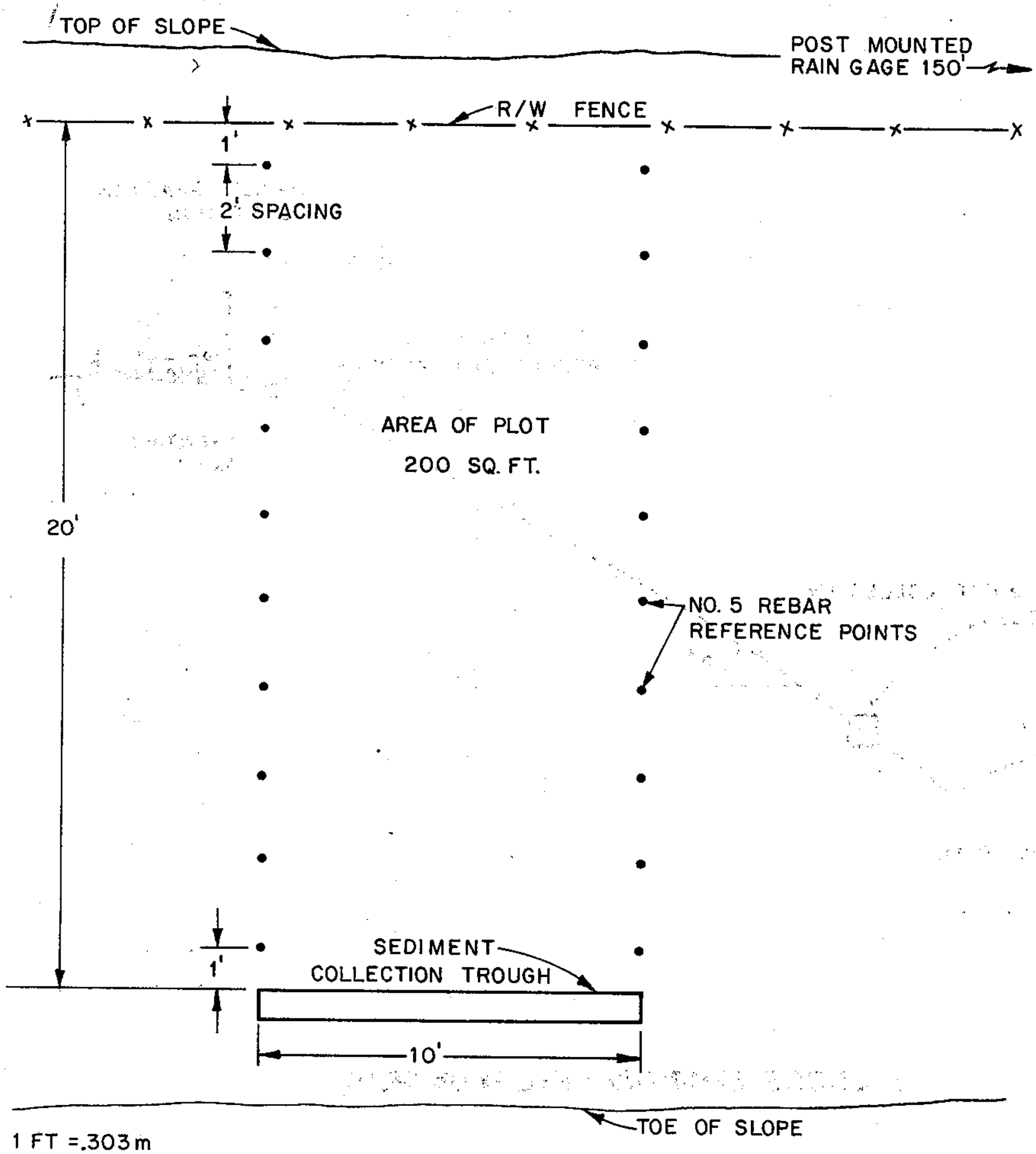
A 10' wide (3.05 m) x 20' high (6.1 m) plot was laid out on the slope. The sediment trough (10' long x .5' wide x .75' deep) (3.05 m x 152 mm x 229 mm) was installed at the slope base. Reference points, consisting of No. 5 re-bar, were placed at two-foot (.61 m) intervals along the sides of the plot. A fence post rain gage was fastened to the right-of-way fence, which ran along the top of the slope about 150 feet (45.7 m) to the east. Figure 2 shows the plot configuration and Figure 3 shows a typical cross-section of the slope.



Erosion Monitoring Plot

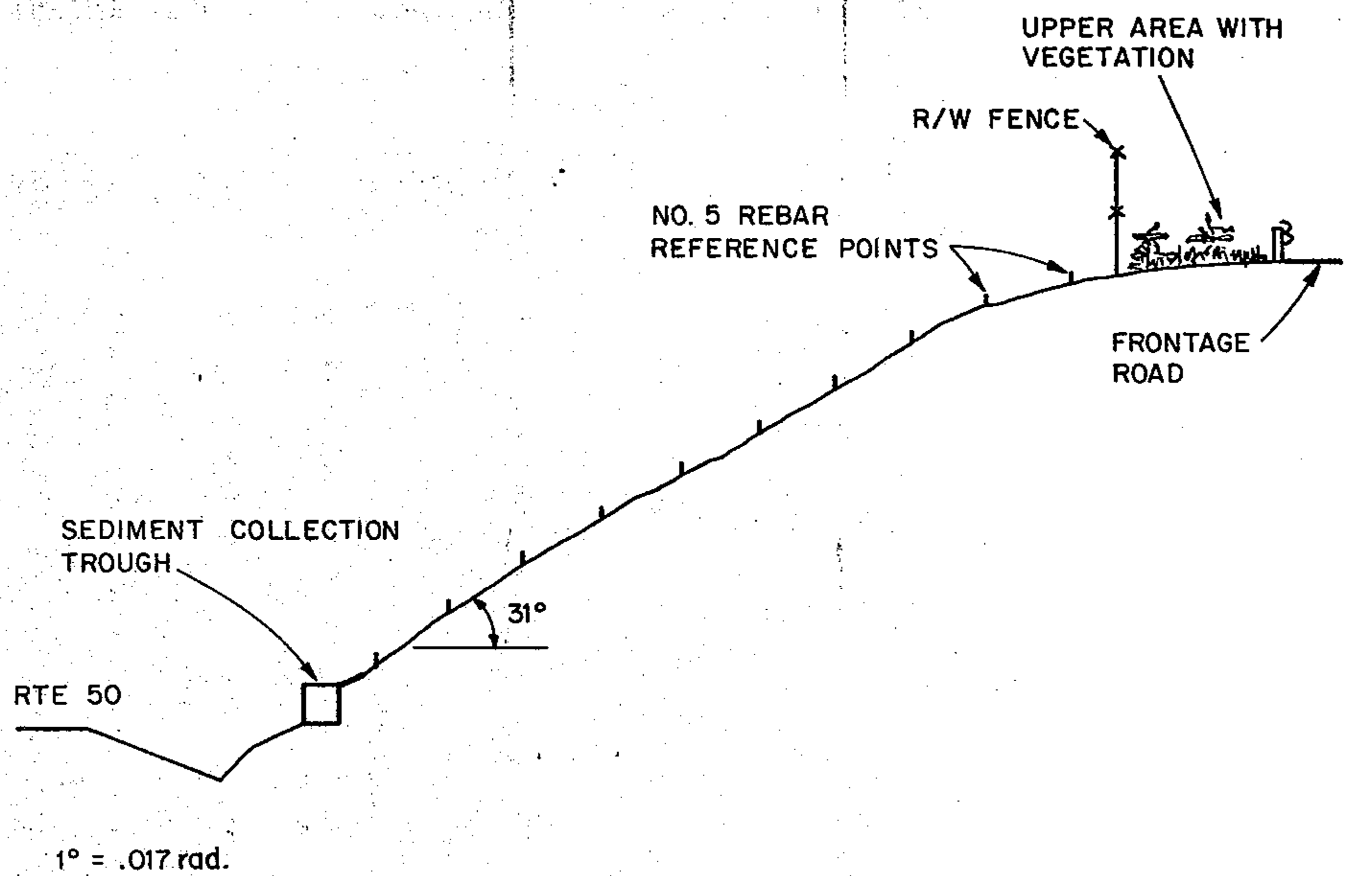


Fence Post Rain Gage



STUDY PLOT

FIGURE 2



CROSS SECTION OF STUDY PLOT

FIGURE 3

After the reference points were established along the sides of the plot, elevations were determined for each one using a rod and level. The elevations were tied into a bench mark.

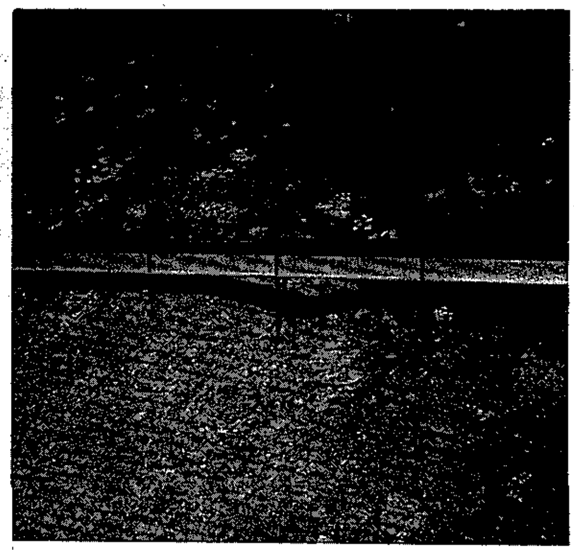
Erosion monitoring of the plot took place from November 23, 1977 through February 22, 1978. The slope configuration was measured 11 times during this time interval with the mechanical slope template(3). The following is a description of the procedures used:

1. The measuring rods were removed from the storage compartment on the template, wiped clean, inserted in the guide holes in the template, and then a hex nut was attached to the top to keep the rods from falling out. A check was made of the straightness of the rods and their ease of movement by sliding them up and down several times.

2. To begin the measurements, two people each held one end of the template and walked up the outside edge of the plot to one set of the reference points. They turned the template upside down which allowed the rods to fall to the fully raised position. A sliding plate was then moved horizontally to lock the rods in place. Wing nuts were then tightened to hold the plate in place while the template was positioned over the reference points.

3. With the template in place, the wing nuts were loosened and the top plate was moved to unlock the rods which then slid through the holes until they touched the slope surface. If one of the rods did not slide through the hole, one of the individuals closest to the stuck rod would tap it with a four foot (1.2 m) lath until the rod slid through.

Template rods locked in
"up" position



Released rods touch slope
surface

4. After the rods were all in contact with the slope surface, the top plate again was moved horizontally to lock the rods in place. The wing nuts were turned to secure the top plate and then the template was lifted off the reference points and brought to the bottom of the slope.

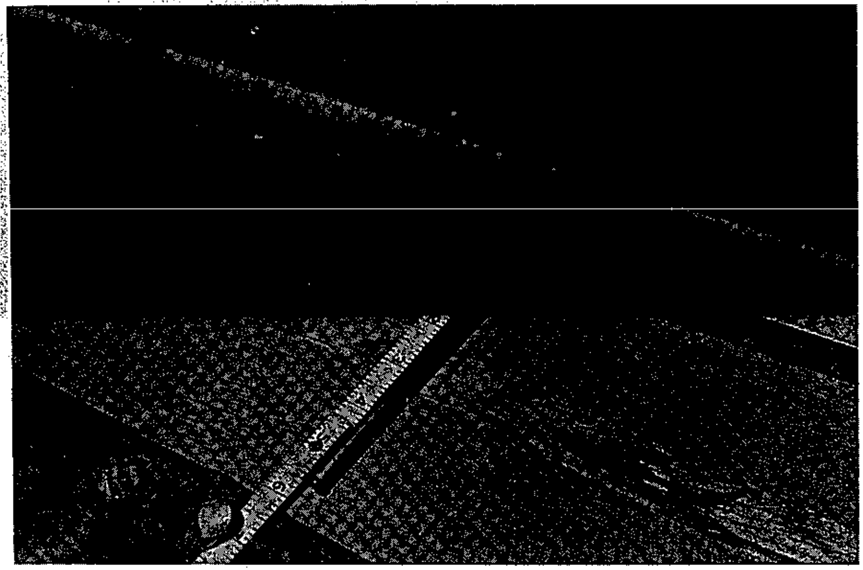
5. The distance from the bottom of the template to the bottom of each rod was measured and recorded on the form shown in the Appendix.

This procedure was repeated for each of the 10 pairs of reference points along the side of the plot. The amount of rainfall since the last set of measurements was recorded also.

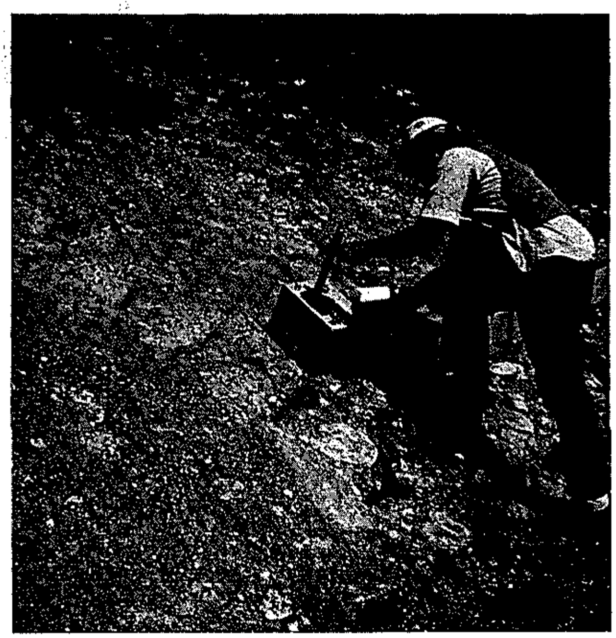
The sediment collection trough was cleaned after each storm period. If the volume was small, the sediment was placed in a container and returned to TransLab where the dry weight was determined. For larger volumes, the wet weight of the total sediment was determined in the field. A representative sample of the sediment was returned to TransLab for a moisture determination which was then used to calculate a dry weight.

A grading analysis was performed on the sediment collected after one storm period. Also, an in-place density determination was made with a nuclear soil density gage.

A slope erosion transect survey was performed to determine the average annual erosion since construction of the slope. The most prominent feature that was used to estimate the amount of sheet erosion was the erosion that had occurred around the concrete base at each of the right-of-way fence posts located along the top of the slope. To measure the



Distance from template to bottom of rod is measured.



In-place soil density being measured with a nuclear soil density gage.

amount of rill erosion, a straight edge was laid across each rill and the depth determined. The cross-sectional area of the rill was multiplied by the rill length to calculate the volume. The volume was converted to a weight using the in-place density factor.

RESULTS

The Slope Erosion Transect Survey and Mechanical Slope Template methods provide volumetric information on slope erosion whereas the Sediment Collection Trough procedure gives the information on a weight basis. Therefore, in-place soil density was determined to provide for a comparision of data between the methods. The in-place soil density was determined to be 109 lbs/cubic foot (1,745 kg/m^3).

The Slope Erosion Transect Survey showed that sheet erosion had removed about an average of 1.5" (38 mm) of the surface material for 160 sq.ft. (14.9 m^2) and 0.5" (12.7 mm) for 20 sq.ft. (1.86 m^2) during the 1963 to 1978 period. This calculates to be about 1.39 cu.ft./yr (.04 m^3/yr) for the 200 sq.ft. (18.6 m^2) plot. In addition, the volume of the three rills was measured. The average width for two of the triangular shaped rills was 12" (305 mm), depth was 1" (25 mm), and the rills were about 16' (4.9 m) long. Therefore, the volume of two rills was calculated to be 2.00 cu.ft. (.06 m^3). The third rill was 8" (203 mm) wide, 1" (25 mm) deep for 4 ft. (1.2 m) and 12" (25 mm) wide, 1" (25 mm) deep for 8 ft. (2.4 m). The volume of this rill was calculated to be .89 ft^3 (.02 m^3). For the three rills, this totaled 2.89 cu.ft. (.08 m^3) which was assumed to be uniformily developed over the 15 year period. This yields an average rill erosion rate of 0.19 cu.ft./yr (.01 m^3/yr). The total average annual erosion rate from the Slope Erosion Transet Survey for the 200 sq.ft. (18.6 m^2) plot is:

Sheet Erosion	1.39 cu.ft./yr (.04 m^3/yr)
Rill Erosion	.19 cu.ft./yr (.01 m^3/yr)
	1.58 cu.ft./yr (.05 m^3/yr)

Using the in-place soil density of 109 lbs/cu.ft. (1,745 kg/m^3), this calculates to be 172 lbs/yr (77.9 kg/yr). On a unit area basis, this is equivalent to 18.7 tons/ac/yr (4.2 kg/m^2/yr).

Sediment was collected in the sediment collection trough and was removed after each of the 11 storm events. Table 1 shows the sediment data:

TABLE 1

Sediment Collection Trough

Date of Measurement	Precipitation, inches*		Sediment, lbs(dry)**	
	P	ΣP	wt	Σwt
11-23-77	2.65	2.65	1.0	1.0
12-13-77	0.60	3.25	.8	1.8
12-15-77	2.40	5.65	11.5	13.3
12-19-77	1.70	7.35	41.9	55.2
12-22-77	0.51	7.86	.8	56.0
12-29-77	4.15	12.01	13.8	69.8
1-4-78	1.35	13.36	3.2	73.0
1-6-78	3.35	16.71	16.6	89.6
1-12-78	1.72	18.43	2.4	92.0
1-18-78	5.75	24.18	24.7	116.7
2-22-78	5.58	29.76	7.9	124.6

Total rainfall at the Camino site was approximately 63 inches (1.12 m) for 1977-78. Therefore, data were collected for about 47% of the total rainfall. However, the monitoring was conducted during the major portion of the winter season.

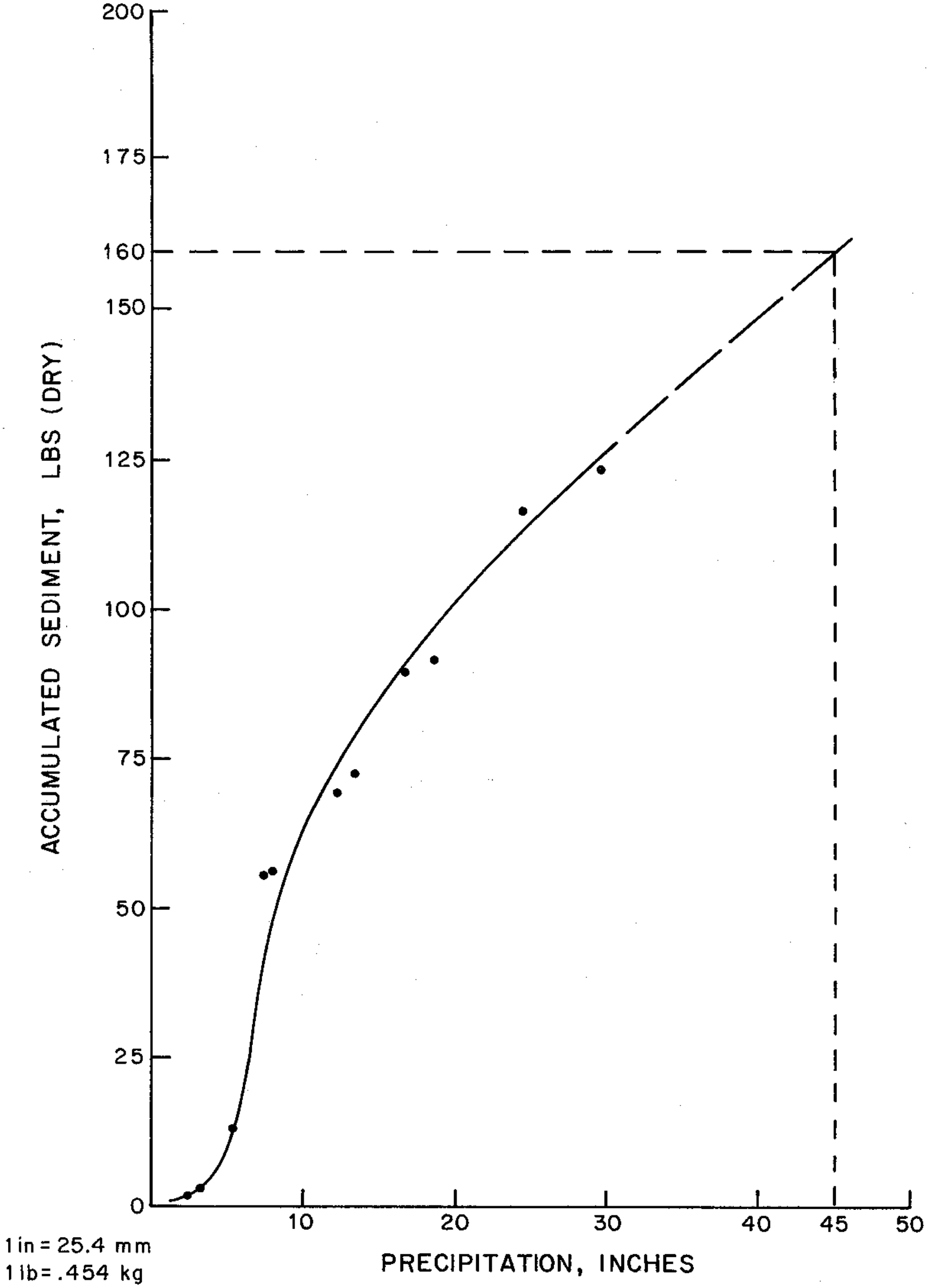
*1 in. = 25.4 mm

**1 lb. = .454 kg

A plot of the sediment collection trough data is shown in Figure 4. A curve was drawn through the points to indicate the general relationship between precipitation and sediment yield.

Using the normal annual rainfall of 45" (1.14 m) for this site, the curve in Figure 4 shows the total sediment from the plot to be about 160 lbs (72.5 kg) (dry weight). On a unit area basis, the annual sediment yield would be 17.4 tons/ac/yr (3.9 kg/m^2/yr).

Changes in slope configuration were measured with the mechanical slope template after various storm periods. The changes in elevation of each of the grid points were multiplied by 2 sq.ft. (.19 m^2) which was the area represented by each of the rods. This represented an area of 180 sq.ft. (16.7 m^2). The total change in volume was calculated by the use of a computer program on the Tenet Time Share System. A copy of the computer program is shown in the Appendix. To convert the volume to weight, an in-place density of 109 lbs/cu.ft. (1,745 kg/m^3) was used. Table 2 shows the data results.



SEDIMENT COLLECTION TROUGH SEDIMENT CURVE

FIGURE 4

TABLE 2

Mechanical Slope Template

Date of Measurement	Precipitation, inches* P	ΣP	Sediment Volume, cu.ft.**	Sediment, lbs.*** wt.	Σwt.
11-23-77	2.65	2.65	0.81	88	88
12-13-77	0.60	3.25	0.36	39	127
12-15-77	2.40	5.65	2.03	221	348
12-19-77	1.70	7.35	0[1/]	0	348
12-22-77	0.51	7.86	1.89	206	554
12-29-77	4.15	12.01	0[1/]	0	554
1-4-78	1.35	13.36	1.01	110	664
1-6-78	3.35	16.71	0[1/]	0	664
1-12-78	1.72	18.43	0[1/]	0	664
1-18-78	5.75	24.18	0.29	32	696
2-22-78	5.58	29.76	0.53	58	754
			6.92		

[1/] The net changes in elevation between the current and previous readings indicates more material was deposited than eroded. The net amount of material deposited for each date is as follows:

Date	Net Amount of Deposit, cu.ft.**
12-19-77	1.43
12-29-77	1.65
1-6-78	1.17
1-12-78	.09
	4.34

*1 in. = 25.4 mm

**1 ft^3 = .028 m^3

***1 lb. = .454 kg

The source of the deposited material was from areas above the test plot. As shown in Figure 3, the cut slope continues above the test plot for about 30 feet (9.1 m) to the frontage road. During storm periods, some drainage water from the area between the frontage road and the test plot flows over the slope. The drainage water evidently transports some sediment from these upper slope areas. Therefore, when template readings showed that more sediment was deposited on the test plot than was eroded, the net sediment volume was reported as zero.

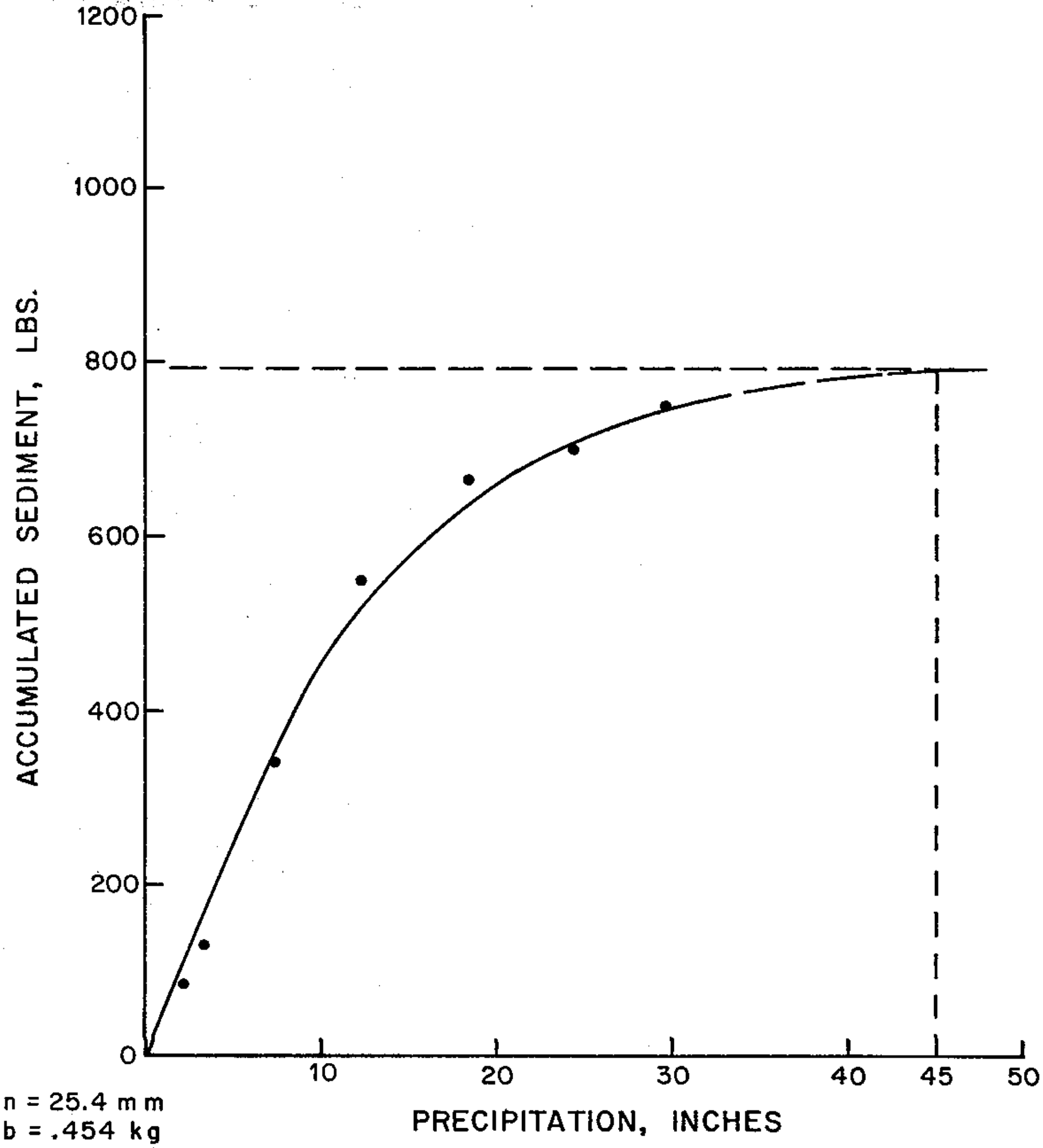
Figure 5 shows a plot of the Mechanical Slope Template data. For the normal annual rainfall of 45" (1.14 m) at this site, the Mechanical Slope Template shows the erosion to be 800 lbs/yr (3.62 kg/yr) from the plot. This calculates to be 87.1 tons/ac/yr (19.6 kg/m^2/yr).

A summary of the results is shown in Table 3.

TABLE 3

Summary of Results

Method	Estimated Average Annual Erosion Rate tons/ac/yr	($kg/m^2/yr$)
Sediment Collection Trough	17.4	(3.9)
Slope Erosion Transect Survey	18.7	(4.2)
Mechanical Slope Template	87.1	(19.6)



1 in = 25.4 mm
1 lb = .454 kg

MECHANICAL SLOPE TEMPLATE SEDIMENT CURVE

FIGURE 5

An estimate of the cost to perform this study was made to provide some guidance for determing costs of future studies. The costs consisted of initial capital for equipment, site installation and removal, monitoring, and computer analysis. Table 4 shows a breakdown of these costs.

TABLE 4

Study Costs

Equipment		
Mechanical Slope Template	$ 0*	
Re-bar reference points	25	
Fence Post Rain Gage	5**	
Sediment Collection Trough	350**	
Subtotal		$ 380
Labor		
Site Installation and Removal		150
Monitoring $50/event (11 events)		550
Computer Analysis Data entry and program execution $50/event (11 events)		550
Miscellaneous Materials		50
Travel		150
Total		$1,830

*The Mechanical Slope Template was fabricated in 1973 at TransLab at a cost of about $500.

**The fence post rain gage and sediment collection trough are salvageable and can be used on other projects.

DISCUSSION

Two of the three methods used to estimate erosion from the 200 sq.ft. (18.6 m^2) plot at Camino yielded essentially the same rate. The Mechanical Slope Template method gave a result about 5 times that of the Sediment Collection Trough method and 4.7 times the rate for the Slope Erosion Transect Survey method.

The monitoring with the Sediment Collection Trough and the Mechanical Slope Template only covered a 3 month portion of the winter season (November 23, 1977 to February 22, 1978). During this period about 66% of the normal annual rainfall of 45" (1.14 m) occurred. The 1977-78 winter followed two years of extreme drought in California. These factors may have influenced the erosion rate of the soil as compared to the long-term average erosion rate.

The Slope Erosion Transect Survey method represents an erosion rate that reflects average erosion since the time of construction. Hence, initial erosion rates may have been more rapid than current rates. This usually is the case where the exposed slope erodes very quickly after construction and then as vegetation and weathering of loose material occurs, the erosion rate decreases.

In the case of the slope at Camino, the cut slope appears to have had a higher erosion rate in the past than it currently exhibits. The exposed concrete at the base of some fence posts located at the top of slope confirm the fact that more rapid erosion previously occurred.

Therefore, for an environmental investigation, the Slope Erosion Transect Survey average annual erosion rate would probably provide a more accurate estimate of expected erosion over several years for a new slope that will be constructed similar to the existing one and in the same location and soil type.

The Sediment Collection Trough average annual erosion rate can be used for current erosion quantities on the existing slope, especially for designing a mitigation plan for controlling slope erosion. The erosion rate determined from this method can also be used for estimating erosion from various sources as was done in the 208 Nonpoint Source Sediment Study for the Camino-Fruitridge area(5).

The Mechanical Slope Template method did not provide meaningful results. The data collected at each grid point was extrapolated over a two square foot (.19 m^2) area which apparently was too large an area. As a result, larger erosion quantities were calculated than the sediment that was actually trapped in the sediment trough located at the base of the slope.

Other problems with the Mechanical Slope Template included: 1) difficulty in climbing up and down the slope to obtain measurements, 2) the rods frequently would not slide through the holes in the template and had to be tapped, 3) because of the slope angle, it was difficult to get a perpendicular reading, 4) the ends of the rod penetrated into the wet soil giving a possible false reading of the erosion depth, and 5) small rills were not measured when they fell between adjacent rods which were spaced one foot (.305 m) apart.

Because of the above problems with the Mechanical Slope Template and the unusually high results, it is felt that this method can not be used successfully for highway slopes.

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