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TESTS OF CHEMICALS TO REDUCE EROSION FROM BURNED WATERSHEDS

by

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INTRODUCTION

The high flood and erosion potential of southern California Mountain watersheds, and the risk they impose on both upstream and downstream urban and interurban developments are perhaps unparalleled elsewhere in the United States. The high erosion rates are directly related to extremes in the physiographic features of the watersheds, particularly those of climate (rainfall), topography, soil and geology, disturbances by man, and wildfires (Sinclair, 1954; Krammes, 1960). A wildfire accentuates the flood and erosion potential in these steep unstable watersheds. Consequently, following a major wildfire emergency remedial measures must be undertaken.

During July of 1960, a fire swept through the 17,500 acre San Dimas Experimental Forest in southern California (Figure 1). The major research emphasis before the fire had two broad objectives: to determine how watersheds function and to develop methods of watershed management to ensure maximum yields of usable water with a minimum of flood runoff and soil erosion. Following this disaster, a unique opportunity existed to conduct intensive studies of the effectiveness of various measures used to reduce flood runoff, erosion and sedimentation on fire-denuded watersheds (Hopkins, Bentley, and Rice, 1961).

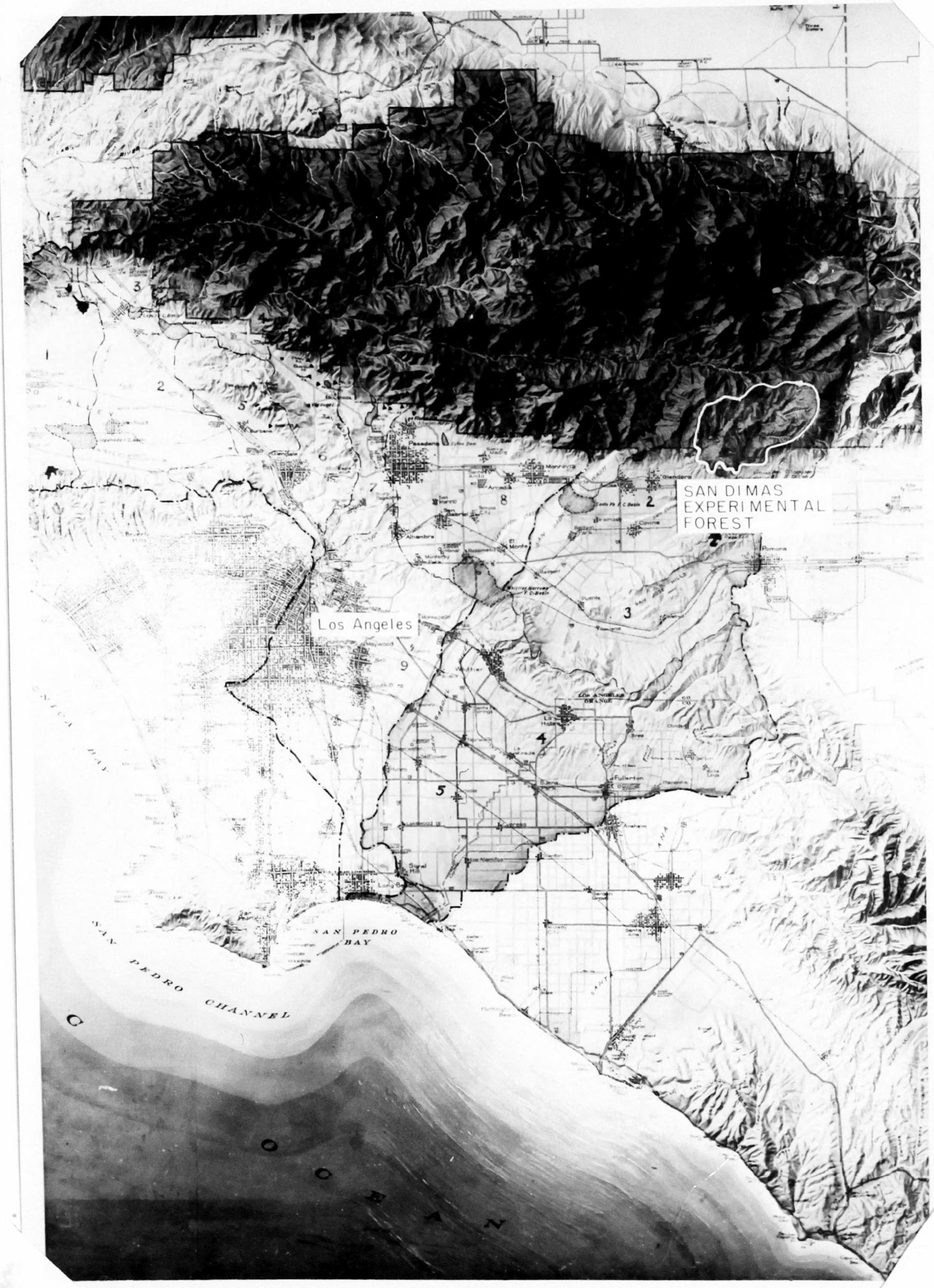

Figure 1. - - Location of the San Dimas Experimental Forest

A research program was established to evaluate several physical and vegetative treatments for rehabilitation of burned watersheds. One of the treatments proposed was to stabilize the soil surface by chemical means. This paper covers the selecting and testing of erosion control chemicals as a preliminary analysis of several chemicals available for use as an emergency "first aid" measure on burned watersheds.

Past Work

In southern California, the most common emergency treatment of burned watersheds consists of sowing annual grasses that germinate quickly and grow a protective soil cover for the first years after a fire, while the slower growing native shrubs are recovering (Hellmers, 1957). However, early rains can cause severe erosion damage before the seeds germinate and the plants have a chance to grow. Also, föehn winds frequently blow seeds and soil from exposed sites. Consequently, following a major wildfire, emergency remedial measures must be undertaken. One way this might be accomplished is to stabilize the soil surface with chemical additives.

Stabilization of the soil surface can be accomplished by blending the soil surface with bituminous materials, cement, resinous materials, deliquescent materials, and by injecting materials into the soil (Lamb and Michaels, 1954). Trauxe, O'Brien, and Young (1947) have prepared a bibliography on soil stabilization by the various methods mentioned. All of the past work up to 1952 deals with stabilizing the soil to depths greater than six inches (Massachusetts Institute of Technology, 1952). The early literature indicates that soil stabilization by chemical means is done primarily as an engineering approach to holding soil permanently in place rather than as an emergency remedial treatment.

There has long been a need for some inexpensive, easy-to-apply substance that could be added to the soil surface which would stabilize its aggregates against pelting rains (Krammes and Hellmers, 1961). Any chemical soil additive should also allow waters to pass through but not tear and separate under strains. The solution must be capable of maintaining its original polymerization after each wetting so as to form a "seal" against subsequent evaporation, thus serving to trap and retain valuable soil moisture. Any formulation should have a long self life and be capable of offering satisfactory performance under water dilutions. No phytotoxicity can be tolerated, yet the formulation should be capable of accepting a suitable non-crop herbicide or a fertilizer additive whenever this might be desirable.

In recent years, chemicals meeting these requirements have been used to stabilize critically eroding slopes along highway cuts and fills and newly landscaped areas, protect against wind erosion, and promote seed germination (Alco Oil and Chemical Co., 1959; Popular Mechanics, 1960; Swift and Co., 1958). It would seem natural that the newer formulation of chemicals might reduce debris movement down burned slopes and protect the soil surface until an emergency seeding treatment has a chance to become effective.

CHAPTER I

DESCRIPTION OF AREA

A. Climate

Virtually all of the precipitation in southern California occurs between October and April. The four wettest months, December, January, February and March produce 77 percent of the annual total (Table 1). Snow is practically unknown at the lower elevations, but is recorded in large amounts above 4,000 feet.

The amount of precipitation received by any area in this region depends upon its distance from the ocean, the altitude, the shape and steepness of mountain slopes, and the direction of the slopes in relation to the direction of the storm. As a rule, precipitation increases from south to north and is much heavier on southern and western slopes than on northern and eastern slopes (Hamilton, 1944).

Some of the maximum rainfall intensities have been measured in southern California. In 1926, at Opid's Camp in the Angeles National Forest, 1.02 inches of rain fell in 1 minute and at another location in 1943, 26.12 inches of rain fell in a 24-hour period (Sinclair, 1954). At the San Dimas Experimental Forest, 25 percent of the total precipitation fell in 3 percent of the storms and 51 percent of the storms produced only 7 percent of the rainfall during a 25 year period. Details of rainfall distribution are shown in Table 2.

Table 1. -- Number of storms and total rainfall by months for the period 1933 through 1958, San Dimas Experimental Forest 1/

Month	Storms		Rainfall	
	Number	Percent	Inches	Percent
October	47	7.6	29.60	4.2
November	49	7.9	52.55	7.4
December	79	12.7	144.50	20.5
January	96	15.4	142.19	20.1
February	87	14.0	137.51	19.5
March	89	14.3	117.89	16.7
April	78	12.5	57.34	8.1
May	44	7.1	10.75	1.5
June	18	2.9	2.31	0.3
July	5	0.8	0.13	0.02
August	13	2.1	2.19	0.3
September	17	2.7	9.19	1.3
Total	622	100	706.15	100

Average annual precipitation 28.25 inches.

1/ Recording raingage #0599-51 at Tanbark Flat (elevation 2750 feet) on the San Dimas Experimental Forest.

Table 2. -- Number of storms and amounts of rainfall by storm size classes for the period 1933 through 1958, San Dimas Experimental Forest [1]

Storm size Class, inches	Storms		Rainfall	
	Number	Percent	Inches	Percent
.01 - .29	263	42.3	24.68	3.5
.30 - .50	57	9.2	22.31	3.2
.51 -1.00	109	17.5	81.46	11.5
1.01 -2.00	98	15.8	141.28	20.0
2.01 -3.00	34	5.5	83.42	11.8
3.01 -4.00	19	3.0	66.62	9.4
4.01 -5.00	12	1.9	52.96	7.5
5.01 -6.00	10	1.6	54.58	7.7
6.01 -7.00	9	1.4	58.28	8.3
over 7.00	11	1.8	120.56	17.1
Total	622	100	706.15	100

---

[1] Recording raingage #0599-51 at Tanbark Flats (elevation 2750 feet) on the San Dimas Experimental Forest.

The torrential winter storms and resultant high storm discharges, although not of annual occurrence, are typical of these mountain areas. Damaging floods occur on an average of about once in 5 to 6 years.

B. Geology

During the 700 to 1000 millions of years since the oldest known rocks in the San Gabriels were formed, several periods of submergence and uplift have occurred. Between these periods the oldest rocks and many of those formed since have been subjected to all recognized types of alteration, such as folding and faulting, extensive weathering and erosion, extreme heat, and pressure.

The rocks of the San Gabriel Mountains may be grouped in two main divisions: (1) sedimentary; (2) igneous and metamorphic. There is considerable variation in the water-carrying capacity and the susceptibility to erosion of these formation.

Sedimentary formations, consisting of interbedded shales, sandstones and conglomerates, underlie almost the entire forest area in the northwestern portion of the San Gabriel range. The rocks vary in water-holding capacity and erodibility according to their composition and the position of their bedding planes. In formations of interbedded sandstones and shales, the shales are eroding faster than the sandstones. None of these sedimentary formations break up as badly when faulted as do the igneous and metamorphic crystalline rocks.

The igneous formation consists largely of granitic types, varying from true granites to diorites. These rocks underlie the major portion of the San Gabriel Mountains. There are some volcanics, but these are generally very localized. The largest part of the granitic rocks occur in the form of massive batholithic bodies made of several successive intrusions. The great amount of jointing and fracturing has allowed ready access to weathering agents, and for this reason weathering is often deep and the surface material easily eroded.

The metamorphic rocks, consisting of schists and gneisses, were formed by alteration of both sedimentary and igneous rocks. These formations strongly resemble sedimentary rocks because of a psuedo-bedding developed by the alignment of minerals during the processes of metamorphism. These rocks, as well as the igneous types, are largely crystalline and tend to shatter extensively during faulting. The large amount of fracturing plus the tendency to break along schist planes causes these rocks to weather fairly rapidly (Storey, 1948).

Three periods of uplifting and erosion during the past one million years has determined the pattern of today's main canyons. Most of the drainages are small, less than 25 square miles in area. They are generally dendritic and have short, steep stream channels and precipitous side slopes. The average slope of the land is over 65 percent, or near the angle of repose for unconsolidated soil materials (Figure 2)(Table 3). Channel gradients average over 40 percent, or 2,100 feet per mile. Uplifting of the mountains in geologic time rejuvenated the streams. Rapid down-cutting of stream channels and under-cutting of slopes have continued since rejuvenation and contribute greatly to the instability of these mountains.

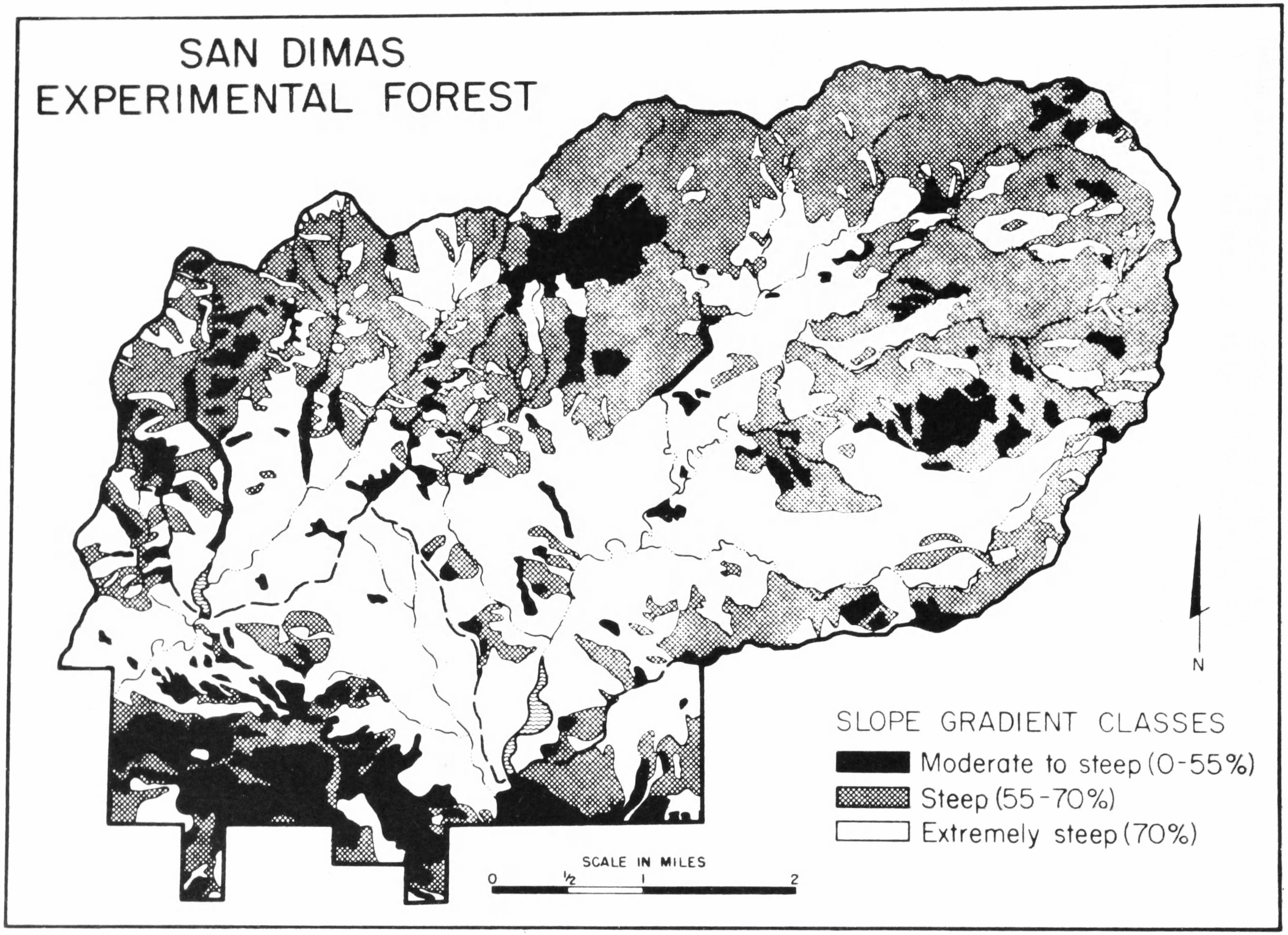

Figure 2.--Slope gradient classes on the San Dimas Experimental Forest. (Bentley, 1961)

Table 3. -- Percent of area on the San Dimas Experimental Forest, by slope gradient and soil depth classes (Bentley, 1961).

Steepness of slope	Very Shallow	Shallow	Medium	Deep		All Depths
	1 foot	1 to 2 feet	2 to 3 feet	3 to 4 feet	Over 4 feet	
	Percent					
Moderate to steep						
Under 40[1]	--	2	3	1	1	7
40-55	([2])	2	3	1	([2])	7
Steep						
55-70	4	23	12	3	([2])	42
Extremely steep						
Over 70	34	9	1	--	--	44
All gradients	38	36	19	5	2	100

[1] Dominant slope gradient, in percent.
[2] Less than 1 percent of the acreage.

C. Vegetation

Chaparral, which is the dominant vegetation formation, occupies the bulk of the watershed area on the San Gabriel Mountains below elevations of 5000 feet. The chaparral is a dense growth of shrubs composed of many different species. The density and species of vegetation vary in relation to age of cover, amount of rainfall, depth of soil, and other site factors. All of the species comprising the chaparral complex are able to withstand the long, dry summers. During the rainless periods, the brush becomes very flammable, and fire hazards are critical. Local fire records show that during the last 65 years most of the chaparral cover has been burned over at least once. Ferrell (1959) concluded from these fire records that the frequency of occurrence for burning over the San Gabriel Mountains is approximately once every 25 years. The chaparral formation has the ability to perpetuate itself following burning. Since the plants usually grow on loose soils and steep slopes that when denuded favor rapid runoff and high erosion rates, the increases of runoff and erosion are felt for many years while the brush is recovering (Rowe, Countryman, and Storey, 1954).

D. Soils

The soils of southern California mountains vary considerably both in composition and depth. The mountain soils are generally shallow; large areas are three feet or less in depth and in some places soil is measured in inches (Crawford, 1962). Although there are limited areas of soil six to eight feet deep, these soils are very scattered throughout the mountain region (Table 3) (Figure 3). The Experimental Forest is considered to be typical of the San Gabriel Mountains, hence, deep soils occupy almost 2 percent of the mountain area. Table 3 shows the percent of area, on the San Dimas Experimental Forest, by slope gradient and soil depth class.

The soils of this region are very youthful and are closely correlated with the parent materials, in most cases consisting of physically disintegrated parent rock. Throughout most of southern California forests the soils show little profile development.

The soils of the watersheds, whether deep or shallow, serve as an important water regulating medium. Soil moisture is at or often below the wilting point at the beginning of the rainy season and its capacity to store water is at a maximum. Drainage into the underlying rocks begins as soon as the soil reaches field capacity. There is still a remaining storage space in the soil which is the volume between field capacity and saturation. Where the capacity of the underlying rock to take in water is less than the soil, the storage space in the soil serves as a reservoir, which reduces

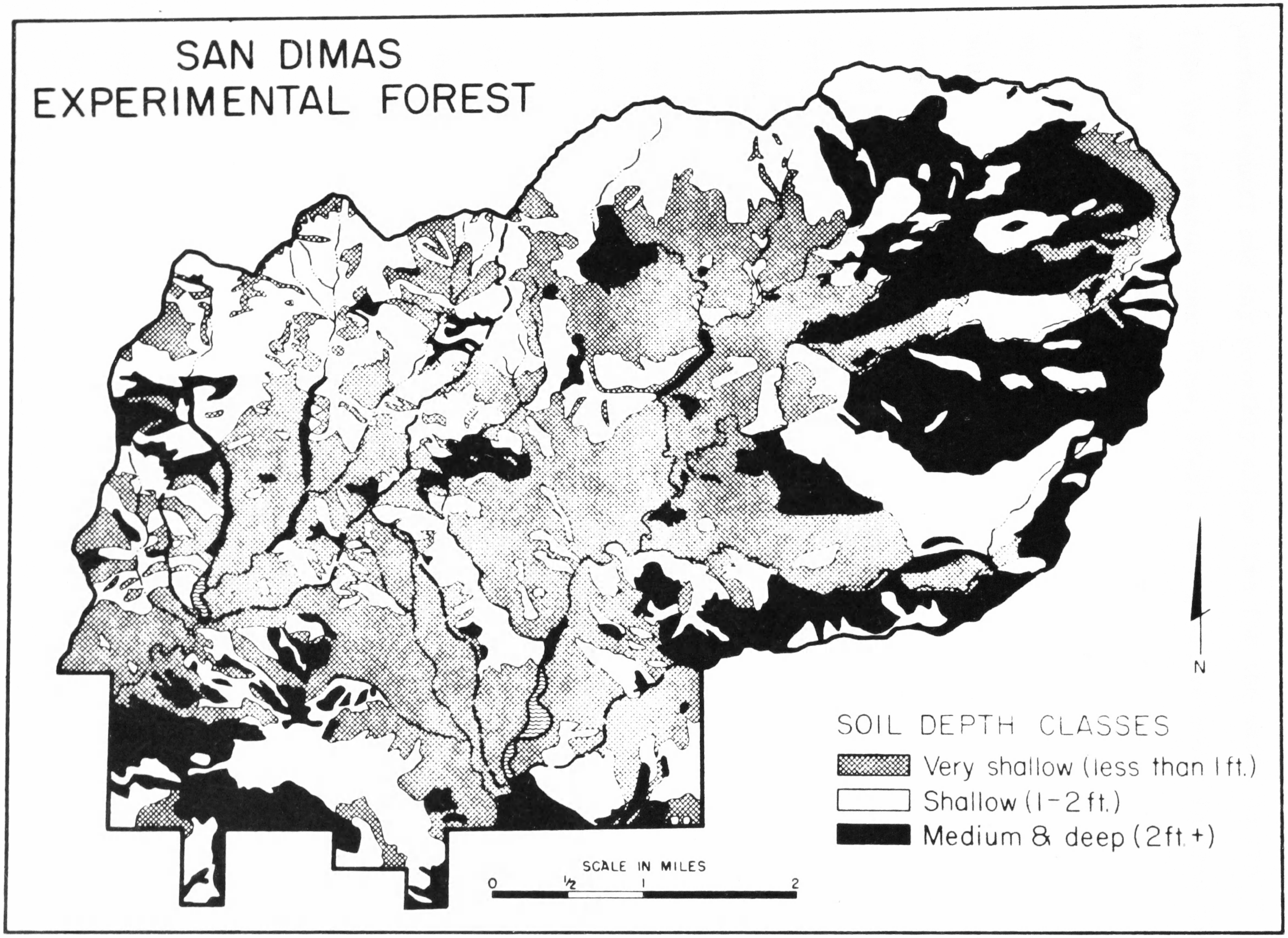

Figure 3.--Soil depth classes on the San Dimas Experimental Forest. (Bentley, 1961).

surface runoff and may possibly allow time for the water to run into the fissured rock (Rowe, 1943). A vegetative cover insures the maintenance of a high soil infiltration capacity.

The soils vary considerably in their erodibility, both as to the rate and type. The sandy, gravelly soils on the slopes are more subject to sheet erosion. Barren areas of sandy or gravelly soil sometimes tend to develop a comparatively low rate of erosion because of the formation of an erosion pavement. Even under conditions of undisturbed vegetation cover, average annual erosion rates are high, ranging from 1,000 to more than 3,000 cubic yards per square mile (Sinclair, 1954). Anderson, Colman and Zinke (1959) reported that during a 5-year period, soil creep during the dry season exceeded wet season erosion on the steep unstable slopes.

Disturbances by man or destruction of the vegetative cover results in greatly accelerated erosion rates. Usually wildfires in the chaparral zone produce intense heat that consumes most of the brush and all of the litter leaving only a layer of powdery black and white ash. The surface soil which is generally low in moisture at the time of the fire, is reduced to a dust layer. The ash-dust layer over the soil surface reduces the infiltration rate causing excessive surface runoff. As the volume and velocity of the water increases, large amounts of debris are carried down the slopes. Reducing water and debris movement down burned slopes, therefore, appears to be a problem of getting water into the soil mantle.

Stabilizing the soil surface and ash-dust layer might be accomplished by an application of a chemical soil binder. When rain reaches the ground, the dust and ash particles being small and light, resist wetting. Instead, they float up and around the rain drops and coat them with a dry layer. This dry layer prevents the water from wetting the ground by not allowing the water to flow through ground pores that are smaller than the coated drops. A stable surface would allow the water to flow around the ash and soil particles instead of floating them. The water would have more time to penetrate into the soil, and a stabilized soil surface would not have its pores closed by a shifting of the particles.

CHAPTER II

LABORATORY TESTS

Nine chemicals were first evaluated in the laboratory to determine which preparation could be used as an emergency erosion control measure. An evaluation of the binding qualities of each chemical was made by subjecting treated flats of soil to artificial rain.

Only meager data were available from the manufacturers regarding their respective soil additives. The main objective of the study was to test and evaluate chemical soil binding additives and determine if they could be used to control erosion on steep, unstable slopes. Past literature indicates that soil binding chemicals have not been used as an emergency treatment following wildfires.

All tests were made using a homogenized lysimeter soil in 16.5 x 17 inch greenhouse flats. To prevent soil leakage through the cracks in the bottom of the flats, plastic sheeting was placed on the bottom and pulled back 1 inch from the lower edge of sloping flats to provide drainage (Figure 4). Soil was placed loosely in the flats and struck off level with a straight edge. The loosely placed homogenous soil was used to eliminate possible error due to variations in soil. The chemicals were applied with a specially designed sprayer, which distributed the chemical uniformly at the manufacturers prescribed rates (Table 4)(Figure 5).

Figure 4. - - Side view of laboratory test stand.

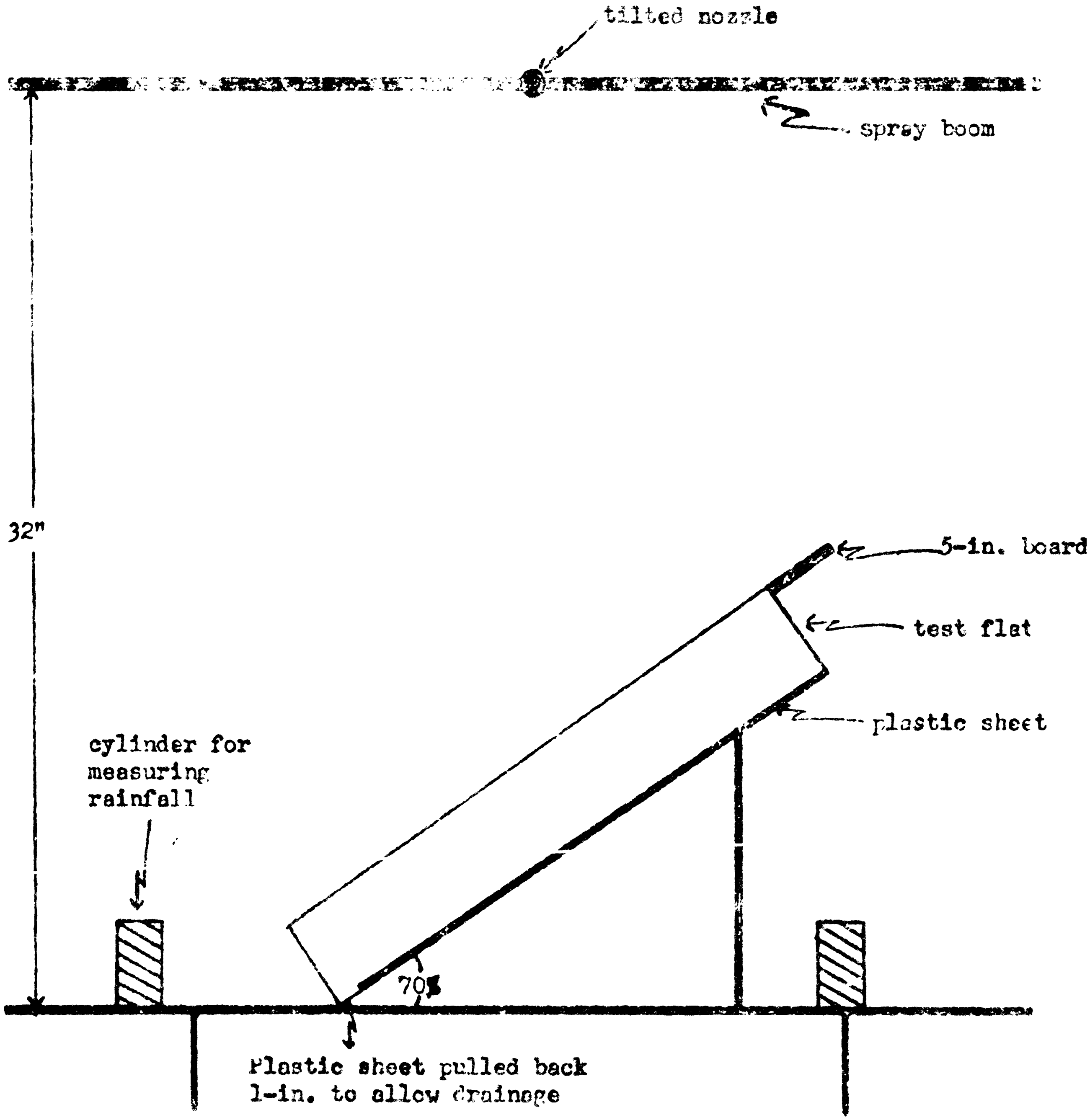

Table 4. -- Chemical soil binders tested in the laboratory and field plots

Product name	Source	Quantity applied	
		Unit	Dilution
		Per 50 sq.ft.	Water to chemical
		Gallons	
Formula S.[1] (aqueous resin)	University of California, Los Angeles	1.00	undiluted
Elvanol (polyvinyl Alcohol)	DuPont de Nemours E I and Company	1.00	1 to 1
SS-2 (asphalt emulsion)	American Bitumuls & Asphalt Company	1.68	5 to 1
Docal 1002[1] (asphalt emulsion)	Douglas Oil Company of California	1.68	10 to 1
SS-1 (asphalt emulsion)	Douglas Oil Company of California	1.68	undiluted
3876 SEC (aqueous resin)	Swift and Company	1.00	1 to 1
Organic base size (aqueous resin)	Swift and Company	1.00	undiluted
		Pounds per gallon	
Orzan A (lignin product)	Crown Zellerbach Corporation	1.10	4 to 1
Orzan S[1] (lignin product)	Crown Zellerbach Corporation	1.10	4 to 1

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[1] Used for field tests

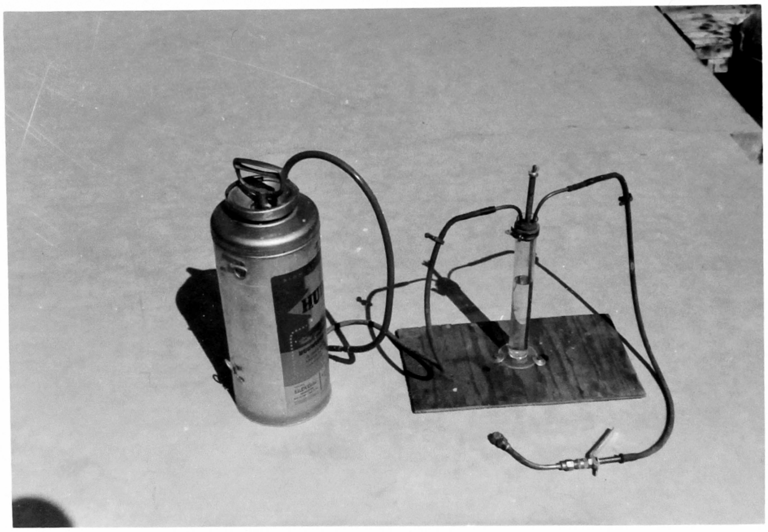


Figure 5. -- Sprayer used to apply soil binding chemical on test flats

After standing 24 hours the flats were tested under simulated rainfall applied at a pressure of 26 psi, through a 54-inch square boom. Four Tee C D-3 nozzles on the boom delivered about 2.5 inches per hour. The boom was placed 32 inches above the testing table with spray nozzles tilted upward and toward the test flats at 75 degrees from horizontal.

Rainfall was determined for each test by distributing 10 cylinders evenly adjacent to the test flat. Total catch in cubic centimeters was converted to inches per hour.

Since most of our critically eroding areas are on steep slopes, the rainfall tests were made with the flats placed at steep angles. Each of the chemicals were applied to three flats and subjected to artificial rainfall. Two replications were made with the treated flats resting at a 70 percent slope. The third test flat was raised to a 90 percent slope (Table 8). Three unsprayed flats were also tested using the same steep slopes.

Detachment and transportation of soil are the main erosional processes (Ellison, 1947). Detachment of soil particles by raindrop impact was provided to a certain degree by the artificial rainfall. Transportation of the soil particles was encouraged by fixing a 5-inch wide board to the top of each flat to collect and distribute surface runoff across the treated soil surface.

The length of time and inches of water required to initiate slumping of soil from the flat was recorded. Also, visual observation of length of time for runoff to occur, first signs of rilling, and accelerated scouring were made for each chemical (Table 8). The criterion for accepting or rejecting the chemicals was based on the length of time it took for each treatment to slump from the flats. The performance of only three of the chemicals in these small scale tests were of sufficient promise to warrant further testing (Table 8). These chemicals, a lignin solution, an asphalt emulsion, and an aqueous resin solution withstood the artificial rainfall tests and indicated good soil binding qualities.

All chemicals that were to be diluted proved water soluble and dissolved readily. There were no serious problems encountered during spraying of the flats.

The next step was to further test the three chemicals, a lignin solution, an asphalt emulsion, and an aqueous resin solution, in outdoor field trials as it was not obvious during the laboratory tests how surface runoff from treated flats would reflect debris production on steep slopes. Field plots were established to make a further measure of their effectiveness in controlling erosion under field conditions.

CHAPTER III

FIELD TESTS OF SOIL BINDING CHEMICALS

The three chemicals were sprayed on 6-foot by 40-foot plots on steep (70 percent) fire-denuded slopes. The chemicals were applied through four #8006 Tee Jet nozzles on a six foot boom (Figure 6). Twenty four hours after treatment with the chemicals artificial rainfall was applied using 12 rotating agricultural sprinklers. "Rainfall" was measured in 25 cans placed adjacent to the plots (Table 11). The sprinklers were placed between the plots on the first two replications. Two sets of sprinklers were placed along the outer edges of the plots and the remaining system of sprinklers was placed down a center walkway for the last two replications. The change of sprinkler location delivered a more uniform rainfall pattern to the plots.

Border strips of wood were installed to confine surface runoff to the individual plots (Figure 7). Debris catchment troughs were installed at the lower end of each plot (Figure 8). Runoff water was piped from the troughs and measured in collector cans.

Test runs on the treated plots and untreated controls were replicated four times in a randomized block design (Figure 9). Measurements of surface runoff and total debris were made for each treatment and replication (Tables 9 & 10).

Figure 6. -- Spray boom being calibrated

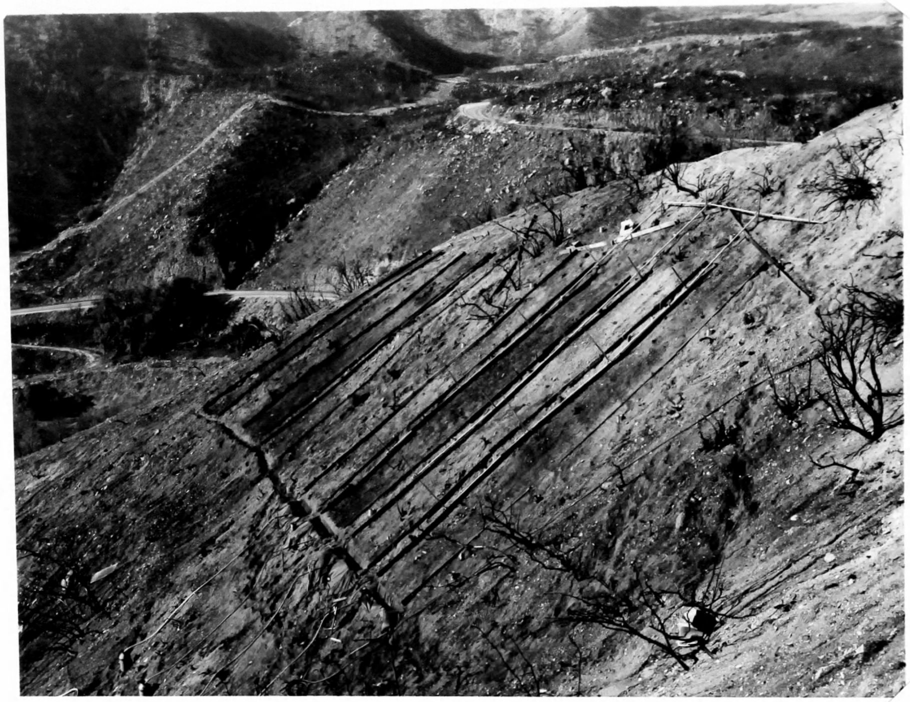
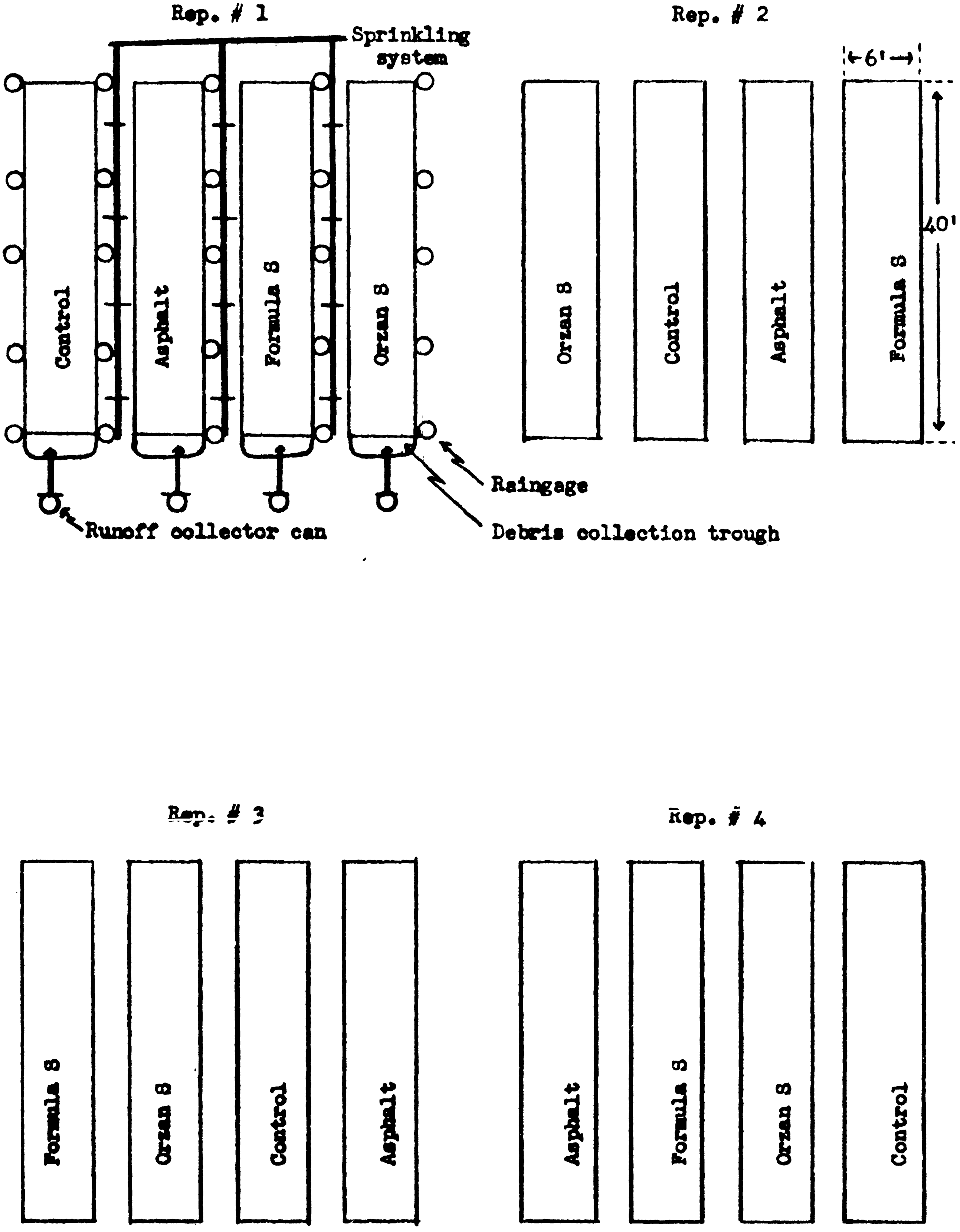


Figure 7. -- Set of plots complete with border strips, debris troughs, and runoff cans in place.

Figure 8. -- Debris catchment troughs and runoff water pipes being installed.

Figure 9.__ Experimental design of field trial plots.



The results for the chemicals used in the field tests were as follows:

Lignin

The lignin formed a thin, hard, almost impervious crust over the soil surface. When artificial rainfall was applied on the plots, surface runoff began only two minutes after the tests started. The accumulated runoff broke the thin crust and eroded material from the slopes causing debris to be deposited in the collector troughs. Increased surface runoff from the crust resulted in a high rate of debris production. More runoff and debris were produced from these plots than the untreated control plots (Tables 5,6,9, and 10). Under the conditions of these tests, it would seem that the lignin product would have little use where water is the cutting agent. However, where wind erosion alone is a problem, this product may be useful.

Asphalt

The asphalt emulsion was sprayed onto the plots in a dilute solution (10 parts water to 1 part emulsion). The asphalt solution penetrated the soil mantle to a depth of one-eighth inch. Surface runoff began approximately 7 minutes after the artificial rainfall started. Surface runoff and total debris yield was higher on these plots than on the control plots (Tables 5,6,9, and 10). Again, the accumulated surface runoff broke through the crust. Increasing the concentration of emulsion would probably hold more soil in place for a longer period of time but it would also follow that surface runoff

Table 5. -- Percent of artificial rainfall appearing as surface runoff by replication

Rep. #	Control	Lignin	Asphalt	Resin
1 (40 minutes)	3.4	14.4	3.8	12.2
2 (25 minutes)	12.7	21.8	20.6	17.8
3 (71 minutes)	13.0	16.6	24.4	8.1
4 (38 minutes)	34.2	37.6	25.6	24.4

Table 6. -- Ratio of debris to artificial rainfall (cu. ft. x 10 per inch), by replication

Rep. #	Control	Lignin	Asphalt	Resin
1 (40 minutes)	4.04	9.53	2.80	8.44
2 (25 minutes)	6.90	20.23	16.17	12.77
3 (71 minutes)	4.69	2.96	3.81	4.43
4 (38 minutes)	5.30	8.17	2.94	2.40

would increase. Consequently, where the flow becomes concentrated, additional protection would be necessary to withstand the high total discharge with increased cutting power.

It was found that a pressure type sprayer was necessary to apply this chemical. The asphalt emulsion is not harmful to equipment, but in pumps with a close tolerance, the asphalt adheres to the impellers and causes the pump to freeze.

Resin

The aqueous resin used was not available commercially at the time of testing. The formulation was prepared as a research project by members of the faculty and staff of the University of California at Los Angeles.

The resin formulation penetrated the soil mantle to an average depth of three-sixteenth of an inch. Surface runoff began approximately 14 minutes after artificial rainfall started.

Debris production from the resin plots exceeded that of the control plots (Tables 6 and 10). Since the time of testing, a number of mixtures have been developed which are claimed to be superior to the formulation used in this study.

General Observations

The chemically treated plots varied widely in their response to the artificially induced and subsequent natural weathering. The plots were examined one month after the tests. Two small storms had occurred in the interval. The lignin plots for the most part were dry and loose as were the control plots. Only traces of the lignin crust could be found. The asphalt emulsion and resin became spongy and pliable when wet, then formed a hard surface crust when dry. The asphalt emulsion and resin solution had again hardened. The resin had the firmer surface apparently because of deeper penetration of the chemical.

Examination of the plots at the end of the rainy season revealed practically no evidence of any remaining soil binder on the lignin or aspahlt plots. The resin solution, in all cases, still had approximately half the soil surface covered with a thin crust of treated soil.

There was no evidence of differences in vegetative cover within the plots. All the chemicals tested, both in the laboratory and field, are claimed by the manufacturers to be beneficial to plant growth rather than growth inhibitors.

An analysis of covariance was computed using the amount of artificial rainfall to adjust debris production. The results of these analysis indicate no significant difference between treatments (i.e. the probability that the observed differences are due to chance variation is about 0.55)(Table 7).

Table 7. -- Covariance table using the amount of artificial rainfall to adjust debris production

Source	D.f.	Sums of squares			Adj. D.f.	Adj. SSy.	Mean Square	Sample F
		xx	xy	yy				
Total	15	3.86	26.61	1,764.71				
Row	3	1.89	-8.82	486.88				
Column	3	0.29	6.03	332.95				
Error	9	1.69	11.76	944.80	8	862.48	107.81	
Col. + error	12	1.97	17.79	1,277.75	11	1,117.10		
treatment					3	254.62	84.87	0.79
Row + error	12	3.57	2.94	1,431.68	11	1,429.26		
replication					3	566.78	188.93	1.75

CHAPTER IV

CONCLUSIONS AND SUMMARY

Stabilization of the ash-dust layer on steep burned slopes by the application of a soil binding chemical that will retain the soils porosity and hold soil in place does not appear to be feasible from the standpoint of the chemicals tested. The volume of material necessary to form a durable layer would appear to limit possibilities severely. However, this research does not imply that soil binding chemicals are unsuitable for their present uses in controlling wind erosion or for helping to stabilize cut and fill slopes following construction and recently landscaped slopes.

This paper reports results of laboratory and field tests to investigate chemical treatments that might protect the soil surface until a vegetative cover becomes effective. The results of the chemicals soil binder tests indicated that the treatments were not effective in reducing surface runoff and erosion. The think crust of soil and chemical binder decreases infiltration rates and in turn increase debris production.

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APPENDIX

Table 8. -- Reaction of Chemicals to Artificial Rainfall, Laboratory Tests

Observations	Untreated Control		Dupont Elvanol		Swift 3876 S.E.C.		Swift Organic Base Size	
	Time of Occurrence in Minutes 1/							
Slope of flat	70%	90%	70%	90%	70%	90%	70%	90%
1st surface runoff	5	5	10	15	9	8	8	8
1st rilling	10	9	21	20	14	19	11	15
General surface runoff	20	20	24	26	23	22	17	18
General slumping of soil	29	26	36	28	32	31	27	25
Rain Inches/hour	2.5	2.8	2.4	2.4	2.4	2.6	2.4	2.4

	UCLA 4/ Formula S		Amer. Bitumals SS-R		Douglas Oil SS-1		Douglas Oil 4/ Docal 1002	
Slope of flat	70%	90%	70%	90%	70%	90%	70%	90%
Ist surface runoff	6	5	6	4	7	6	15	10
Ist rilling	15	13	10	9	11		21	18
General surface runoff	28	28	16	15	16		30	20
General slumping of soil	43	35	32	30	39		56	41
Rain Inches/hour	2.5	2.5	2.4	2.4	2.4	2.4	2.4	2.4

Table 8. -- Cont'd.

Observations	Crown Z Orzan A		Crown Z 4/ Orzan S		Powdered 2/ Orzan S		Diluted 3/ Orzan S	
	Time of Occurrence in Minutes 1/							
Slope of Flat	70%	90%	70%	90%	70%	90%	70%	90%
1st surface runoff	0.2	0.5	0.2	0.5	6	3	6	5
1st rilling	38	32	35	34	11	13	12	10
General surface runoff	2	1	5	3	16	18	15	15
General slumping of soil	76	53	79	77	27	25	33	30
Rain Inches/hour	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4

	Untreated Control	Dupont Elvanol	Swift 3876 S.E.C.	Swift Organic Base Size
Slope of flat	70%	70%	70%	70%
Ist surface runoff	5	9	9	9
1st rilling	11	20	16	10
General surface runoff	21	25	25	18
General slumping of soil	30	35	33	27
Rain Inches/hour	2.4	2.4	2.4	2.4

Table 8. -- Cont'd

Observations	UCLA 4/ Formula S	Amer.Bitumals SS-2	Douglas Oil SS-1	Crown Z Orzan A
	Time of Occurrence in Minutes 1/			
Slope of flat	70%	70%	70%	70%
1st surface runoff	8	5	11	0.5
1st rilling	17	10	17	37
General surface runoff	29	15	28	4
General slumping of soil	46	30	42	63
Rain Inches/hour	2.4	2.4	2.4	2.4

	Crown Z 4/
Slope of flat	70%
1st surface runoff	0.8
1st rilling	33
General surface runoff	3
General slumping of soil	65
Rain Inches/hour	2.4

1/ Test run ended when soil slumped from the flat

2/ Dusted on flat in powder form

3/ Diluted to one-half manufacturers rate

4/ Used for field tests. These chemicals were used for field trials because they withstood the rainfall tests for the longest period of time.

Table 9. -- Total runoff (gal.) by treatment and replication

Rep. #	Control	Orzan	Asphalt	Formula S
1	5	50	11	48
2	22	28	37	25
3	31	42	72	21
4	84	95	65	38

Table 10. -- Total Debris (cu. ft.) by treatment and replication

Rep. #	Control	Orzan	Asphalt	Formula S
1	.40	2.21	.54	2.21
2	.80	1.74	1.94	1.20
3	.75	.50	.75	.75
4	.87	1.38	.50	.25

Table 11. -- Total rainfall (inches) by treatment and replication

Rep. #	Control	Orzan	Asphalt	Formula S
1 (40 minutes)	.99	2.32	1.93	2.62
2 (25 minutes)	1.16	.86	1.20	.94
3 (71 minutes)	1.60	1.69	1.97	1.74
4 (38 minutes)	1.64	1.69	1.70	1.04