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Erosion rates can be derived from the known amount of sediment eroded in a given time frame using known precipitation information. The erosion rate can be used to estimate future quantities of sediment.

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DIVISION OF STRUCTURES AND ENGINEERING SERVICES
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RESEARCH REPORT

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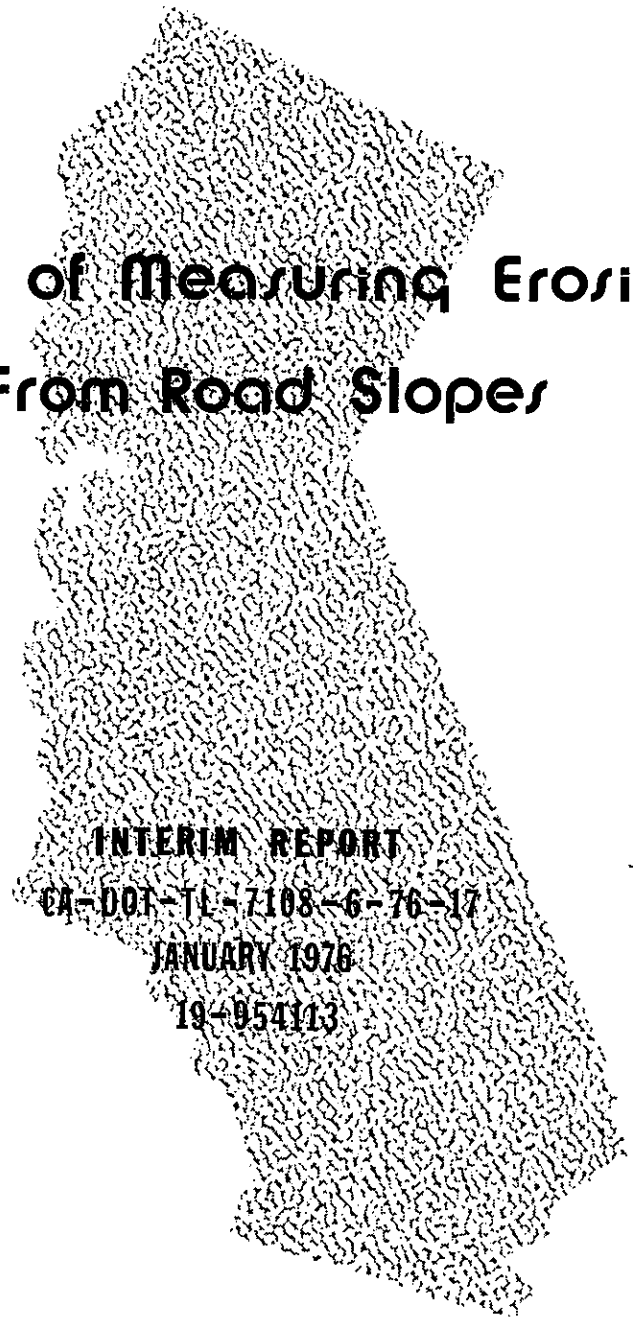

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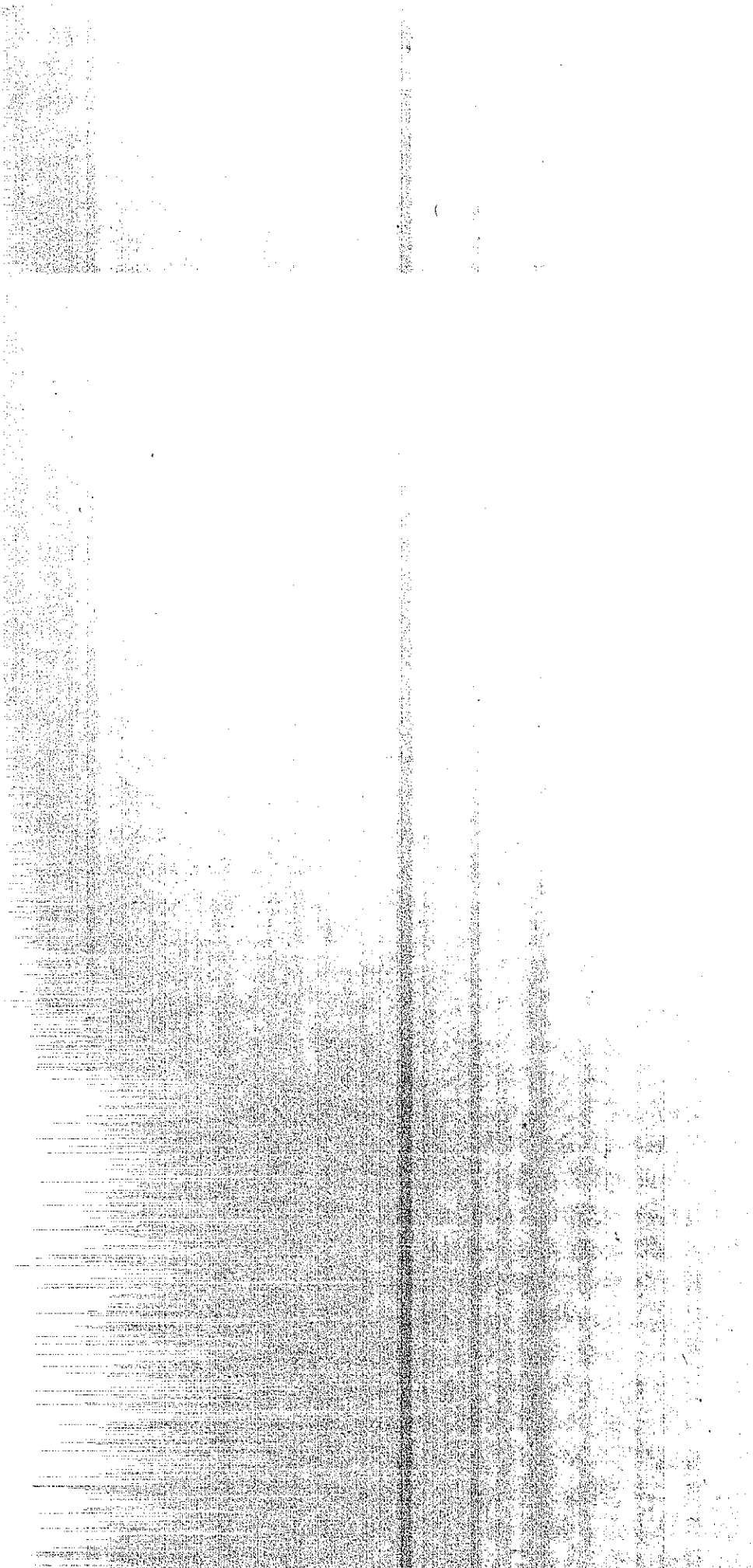

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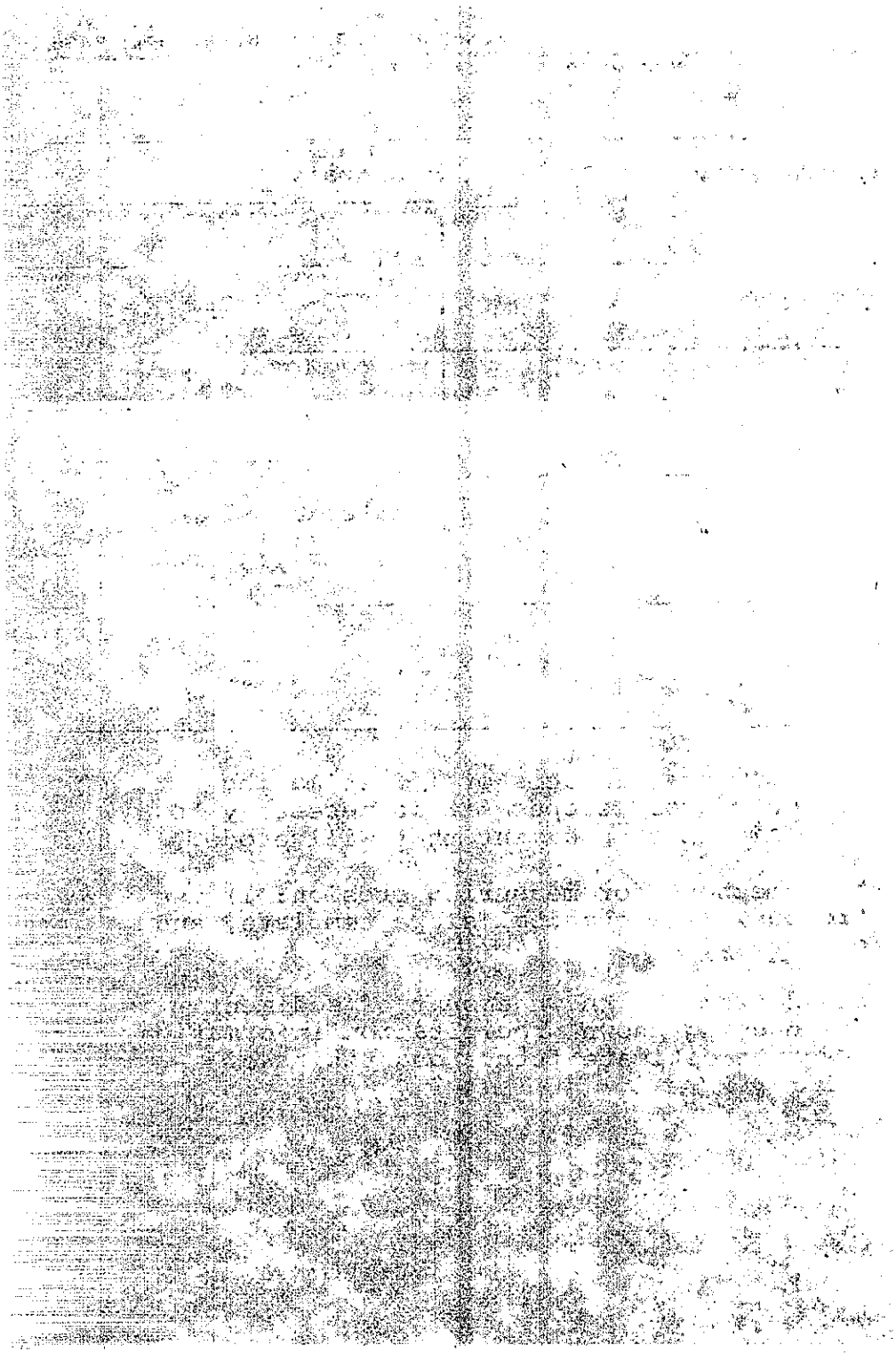

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

January 1976

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:

METHODS OF MEASURING EROSION
FROM ROAD SLOPES

Study made by	Environmental Improvement Branch
Under the Supervision of	Earl Shirley
Principal Investigator	Richard B. Howell
Report Prepared by	Richard B. Howell

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

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The assistance of Bob Breazile in designing and building the mechanical slope template, sediment collection troughs, and modifying the precipitation gages is greatly appreciated. Acknowledgement is also given to Richard Wasser, Joe Halterman and Marty Nolan of the Translab for their work in designing and analyzing data and for implementation of field studies. The technical review of this report by Don Nakao is appreciated.

The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

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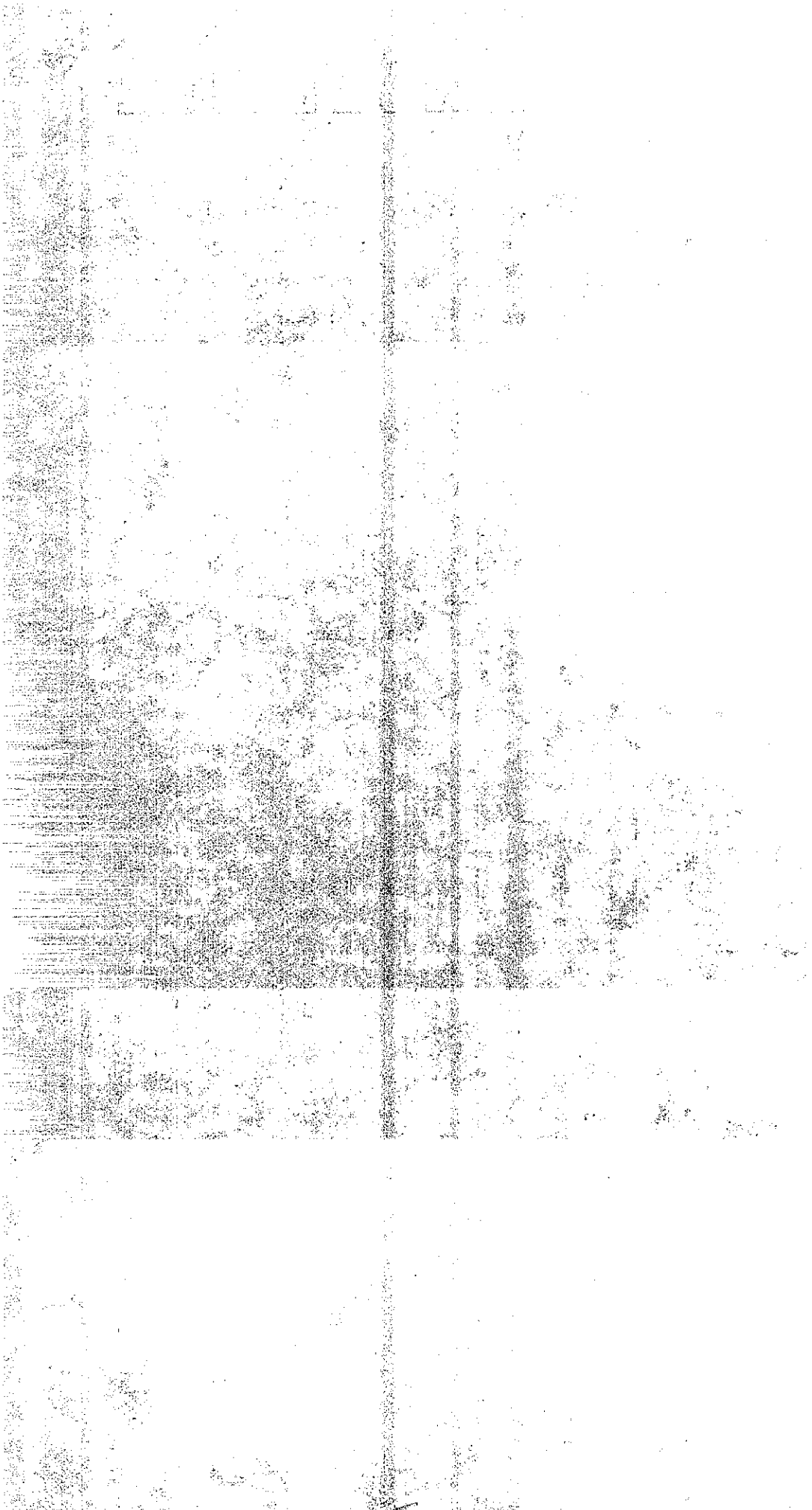

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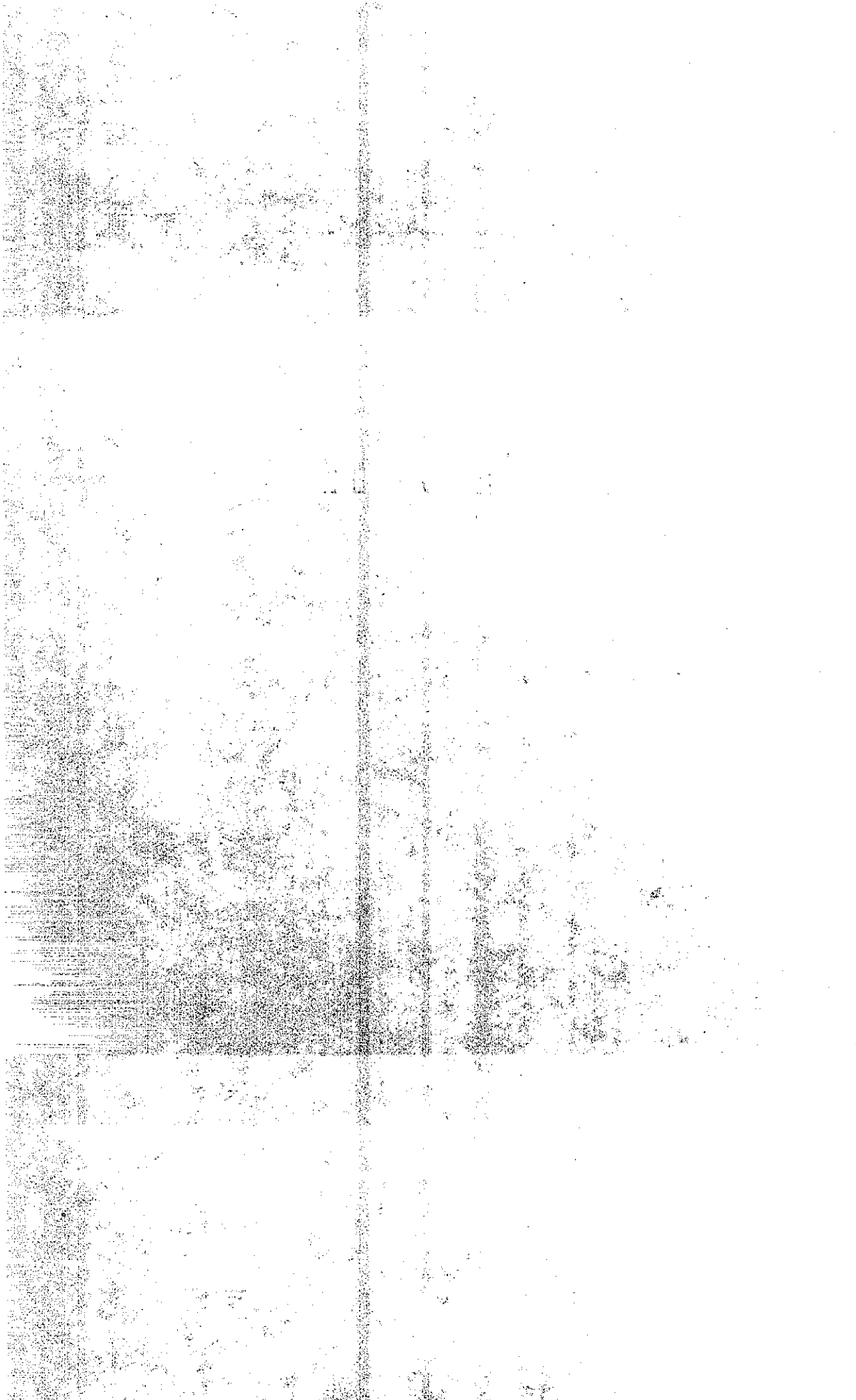

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INTRODUCTION

During the course of highway investigations to quantify potential erosion of slopes for environmental impact assessment, estimates of erosion on existing highway slopes are often made. These estimates are then extrapolated to planned slopes in order to estimate quantities of sediment that may evolve from those slopes over the service life of the project.

Erosion estimates can also be used for existing slopes to design appropriate mitigation measures to reduce the amount of maintenance required to keep drainages open and maintain safety on the traveled way.

This report discusses three methods of measuring slope erosion that have been developed by the Environmental Improvement Branch at the Caltrans Transportation Laboratory (Translab) since 1971. The three methods are: 1) sediment collection troughs, 2) mechanical slope template, and 3) slope erosion transect surveys.

Most transportation districts have utilized the slope erosion transect survey method, or a modification of it, to predict future erosion from unconstructed highway slopes. This information has been used in project environmental impact assessment. Appropriate erosion control measures have been designed to mitigate adverse effects where they have been identified.

The slope erosion transect survey has been used extensively in District 11 (San Diego) and in the Lake Tahoe Basin for District 03 (1, 2).

Sediment collection troughs were developed by the Translab for measuring erosion from experimental plots in the Lake Tahoe

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Basin in 1971. Originally, the V-shaped metal troughs were used to compare the reduction of erosion from bare soil using different chemical sprays (3).

The troughs were modified into a rectangular cross-section for greater stability and have since been used on special investigations in Districts 01, 02 and 03 and on research in District 02.

The mechanical slope template was designed at the Translab to measure the configuration of a slope cross-section. The slope configuration can be remeasured after a series of storms and the eroded volume of soil determined from a plot of the cross-sectional area. This procedure has not been implemented on research studies or on routine district studies as yet.

The University of California, Davis, has implemented a cross-sectional method of measuring erosion losses from cleared areas in the Tahoe Basin (4). This work is being done to determine natural soil losses from erosion for various soil types found in these areas. Instead of using a mechanical slope template, slope configurations are determined by measuring the distance from a reference wire stretched across the slope surface to the ground.

It is hoped that the discussion of these three procedures will enable the transportation specialist to choose from the available tools for predicting erosion rates. Quantitative sediment amounts can be readily applied for the design of appropriate temporary and long-term erosion measures, and can also be used to predict possible impacts in a more precise way.

Another method, not discussed here, uses the Univeral Soil Loss equation, a mathematical method of predicting erosion rates. This is the subject of a special study by the Geotechnical Branch at Translab. Results of this study are inconclusive at this time.

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METHODS

The following is a discussion of three methods for measuring erosion from a road slope. A discussion of each method and a description of equipment and its use is presented.

A. Sediment Collection Troughs

The sediment trough method involves the installation of collection troughs near the toe of a highway slope to periodically collect the sediment eroded from the highway slope. The sediment is weighed and correlated to the precipitation during the collection period. A precipitation vs. erosion curve is developed from these data, and the curve is used to estimate the average annual erosion rate based on the normal yearly precipitation for the area.

This technique was used on an experimental basis on two test slopes in the Lake Tahoe Basin (3). Test data agreed well with estimates from a slope erosion transect survey performed earlier (2).

In selecting an area to study on a slope, factors to include are: area, slope angle, aspect (direction slope is facing), and degree of erosion or characteristics of erosion (rill, gully or sheet erosion). If various soil types or rock outcrops are evident, they should also be taken into account.

The test plot(s) should be planned and located on the basis of the specific erosion rate (or rates) that is to be determined. The erosion rate will depend on six basic physical variables:

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1. Soil type
2. Slope height
3. Slope angle
4. Slope aspect
5. Cover (vegetal or chemical)
6. Climatological conditions

If feasible, at least two plots should be monitored (minimum recommended number of replications) to ensure the determination of a reliable erosion rate. Thus if one of the plots is damaged, or if it yields an unusually high or low erosion rate in comparison to the other plots, the data from that plot can be analyzed and an erosion rate can be determined on the basis of the data from the other plot.

Soil samples should be taken of the surface material and a gradation analysis performed. This information will give a median diameter of the material (D_{50}) which can be used in sediment transport calculations and settling times for sediment basin design.

Colored slides of the slope are also useful for later comparisons. A photo-log of the slope during the course of the study may show areas where significant erosion occurs and may help clarify unusual erosion quantities depicted in the data.

Climatological data should be obtained for the area. If precipitation records are only available from distant points, plans should be made to install a precipitation gage at the site to generate localized rainfall records. It is highly important to characterize rainfall amounts, durations, and intensities during the course of the study since erosion is greatly influenced by these factors. Figure 1 shows typical climatological data.

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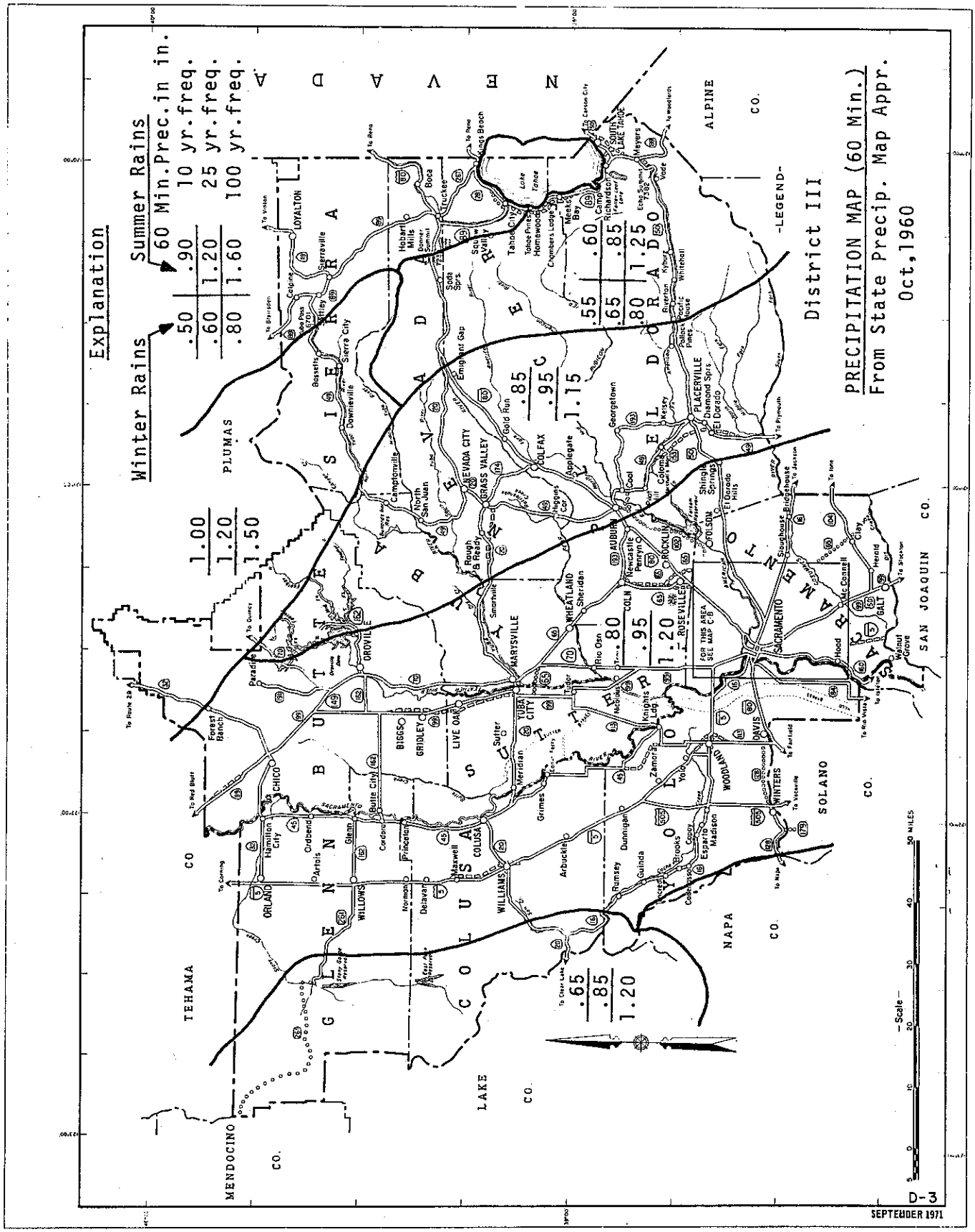
Figure 1
PRECIPITATION MAP



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The sediment collection trough is designed on the basis of expected runoff from the slope. A Rainfall Intensity vs. Time to Fill (Duration) graph is prepared for various size sediment troughs utilizing the rational formula (5):

$$Q = CiA$$

where C = coefficient of runoff
i = rainfall intensity, in./hr.
A = area, acres

To illustrate the procedure for calculating this relationship, assume that a slope to be studied is 10 feet wide and 15 feet high. Also, the runoff coefficient for this area is estimated to be 1.0 for saturated conditions.

Using the rational formula, the following calculations are made for the given intensities:

i, in./hr.	Q, cfs
1/12	.000287
1/2	.001722
2	.006887

Two sizes of V-shaped troughs will be considered for this example: 6" deep x 12" wide x 10' long and 12" deep x 24" wide x 10' long.

For the 6" x 12" x 10' trough, the time to fill for the three rainfall intensities of 2 inches in 24 hours, 1/2 inch per hour, and 2 inches in one hour is as follows:

$$\text{Vol} = \frac{6" \times 12" \times 1/2}{144} \times 10' = 2.5 \text{ cu. ft.}$$

i, in./hr.	$t = \frac{\text{Vol}}{Q}$, sec	t, hrs.
1/12	8711	2.4
1/2	1452	0.4
2	363	0.1

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For the 12" x 24" x 10' trough, the time to fill is as follows:

$$\text{Vol} = \frac{12" \times 24" \times 1/2}{144} \times 10' = 10 \text{ cu. ft.}$$

i, in./hr.	$t = \frac{\text{Vol}}{Q}$, sec	t, Hrs.
1/12	34843	9.7
1/2	5807	1.6
2	1452	0.4

The information is plotted to form the curve relationship shown in Figure 2.

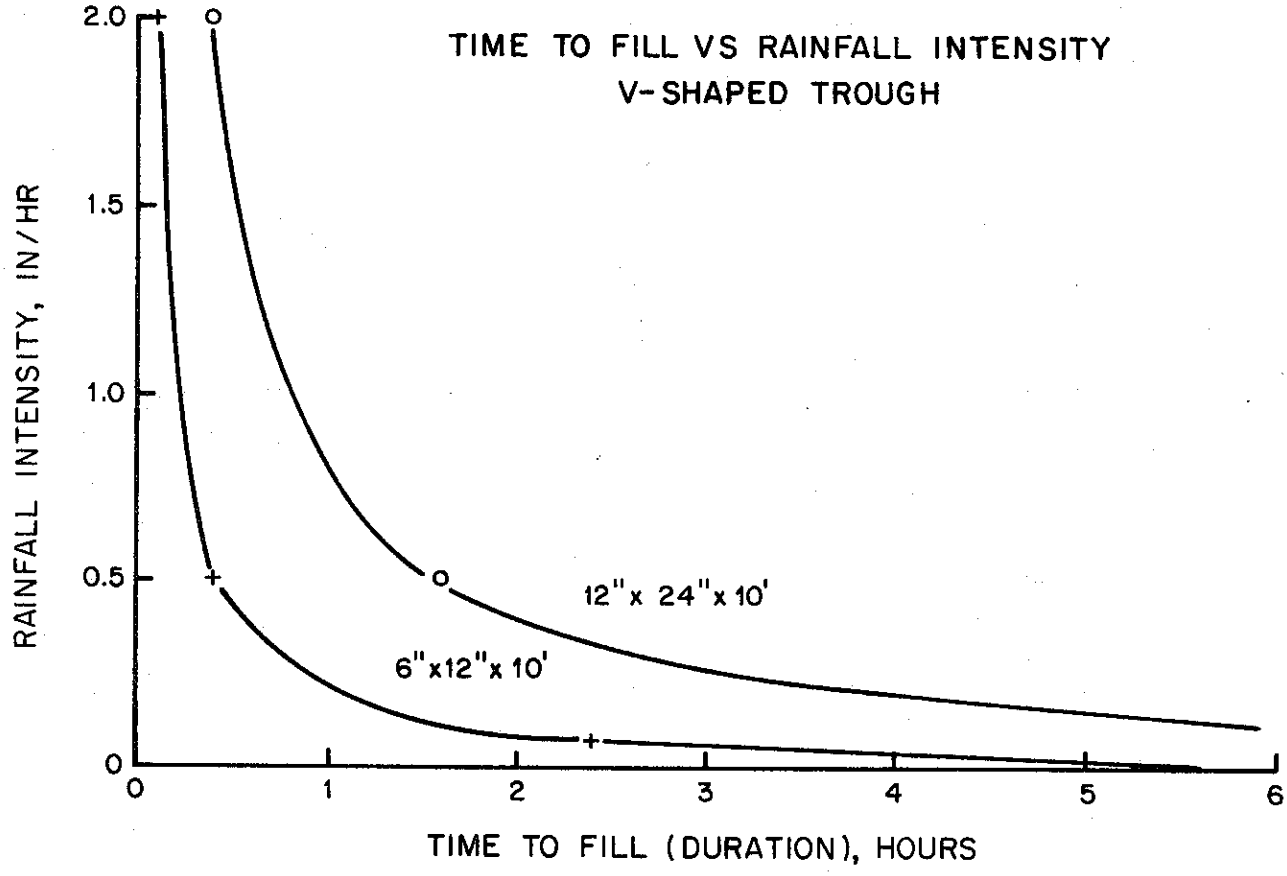

Figure 2

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A similar procedure would be used for other configurations of the sediment troughs.

Historical rainfall records can be reviewed and the appropriate rainfall intensity-duration selected. Using a graph such as Figure 2, a trough size can be selected that will not overflow. For example, if the historic rainfall intensity for this area is, on the average, not more than 1/2 inch per hour and the duration of that intensity storm is 1 hour, then the 12" x 24" x 10' size sediment trough would be needed.

There are two basic types of sediment troughs that can be used to collect the material eroding from a slope: a V-shape or rectangular shape. The type of trough required for a particular slope will depend on the climatological conditions at the location. The troughs are made of 16-gage galvanized sheet metal.

In areas of the state where there are not heavy snow loads to contend with, a V-type trough can be attached to the slope face (see Plate 1). In other areas, where there are heavy snow loads, a rectangular trough will have to be installed by an excavation and backfill process (see Plate 2).

A small V-notch weir is provided at one end of the trough to allow overflow water to escape in the event the trough fills beyond design capacity. The rectangular troughs are made in sections of about five-feet and can be bolted together in the field. This made transport from the shop to the project much easier.

It has been found that the area just above the in-let lip of the trough should be stabilized with mortar. This will prevent

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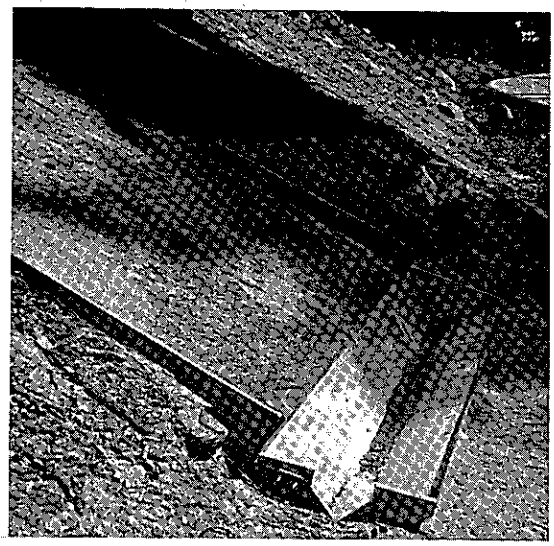

Plate 1. V-shape sediment collection trough.

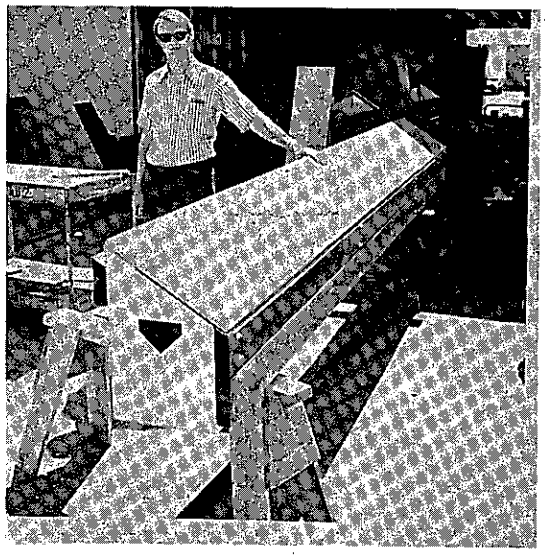

Plate 2. Rectangular shaped sediment collection trough.

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the occurrence of scour from seepage. Small drain holes can be drilled in the bottom of the metal trough to allow trapped water to slowly drain out.

The troughs can be covered with marine plywood to keep extraneous materials out. A two inch deep opening on the uphill side is adequate to allow the passage of incoming sediments.

Plates 3 and 4 show the rectangular shaped trough installed on a test plot.

B. Mechanical Slope Template

The Mechanical Slope Template method measures changes in the profile of a slope surface over a specified time period. To utilize this procedure, a test plot must be selected that typically represents the area of the slope one desires to measure. The Mechanical Slope Template is 10 feet in width, and therefore automatically limits the width of a test section. However, the slope length of the section is unlimited.

The 10 foot wide test section is useful if replications are desired on a slope. Normally, it is recommended that as many as 3 to 5 replications of the experiment be made on the same slope. Therefore, a test slope of from 30 to 50 feet wide or more will be required.

The limits of the test plot are delineated and wood hubs or steel spikes are driven into the slope at the corners and quarter points along the perimeter of the section. Redwood or equivalent boards (recommend 2" x 10") are then fastened to the stakes.

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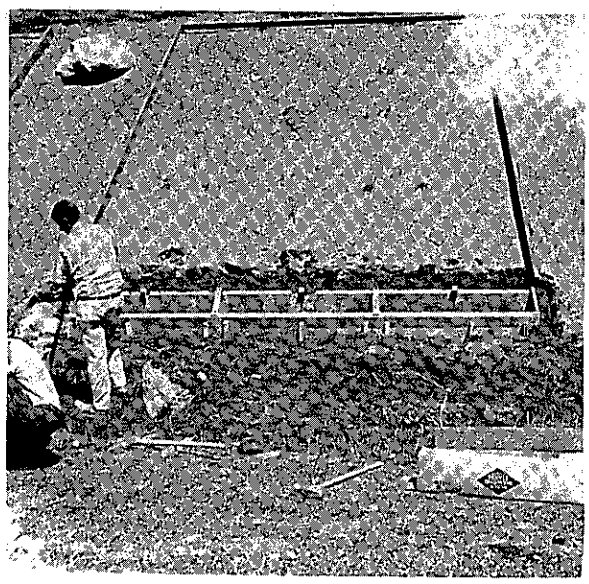

Plate 3. Installation of rectangular shaped sediment trough.

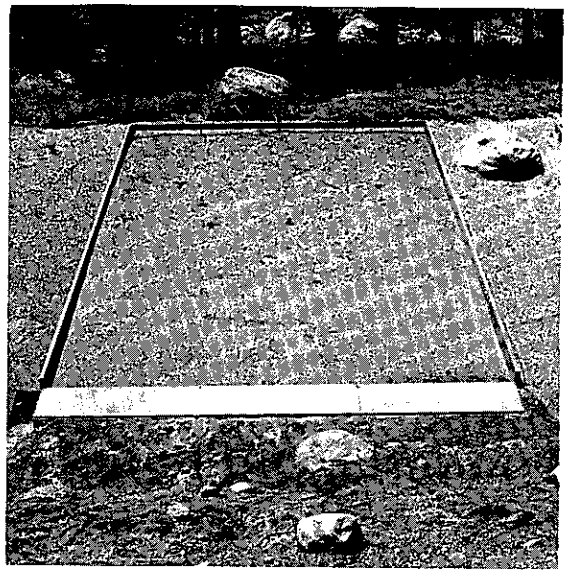

Plate 4. Installed Sediment trough. Plywood cover in-place.

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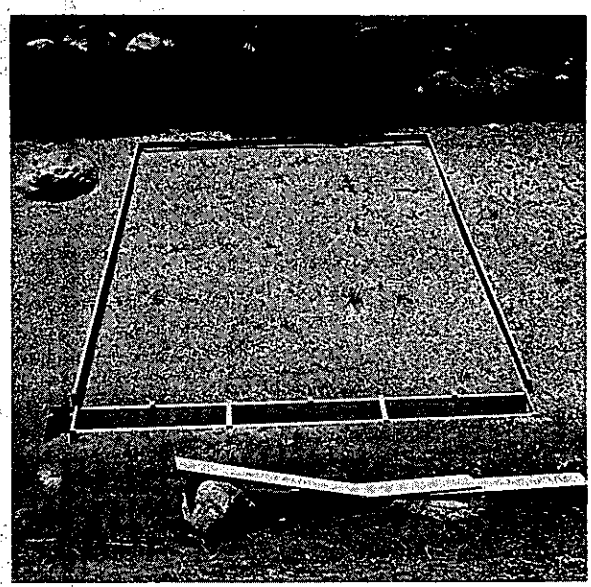

Plate 5 Redwood boards outline test plot (10' x 15').

A bench mark is established at a point off the slope and referenced. Elevations of the corner hubs are then determined. These elevations are recorded for future reference in case the boards accidentally move during the experiment.

Each one foot mark is notched or marked on the redwood side board proceeding from the bottom of the slope to the top. It is recommended that a plot map now be prepared and all elevation and grid points recorded on the map (see Figure 3).

The test plot is also observed and features such as rocks, grass stands, rills, holes, etc., are noted.

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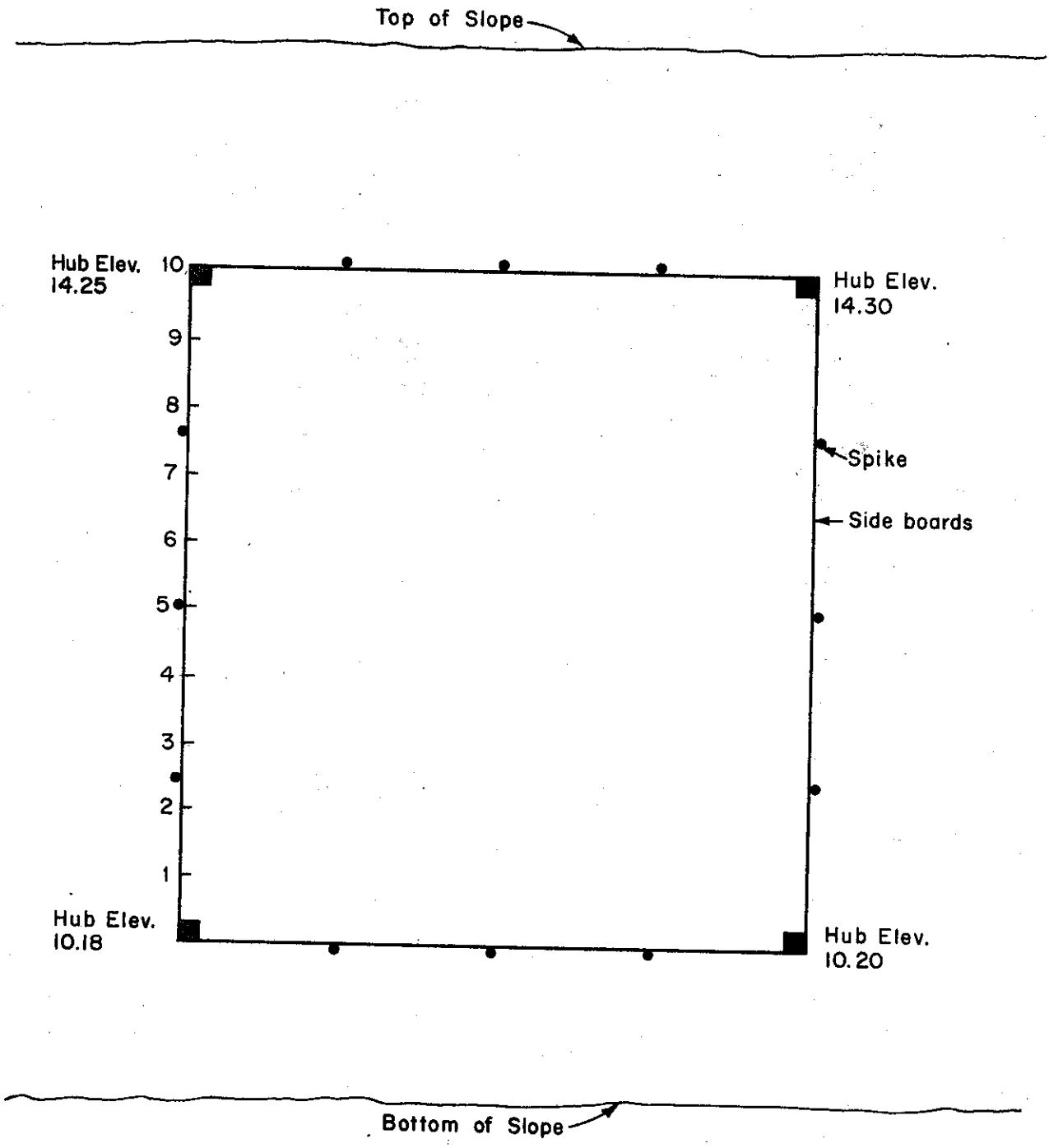
PLOT MAP



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The initial elevations are now measured by placing the Mechanical Slope Template horizontally across the first one-foot mark.

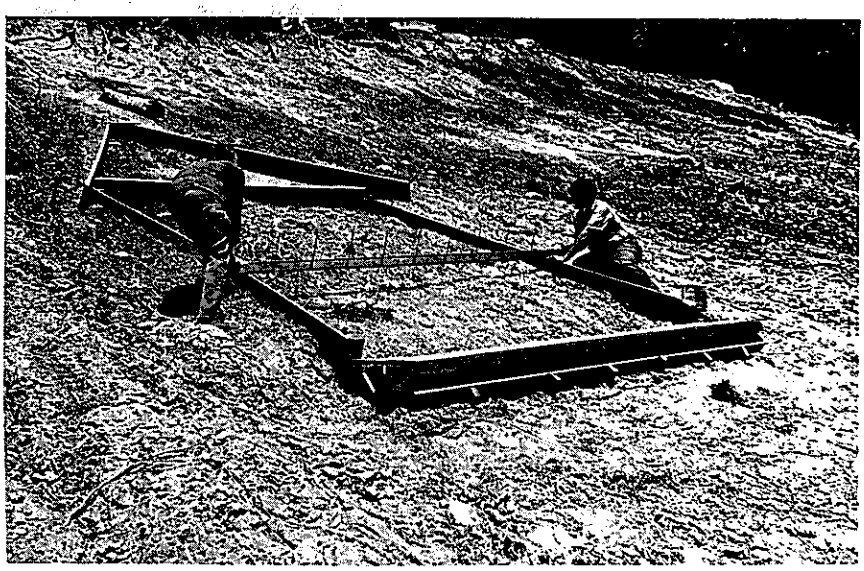

Plate 6 Measuring Slope Elevations with Mechanical Slope Template.

The rod inserts are secured in an upward position while the template is placed on the side boards.

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Plate 7 Rods secured in upward position.

The upper slide of template is now moved thus releasing the rods. The rods drop through the bore holes on the template and come to rest on the slope face. The upper slide is again locked which holds the rods in their new position. The template is now carefully removed and the distance from the template base to the foot of the rod measured. This distance is then recorded for each one foot by one foot grid on the test plot.

The mechanical slope template is shown in Figure 4. It is made of extruded alumnium channel 3 inches high and 11 feet long. The one-foot steel rods are stored in a small compartment located on the template.

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Plate 8. Rods released and then locked duplicating the slope configuration.

Plate 9. Distance from template to slope surface is measured on the rod.

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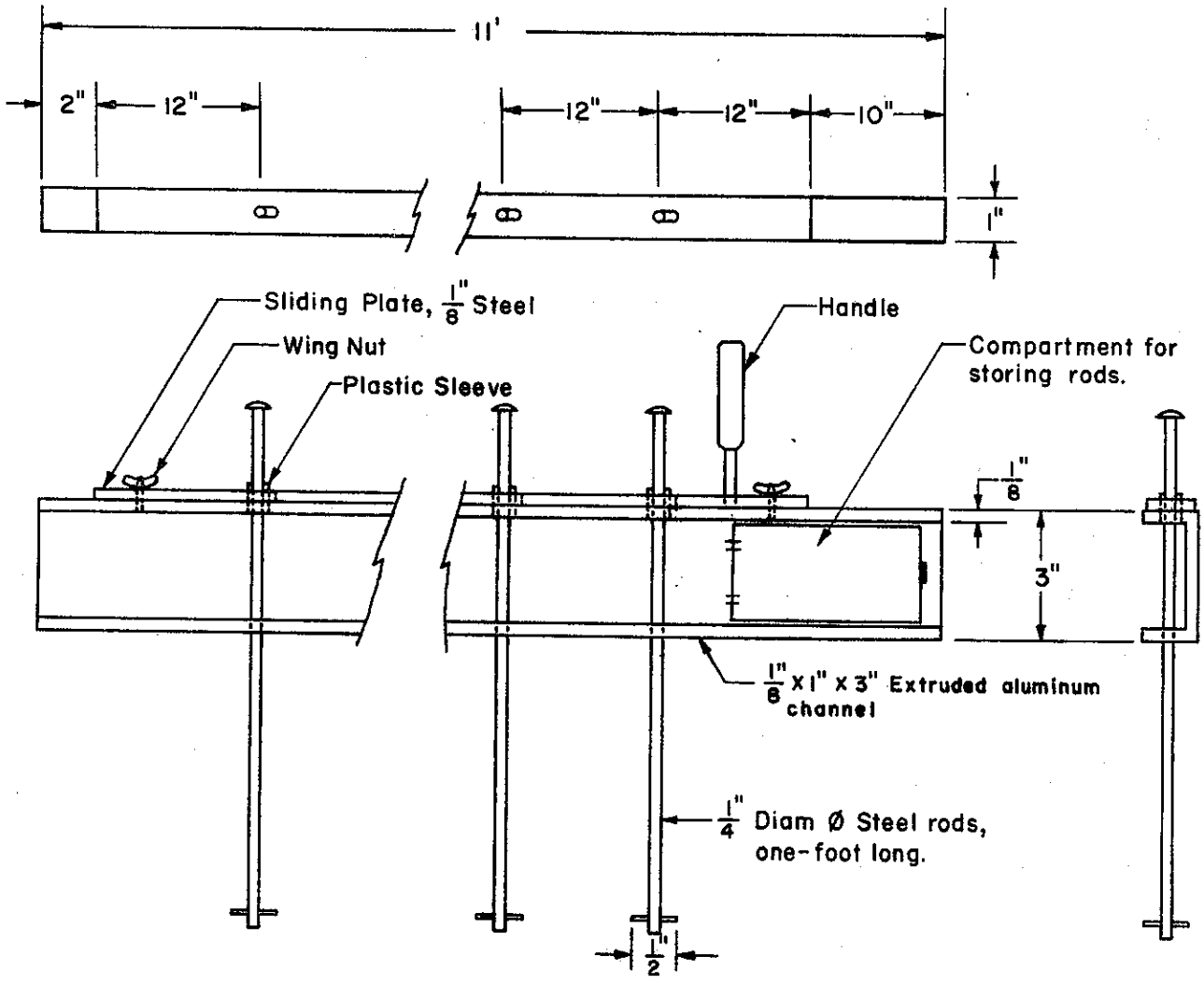
Figure 4

DETAILS MECHANICAL SLOPE TEMPLATE



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ENVIRONMENTAL IMPROVEMENT BRANCH

MECHANICAL SLOPE TEMPLATE

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C. Slope Erosion Transect Survey

This method has been treated in much detail in the Translab Water Quality Manual prepared for district use (6).

The slope erosion transect survey is a procedure whereby existing slopes are examined to determine average annual erosion quantities which can then be applied with certain adjustments to slopes that may be constructed in the vicinity. This method allows the interpreter to see first hand the erosion characteristics that will develop on a future slope in the absence of specific remedial measures.

The slope erosion transect survey can also be used to compare erosion quantities from existing slopes with those from other slopes in a given location. This may be particularly useful information if a remedial program is to be implemented in an attempt to mitigate present environmental impacts, aesthetic problems, or reduce maintenance effort.

Normally, slopes are chosen within the same watershed as the planned future road alignment. This tends to minimize the effect of variables such as rainfall patterns, temperature, vegetative cover, etc. which might result from the selection of slopes in a different watershed. Once the area for the erosion survey is decided, local roads can be examined to determine slopes that will be studied. Generally, slopes are selected that appear to be similar to those that will be constructed. Similarity should include slope angles, exposure, height of slope and area exposed and slopes that are subjected to similar precipitation. If state highway slopes are not available, other local road slopes can be examined such as country, city or subdivision roads, forest roads, etc.

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Preview of slopes on designated sections of State highways should utilize the microlog film (a photographic log of the roadway taken every 50 feet). Although all road slopes are not readily visible in the frames, a general idea of the slope characteristics can be gained. The post mile limits can be obtained from the picture frame for those slopes that may be investigated further in the field. Investigation of geologic maps will also aid in finding slopes of similar composition.

When a slope has been selected for the survey, areas are cordoned off that have representative features. In some cases, the slope may appear to be uniform throughout its length. In others, there may be obvious differences between the lower and upper portions of the slope or along its length. In order to derive an erosion rate in these instances, typical areas should be selected and examined independently of the other portions.

The erosion rates derived for each representative area can then be applied over that portion of the slope that they represent and then summed to obtain a total rate for the slope. For particularly large slopes, it is difficult to estimate an erosion rate for the total slope without investigating several smaller areas first. Erosion signatures can vary quite a bit depending upon the erosion rate at that section of the slope. For these reasons, the process of dividing the slope into smaller sections will help in deriving a more accurate rate for the total area.

In estimating the quantity of eroded material from a slope, a dual procedure is used. First, an estimate of the amount of erosion occurring over an annual period is made. This involves probing the slope surface for evidence of annual movement of material over the slope. One signature is pine needles, leaves or other similar material that are found buried just beneath

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loose slope material thus indicating rate of soil deposition. Exposure of fresh plant roots also are used to determine annual rates of erosion as is the occurrence of coloration on rocks and boulders in the slope as material is eroded. Curvature of the main stem on woody plants also gives a clue as to the movement of material downslope.

The second procedure followed is to determine the amount of erosion occurring over a long period of time. Such a period might be anywhere from two to 15 years. The longer term periods such as 10 years or more are very difficult to analyze and often call for reliance on as-built plans, maintenance records, and memory of personnel working or living in the area. Long term erosion quantities are then reduced to average annual rates for comparison with the annual rates as determined under the first procedure. Sometimes, the two annual quantities are of the same order of magnitude. This indicates a stabilized erosion rate. Other times, the annual rate will be lower than the average annual rate which indicates initial erosion on the slope was extreme. The third case found is where the annual erosion rate is higher than the average annual rate which indicates changing conditions are accelerating the erosion on the slope. In the third case, it is important to look for the factors causing the accelerated erosion and perhaps to instigate remedial action to reduce the erosion.

For most studies, the slope erosion transect survey will provide a rapid means of generating sufficient sediment information that can be used to determine sediment contributions from future road slopes. This is particularly true for water quality studies conducted during the planning stage where several alternative alignments are under consideration. The procedure is subjective and therefore open to interpretation.

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If a significant quantity of sediment is estimated from the proposed road slopes, mitigation measures can be instituted by the designer to reduce that rate.

ANALYSIS OF DATA

Measurements of erosion from highway slopes must be analyzed in terms of the precipitation that caused that erosion. Unusually heavy or intense rainfall in a short time period may cause more erosion than the same amount of rainfall (quantity) falling over several months. A discussion of precipitation, its measurement, and the data required is presented in this section. Development of erosion rates is also discussed and the application of erosion rates for study areas to an entire slope is presented.

A. Precipitation

If precipitation data are not available from an area nearby, a recording type precipitation gage should be installed.

In areas of the state where there is no snow or freezing rain to contend with, a standard rain gage such as the tipping bucket can be installed. In areas of the state where there is snow and ice, a propane heated snow gage should be used.

The precipitation gage consists of an insulated conical cover which houses a tipping bucket mechanism. Precipitation falling into the orifice at the top of the gage is funneled into one of the two small buckets which were calibrated to tip when 0.01 inch of water was collected. As one bucket tips, the other is brought into position to catch the precipitation. If the precipitation is in the form of snow, the heat generated by a

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propane flame located at the base of the instrument is channeled up between the inner and outer cases to heat the collecting funnel and melt the snow.

With each tip of the bucket, a mercury switch closes momentarily in the precipitation gage. The switch permits current from a battery in the recorder to activate an electromagnet which advances the recorder pen one division on the chart. The chart is mounted on drums and driven by a battery operated clock mechanism. The result is a trace of precipitation with time.

The gage should be installed in accordance with the manufacturers instructions. The recorder can be installed in the gage housing or at another location up to 1,000 feet away from the gage. If a maintenance station is located nearby, the gage could be installed there and could be maintained and serviced by maintenance department personnel. Telemetering and other specialized data acquisition and processing systems can be installed with the instrument if it is feasible to do so.

Precipitation data should be recorded on Form HMR T-704 produced at the Translab. This form is illustrated in Figure 5. A daily precipitation record should be filled out with this data as shown on Table 1. High rainfall intensities (>0.10 inch/hour) should be recorded as shown on Table 2.

Plates 10 and 11 show a typical precipitation gage and a recorder.

Annual rainfall amounts derived from the study can be compared with historical average annual amounts. Adjustments to the data can be made for wetter or drier periods.

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Figure 5

PRECIPITATION DATA

ENVIRONMENTAL IMPROVEMENT SECTION, MATERIALS & RESEARCH DEPT.
DIVISION OF HIGHWAYS

Dist. ________ Co. ________ Rte. ________ P.M. ________ Location ________

Job No. ________ Prec. Gage No. ________ Recorder No. ________ Date Installed ________

Calc. By ____________________ Chkd. By ____________________

(1) DATE	(2) T (Hours)	(3) P (Inches)	(4) Type	(5) ΔP (Inches)	(6) ΔT (Hours)	(7) I (in./hr.)	(8) REMARKS

COL.(2) T = Time
COL.(3) P = Precipitation
COL.(4) TYPE: R = Rain, S = Snow, O = Other
COL.(7) = $\frac{\text{COL.(5)}}{\text{COL.(6)}}$ I = Intensity

HMR T-704 (Orig. 4/72)

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TABLE 1
DAILY PRECIPITATION RECORD (INCHES OF WATER)

Day of Month	-1971- Oct.	Nov.	Dec.	-1972- Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
1	-	0	0	0	0	0	0	0	0	0	0	.22R	.46R
2	-	0	0.45S	0	0	.44R	0	0	0	0	0	.01R	.34R
3	-	0	0.25S	0	0	.50R	0	0	0	0	0	0	0
4	-	0	0.01S	0	.12S	0	.06R	0	1.79R	0	0	0	0
5	-	0	0	0	.18S	0	.50R,S	0	.20R	0	0	.25R	0
6	-	0	0.15S	0	0	0	.53R	0	.06R	0	0	0	0
7	-	0	0	0	0	0	.01R	0	.33R	0	0	0	.13R
8	-	0	0	0	0	0	.02R	.01R	.09R	0	0	0	.01R
9	-	0	0.21S	0	0	0	0	0	.04R	0	0	0	.06R
10	-	0	0.41S	0	0	.02R,S	0	0	.07R	0	0	0	.03R
11	-	1.23S	0.08S	0	0	0	0	0	0	0	0	0	0
12	-	0.13S	0.82S	0	0	0	0	0	0	0	0	0	0
13	-	0.19S	0.01S	0	0	0	.34S	0	0	0	0	0	0
14	-	0	0.04S	0	0	0	.56S	0	0	0	0	0	.04R
15	*	0	0.02S	0	0	0	0	0	0	0	0	0	.03R
16	0.15S	0	0	0	0	0	0	0	0	0	0	0	.13R
17	0	0	0	0	0	0	0	0	.17R	0	0	0	0
18	0	0.01S	0	0	0	0	.01S	0	0	0	0	0	.83R
19	0	0	0	.08S	0	0	0	.44S	0	0	0	0	.32R
20	0	0	0	0	0	0	0	.17S	0	.02R	0	0	.19R
21	0	0	0.38S	.07R	.17S	0	0	.05R,S	0	0	0	0	0
22	0	0	2.00S	.14S	.39S	.64S	0	0	0	0	0	0	0
23	0	0	0.38S	.33S	0	.01S	0	0	0	0	0	0	0
24	0	0	1.08S	0	.40S	.07R	.14S	0	0	0	0	0	0
25	0	0	2.18S	.45S	.33S	.16R	0	0	0	0	0	.09R	0
26	0	0.53R	0.01S	.16S	.02S	0	0	.46R	0	0	0	.64R	0
27	0.03S	0.09S	0.22S	1.01S	0	0	0	0	0	0	0	.54R	0
28	0	1.35S	0	.02S	.15R	0	0	0	0	0	0	.01R	0
29	0	0.17S	0	0	.20S	0	0	0	0	0	.20R	0	0
30	0.04S	0	0	0		0	0	0	0	0	.06R	0	0
31	0		0	0		0		0		0	.02R		0
Total	0.22	3.70	8.70	2.26	1.96	1.84	2.17	1.13	2.75	.02	.28	1.76	2.57

R = Rain - S = Snow (Measured in inches of water)
*Precipitation Gage placed in operation

Total Precipitation 10-15-71 to 10-15-72 = 27.89 Inches

TABLE 2
SEVERE RAINFALL INTENSITY (>0.10 Inch/Hr.) RECORD

Date	Time Interval (Hours)	Precip. (Inches)	Duration (Hours)	Intensity (Inches/Hr.)
11-11-71	0235 - 0245	.02	.17	.12
11-11	0345 - 0440	.13	.92	.14
11-11	0510 - 0635	.30	1.42	.21
11-11	0750 - 0800	.02	.16	.13
11-11	0830 - 0930	.15	1.00	.15
11-11	1150 - 1305	.23	1.25	.18
11-11	1355 - 1400	.02	.08	.25
11-11	1905 - 1915	.03	.17	.18
4-6-72	0980 - 1425	.53	4.45	.12
5-26	1700 - 1750	.46	.50	.92
6-4	1490 - 1750	1.55*	2.60	.60
6-4	1750 - 1950	.24*	2.00	.12
6-5	2230 - 2260	.08	.30	.27
6-6	1640 - 1660	.04	.20	.20
6-7	1190 - 1210	.06	.20	.30
6-7	1770 - 1820	.15	.50	.30
6-8	1250 - 1260	.02	.10	.20
6-17	1700 - 1750	.12	.50	.24
8-29	1580 - 1620	.17	.40	.43
8-30	1400 - 1430	.04	.30	.13
9-1	1750 - 1880	.22	1.30	.17
9-5	0330 - 0370	.23	.40	.58
9-26	0110 - 0380	.36	2.70	.13
9-26	0540 - 0590	.13	.50	.26
9-27	0020 - 0050	.07	.30	.23
9-27	0110 - 0250	.18	1.40	.13
10-1	2110 - 2210	.24	1.00	.24
10-2	1700 - 1790	.29	.90	.32
10-7	1150 - 1160	.02	.10	.20
10-18	0960 - 1130	.23	1.70	.14
10-19	1450 - 1490	.07	.40	.18

*Possibly including some hail.

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Plate 10. Typical precipitation gage with wind shield.

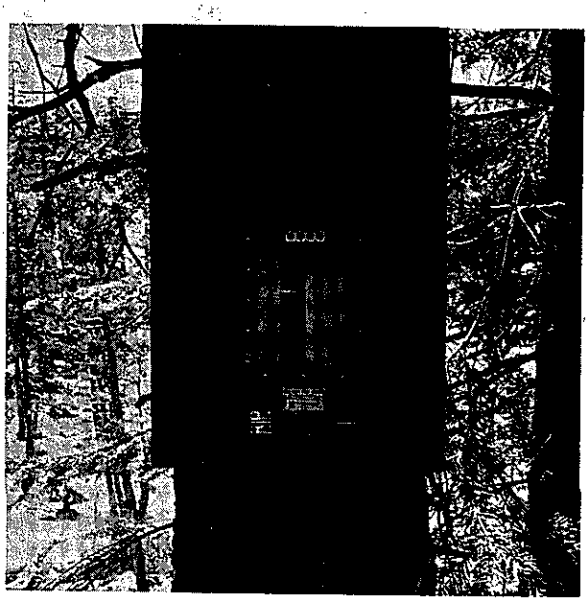

Plate 11. Recorder for precipitation gage.

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B. Sediment Rate

Sediment rates are determined from the data collected. They are normally presented in terms of tons/acre/year or cubic yards/acre/year. Other rates can be used also.

In some cases, the amount of sediment eroded is highly dependent on the amount and characteristics of the rainfall. In the discussion that follows, the procedures for developing sediment rates and relating them to rainfall is presented. This method is related to the sediment trough procedure for collecting sediment.

Sediment Trough Method

Record erosion (dry weight) and precipitation data for the various collection periods and calculate the total accumulated erosion and total accumulated precipitation for the various periods. An example is shown in Table 3. A grading analysis curve is illustrated in Figure 6.

An Erosion vs. Precipitation curve is prepared by linear regression analysis. The sample shown in Table 3 is illustrated on Figure 7.

The normal yearly precipitation is determined for the area from climatological records. The normal precipitation for the slope location can be correlated to the precipitation at the climatological record site by referring to a Rainfall Pattern chart of the area, if one is available.

Referring to the Precipitation vs. Erosion curve on Figure 7 (with precipitation = 34"), an average yearly erosion rate of about 800 pounds for the 10' x 15' area of slope is found. This figure could be used to estimate the erosion rate from a

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TABLE 3
EROSION AND PRECIPITATION

Test Plot 2

Period	Prec. Type	Prec. (Inches)	Total Accum. Prec. (Inches)	Sediment (lbs)	Total Accum. Sed. (lbs.)
10-15 to 10-27-71	Snow	.15	.15	50.8	50.8
10-27 to 11-10	Snow	.07	.22	131.5	182.3
11-10 to 11-18	Rain & Snow	1.55	1.77	22.2	204.5
11-18 to 12-7	Rain & Snow	3.00	4.77	2.1	206.6
Test plot was covered with snow between 11-18-71 and 3-10-72.					
12-7-71 to 2-10-72	Rain & Snow	13.02	17.79	Sediment was not collected	
3-10 to 3-21	-----	0	17.79	17.1	223.7
3-21 to 3-28	Rain & Snow	.88	18.67	25.0	248.7
3-28 to 4-21	Rain & Snow	2.03	20.70	46.1	294.8
4-21 to 5-17	Rain & Snow	.15	20.85	119.1	413.9
5-17 to 5-23	Rain & Snow	.66	21.51	6.5	420.4
5-23 to 6-2	Rain	.46	21.97	9.8	430.2
6-2 to 6-21	Rain	2.75	24.72	46.8	477.0
6-21 to 8-9	Rain	.02	24.74	55.0	532.0
8-9 to 8-30	Rain	.26	25.00	43.8	575.8
8-30 to 10-2	Rain	2.58	27.58	42.1	617.9
10-2 to 10-26	Rain	1.77	29.35	57.0	674.9

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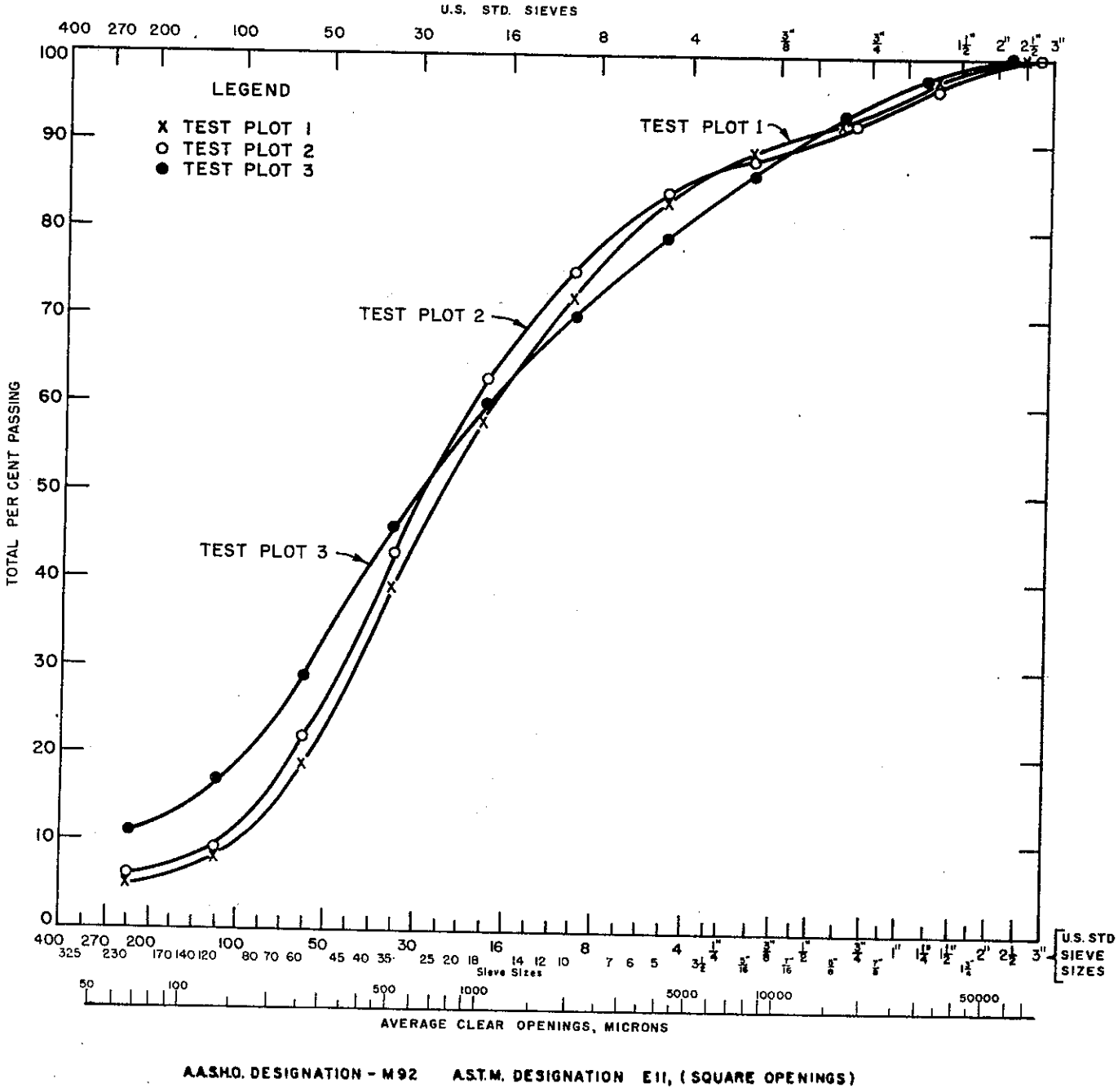
Figure 6

GRADING ANALYSIS
TEST PLOTS 1,2 AND 3

LUTHER PASS SLOPE TREATMENT
LAKE TAHOE BASIN
ROAD 03-ED-89, PM 2.4



A.A.S.H.O. DESIGNATION - M92 A.S.T.M. DESIGNATION E11, (SQUARE OPENINGS)

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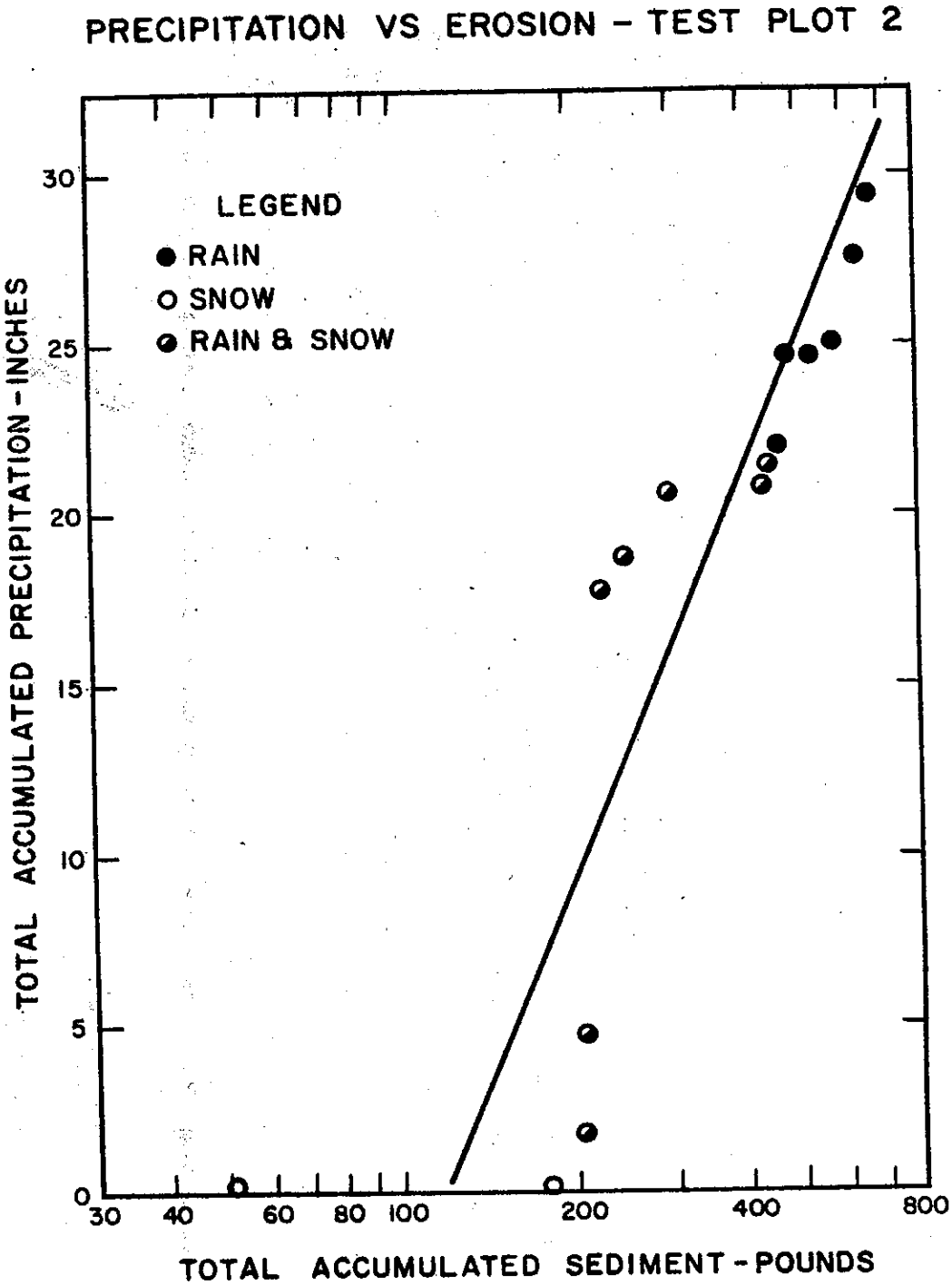
Figure 7



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highway slope (of about the same soil type, slope, height and aspect). For this example, the average yearly erosion rate would be:

$$\frac{800 \text{ lbs/yr}}{.003444 \text{ AC}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} = 116.1 \text{ Tons/acre/year}$$

Mechanical Slope Template Method

A comparison between grid elevation readings shows the depth of sediment that has either been eroded or deposited over the time period of measurement. This distance times the one square foot area it represents will equal either a plus or minus quantity of sediment. The summation of the total readings gives the sediment yield or quantity of erosion of the given test section.

$$\Sigma \text{ Total Erosion} = K \frac{(1 \text{ sq ft})(\text{Depth}_2 - \text{Depth}_1)}{\text{Time}} \text{ Tons/year}$$

where K = conversion factor of volume to weight
Depth_1 = initial measurement
Depth_2 = second measurement

Replications of the test plot for a particular slope will provide more reliable data.

The total volume or weight of sediment eroded from the test plot for a specified time period (normally one-year) divided by the area of the plot will yield an erosion rate per unit area. This rate can be used to estimate slope erosion for future highway slopes that exhibit similar characteristics as the measured slope. These characteristics should include slope angle and aspect, soil type, similar precipitation patterns, etc.

It is recommended that records of precipitation during the test period be maintained. A similar method of analysis would be performed as discussed under the Sediment Trough Method.

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Slope Erosion Transect Survey Method

Suppose a slope erosion survey was conducted on a slope that was constructed 8 years ago as shown in Figure 8. The west facing slope had an angle of 2:1. The slope is broken into five sections as shown and the computation of the respective areas is indicated. This information is entered on Form HMRT-703.

Erosion signatures were examined on each segment with the following results:

Area A

Uniform erosion with an estimated 2 inches of soil removed since construction. Short term erosion signatures revealed about 2 cubic yards of material were eroded during the past year.

$$\text{Long Term} = \frac{5200 \text{ sq ft} \times 0.17 \text{ ft}}{27 \text{ ft}^3/\text{cy} \times 8 \text{ yrs}} = 4.1 \text{ cy/yr; Short Term} = 2 \text{ cy/yr}$$

Area B

Several rills and gullies with small overhang near top of slope. A volumetric measurement indicates approximately 40 cubic yards of eroded material since construction. It appears that about 5 cubic yards were eroded during the past year.

$$\text{Long Term} = \frac{40 \text{ cy}}{8 \text{ yrs}} = 5 \text{ cy/yr;} \quad \text{Short Term} = 5 \text{ cy/yr}$$

Area C

Similar signatures as Area B but gullies are a little deeper. Volumetric measurements show 60 cubic yards of eroded material since construction. During the past year it appears 5 cubic yards were eroded.

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Figure 8

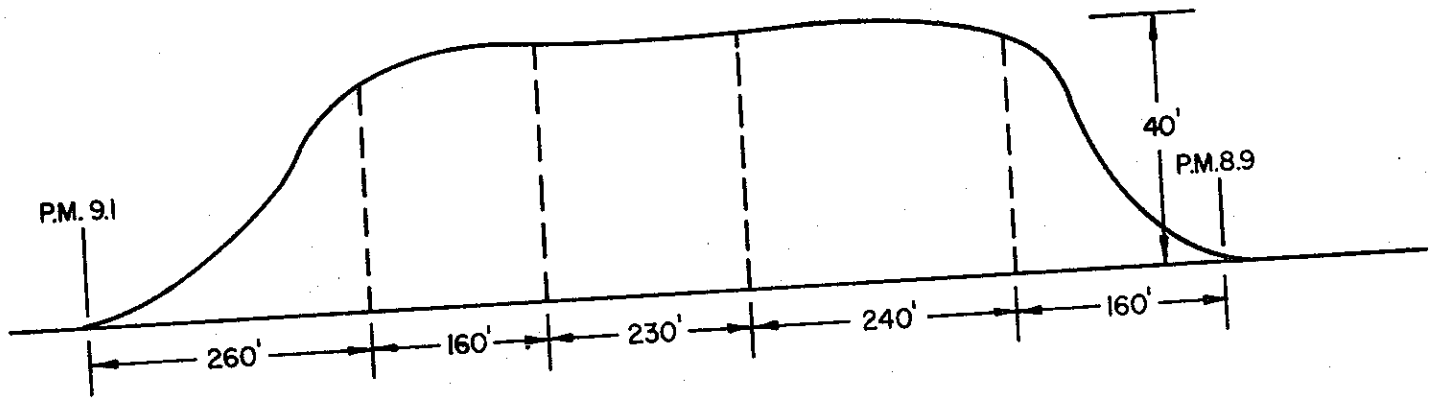

Figure 8 EXAMPLE PROBLEM OF SLOPE EROSION SURVEY

Segment			Area,sf	% Total
A	1/2 x 260 x 40	=	5200	15
B	160 x 40	=	6400	19
C	230 x 40	=	9200	27
D	240 x 40	=	9600	29
E	1/2 x 160 x 40	=	3200	10
			33,600	100

Long Term = $\frac{60 \text{ cy}}{8 \text{ yrs}}$ = 7.5 cy/yr; Short Term = 5 cy/yr

Area D

Larger rills and gullies with overhang at the top of cut indicate about 80 cubic yards of material has eroded since construction. Erosion signatures indicate that approximately 8 cubic yards were eroded during the past year.

Long Term = $\frac{80 \text{ cy}}{8 \text{ yrs}}$ = 10 cy/yr; Short Term = 8 cy/yr

Area E

More uniform erosion occurred over most of slope with small rills evident. Erosion signatures indicate that approximately 3 inches of erosion had occurred since construction. On short term basis, approximately 1/2 inch was eroded.

Long Term = $\frac{3200 \text{ sq ft} \times .25 \text{ ft}}{27 \text{ ft}^3/\text{cy} \times 8 \text{ yrs}}$ = 3.7 cy/yr

Short Term = $\frac{3200 \text{ sq ft} \times .042 \text{ ft}}{27 \text{ ft}^3/\text{cy} \times 1 \text{ yr}}$ = 5 cy/yr

Total erosion rates are as follows and are entered in the column headed "Volume-CY" on Form HMRT-703:

	Long Term	Short Term
Area A	4.1	2.0
Area B	5.0	5.0
Area C	7.5	5.0
Area D	10.0	8.0
Area E	3.7	5.0
Total	30.3 cy/yr	25 cy/yr

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ROAD EROSION TRANSECT SURVEY

BASIN Sacramento
WATERSHED Pitt R.
SUBUNIT Burney Cr.
ROAD DESCRIPTION Two-Laned Paved Road

DATE August 15, 1968
PARTY T. Jones S. Albert J. West
LOCATION: T___ R___ S___ B&M___

START POST MILE 8.9 END POST MILE 9.1

ODOMETER READING START	ODOMETER READING END	EQUIVALENT POST MILES START	EQUIVALENT POST MILES END	DISTANCE	CUT FILL / RIGHT LEFT	ASPECT / ANGLE	HEIGHT OF CUT FEET	AREA S.F. X 10	DEPTH EROSION	VOLUME - C.Y. YR. 8 DISPL. / TO STR.	VOLUME - C.Y. YR. 1 DISPL. / TO STR.	REMARKS
A		9.1		260'	C / R	W / 2:1	40	52	2"	4.1	2	Long Term = $\frac{5200 \times .17}{27} = 32.8$
B				160'	C / R	W / 2:1	40	64	—	5.0	5	
C				230'	C / R	W / 2:1	40	92	—	7.5	5	
D				240'	C / R	W / 2:1	40	96	—	10.0	8	
E			8.9	160'	C / R	W / 2:1	40	32	3" / .5"	3.7	5	Long Term = $\frac{3200 \times .25}{27} = 29.6$ Short Term = $\frac{3200 \times .042}{27} = 5$
							TOTAL	ANN	UAL=	30.3	25.0	

HMRT-703 (Orig. 11/71)

An analysis of the two erosion rates indicates that during the past year slope erosion has decreased somewhat from the long term average rate. This may be due to several factors such as decreased rainfall, etc., and must be explored further if it is desirable to determine the cause.

To determine the erosion rate per unit area for application to unconstructed slopes, the following computations are made. First, the rate per unit area is determined for Section A through E. The rate is then multiplied by the ratio of that area to the total area. The total of these computations represent the weighted average annual erosion rate per unit area.

	Long Term Rate/SF		Ratio of Subarea to Total Area		CY/SF/YR
A	$\frac{4.1}{5200}$ = .00079	x	.15	=	.00012
B	$\frac{5.0}{6400}$ = .00078	x	.19	=	.00015
C	$\frac{7.5}{9200}$ = .00082	x	.27	=	.00022
D	$\frac{10.0}{9600}$ = .00104	x	.29	=	.00030
E	$\frac{3.7}{3200}$ = .00116	x	.10	=	.00012
			Weighted Average	=	.00091

Similar calculations for the short term yield a value of .00076 cy/sf/yr. The investigator must now interpret which rate to use on the unconstructed slope.

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If it is desired to estimate the average annual slope erosion on an unconstructed slope with similar characteristics as the slope surveyed in the example above, and the area of the new slope is calculated to be 45,000 square feet, the rate would be (using the Long Term Rate):

.00091 cy/sf/yr x 45,000 sf = 41 cy/yr.

This information can be used to determine if the ecosystem or physical hydrologic system would be impacted. For example, decreases in the sediment storage pool at a downstream retention dam may result from increased sediment yield and an economic determination could be made for this impact. A sediment settling basin could also be designed on the basis of knowing the incoming annual sediment volume.

CONCLUSIONS

It is hoped that design procedures for erosion control features can be made cost-effective through the development of quantitative methods for estimating future erosion from highway slopes. Likewise, the interpretation of potential environmental impacts from the construction of road slopes can be better made when the quantity of erosion sediments are known.

The three methods for measuring sediment rates from eroding road slopes presented in this report represent methods used by Caltrans Transportation Laboratory in research and special studies. They have been found to be useful in measuring sediment rates and are recommended for use by the Districts.

Other methods are available which can also be tried and were not included in this report (6).

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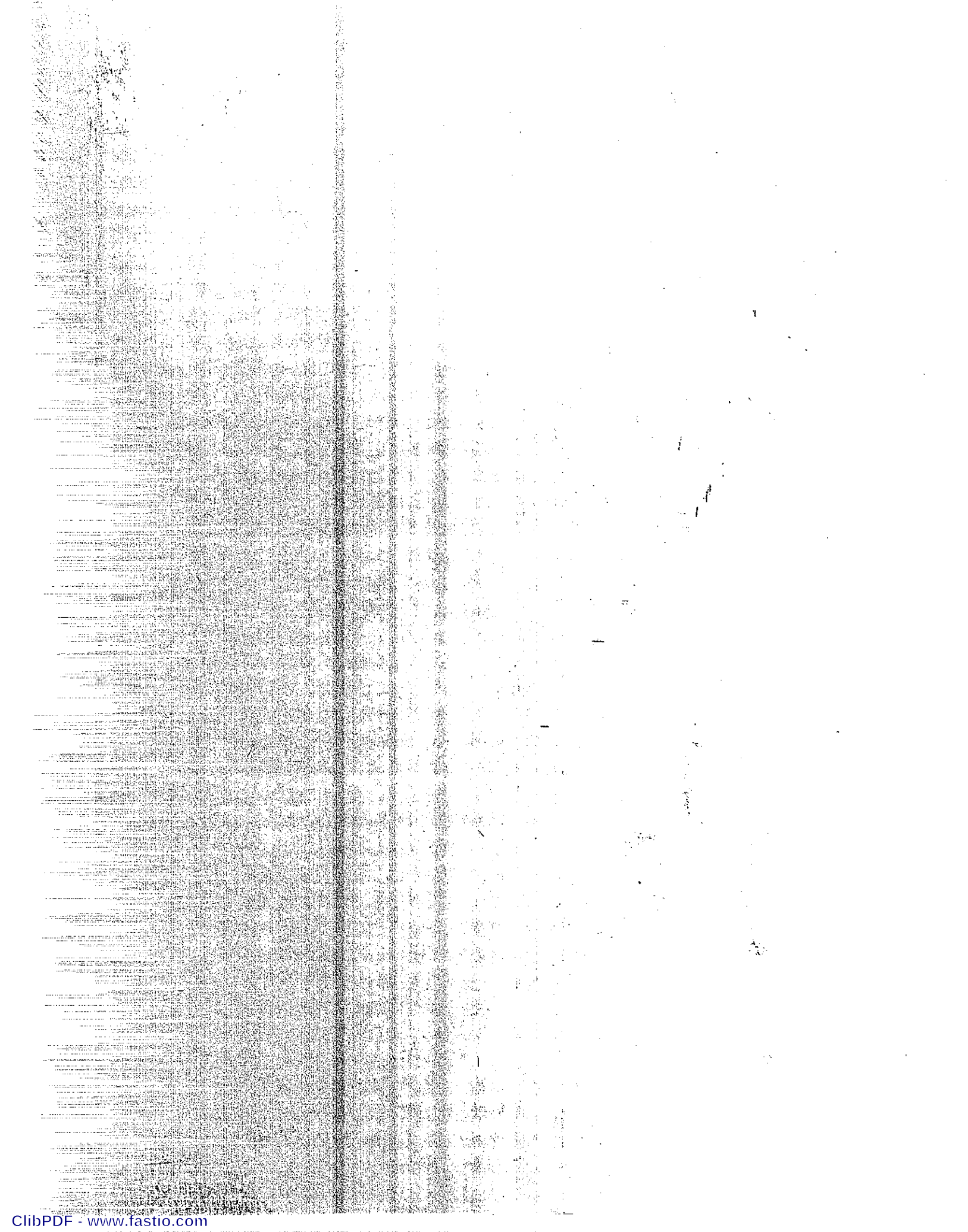

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