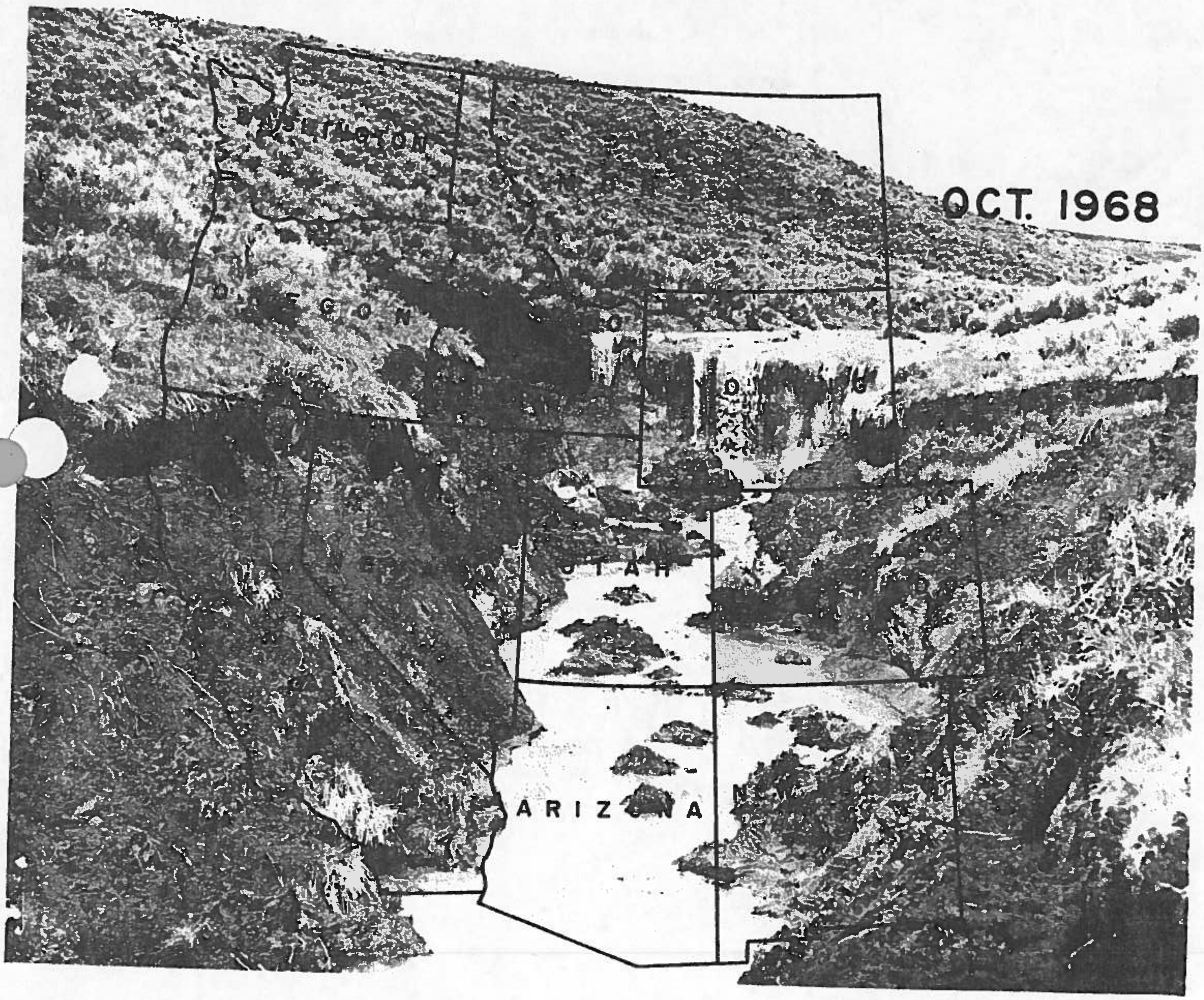
Pacific Southwest
INTER - AGENCY COMMITTEE

Report of the Water Management Subcommittee

OCT. 1968



FACTORS AFFECTING SEDIMENT YIELD AND
MEASURES FOR THE REDUCTION OF EROSION AND SEDIMENT YIELD

PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE

REPORT

of the

WATER MANAGEMENT SUBCOMMITTEE

on

FACTORS AFFECTING SEDIMENT YIELD IN THE PACIFIC SOUTHWEST AREA

and

SELECTION AND EVALUATION OF MEASURES FOR REDUCTION OF EROSION AND SEDIMENT YIELD

October 1968

AN EXPLANATION OF THE USE OF THE RATING CHART FOR EVALUATING

FACTORS AFFECTING SEDIMENT YIELD IN THE PACIFIC SOUTHWEST FOLLOWS

Use of the Rating Chart of Factors Affecting Sediment Yield in the Pacific Southwest

The following is the sediment yield classification originally presented on page 2.

Classification	Rating	Sediment Yield AF/sq.mi.
1	> 100	3.0
2	75 - 100	1.0 - 3.0
3	50 - 75	0.5 - 1.0
4	25 - 50	0.2 - 0.5
5	0 - 25	< 0.2

In most instances high values for the A through G factors should correspond to high values for the H and/or I factors.

An example of the use of the rating chart is as follows:

A watershed of 15 square miles in western Colorado has the following characteristics and sediment yield levels:

	Factors	Sediment Yield Level	Rating
A	Surface geology	Marine shales	10
B	Soils	Easily dispersed, high shrink-swell characteristics	10
C	Climate	Infrequent convective storms, freeze-thaw occurrence	7
D	Runoff	High peak flows; low volumes	5
E	Topography	Moderate slopes	10
F	Ground cover	Sparse, little or no litter	10
G	Land use	Intensively grazed	10
H	Upland erosion	More than 50% rill and gully erosion	25
I	Channel erosion	Occasionally eroding banks and bed but short flow duration	5
		Total	92

This total rating of 92 would indicate that the sediment yield is in Classification 2. This compares with a sediment yield of 1.96 acre-feet per square mile as the average of a number of measurements in this area.

FACTORS AFFECTING SEDIMENT YIELD IN THE PACIFIC SOUTHWEST

Sediment Yield Levels	A SURFACE GEOLOGY	B SOILS	C CLIMATE	D RUNOFF	E TOPOGRAPHY	F GROUND COVER	G LAND USE	H UPLAND EROSION	I CHANNEL EROSION & SEDIMENT TRANSPORT
High	(10)* a. Marine shales and related mudstones and siltstones.	(10) a. Fine textured; easily dispersed; saline-alkaline; high shrink-swell characteristics. b. Single grain silts and fine sands	(10) a. Storms of several days' duration with short periods of intense rainfall. b. Frequent intense convective storms c. Freeze-thaw occurrence	(10) a. High peak flows per unit area b. Large volume of flow per unit area	(20) a. Steep upland slopes (in excess of 30%) High relief; little or no floodplain development	(10) Ground cover does not exceed 20% a. Vegetation sparse; little or no litter b. No rock in surface soil	(10) a. More than 50% cultivated b. Almost all of area intensively grazed c. All of area recently burned	(25) a. More than 50% of the area characterized by rill and gully or landslide erosion	(25) a. Eroding banks continuously or at frequent intervals with large depths and long flow duration b. Active headcuts and degradation in tributary channels
**									
Moderate	(5) a. Rocks of medium hardness b. Moderately weathered c. Moderately fractured	(5) a. Medium textured soil b. Occasional rock fragments c. Caliche layers	(5) a. Storms of moderate duration and intensity b. Infrequent convective storms	(5) a. Moderate peak flows b. Moderate volume of flow per unit area	(10) a. Moderate upland slopes (less than 20%) b. Moderate fan or floodplain development	(0) Cover not exceeding 40% a. Noticeable litter b. If trees present understory not well developed	(0) a. Less than 25% cultivated b. 50% or less recently logged c. Less than 50% intensively grazed d. Ordinary road and other construction	(10) a. About 25% of the area characterized by rill and gully or landslide erosion b. Wind erosion with deposition in stream channels	(10) a. Moderate flow depths, medium flow duration with occasionally eroding banks or bed
**									
Low	(0) a. Massive, hard formations	(0) a. High percentage of rock fragments b. Aggregated clays c. High in organic matter	(0) a. Humid climate with rainfall of low intensity b. Precipitation in form of snow c. Arid climate, low intensity storms d. Arid climate; rare convective storms	(0) a. Low peak flows per unit area b. Low volume of runoff per unit area c. Rare runoff events	(0) a. Gentle upland slopes (less than 5%) b. Extensive alluvial plains	(-10) a. Area completely protected by vegetation, rock fragments, litter Little opportunity for rainfall to reach erodible material	(-10) a. No cultivation b. No recent logging c. Low intensity grazing	(0) a. No apparent signs of erosion	(0) a. Wide shallow channels with flat gradients, short flow duration b. Channels in massive rock, large boulders or well vegetated c. Artificially controlled channels

* THE NUMBERS IN SPECIFIC BOXES INDICATE VALUES TO BE ASSIGNED APPROPRIATE CHARACTERISTICS.
THE SMALL LETTERS a, b, c, REFER TO INDEPENDENT CHARACTERISTICS TO WHICH FULL VALUE MAY BE ASSIGNED.

** IF EXPERIENCE SO INDICATES, INTERPOLATION BETWEEN THE 3 SEDIMENT YIELD LEVELS MAY BE MADE.

FACTORS AFFECTING SEDIMENT YIELD IN THE PACIFIC SOUTHWEST AREA

Recommendations of the Water Management Subcommittee
Sedimentation Task Force, PSIAC
October 1968

Introduction

The material that follows is suggested for use in the evaluation of sediment yield in the Pacific Southwest. It is intended as an aid to the estimation of sediment yield for the variety of conditions encountered in this area.

The classifications and companion guide material are intended for broad planning purposes only, rather than for specific projects where more intensive investigations of sediment yield would be required. For these purposes it is recommended that map delineations be for areas no smaller than 10 square miles.

It is suggested that actual measurements of sediment yield be used to the fullest extent possible. This descriptive material and the related numerical evaluation system would best serve its purpose as a means of delineating boundaries between sediment yield areas and in extrapolation of existing data to areas where none is available.

This may involve a plotting of known sediment yield data on work maps. Prepared materials such as geologic and soil maps, topographic, climatic, vegetative type and other references would be used as aids in delineation of boundaries separating yield classifications. A study of the general relationships between known sediment yield rates and the watershed conditions that produce them would be of substantial benefit in projecting data to areas without information.

Sediment Yield Classification

It is recommended that sediment yields in the Pacific Southweat area be divided into five classes of average annual yield in acre-feet per square mile. These are as follows:

Classification	1	$>$ 3.0	acre-feet/square mile	VERY HIGH
	2	1.0 - 3.0	" "	HIGH
	3	0.5 - 1.0	" "	MODERATELY HIGH
	4	0.2 - 0.5	" "	MODERATE
	5	$<$ 0.2	" "	LOW

Nine factors are recommended for consideration in determining the sediment yield classification. These are geology, soils, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion and sediment transport.

Characteristics of each of the nine factors which give that factor high, moderate, or low sediment yield level are shown on the attached table. The sediment yield characteristic of each factor is assigned a numerical value representing its relative significance in the yield rating. The yield rating is the sum of values for the appropriate characteristics for each of the nine factors. Conversion to yield classes should be as follows:

Rating	Class
>100	1 VERY HIGH
75 - 100	2 HIGH
50 - 75	3 MODERATELY HIGH
25 - 50	4 MODERATE
0 - 25	5 LOW

Guidelines which accompany the table are an integral part of the procedure. They describe the characteristics of factors which influence sediment yield and these are summarized in the space provided on the table.

The factors are generally described, for purposes of avoiding complexity, as independently influencing the amount of sediment yield. The variable impact of any one factor is the result of influence by the others. To account for this variable influence in any one area would require much more intensive investigational procedures than are available for broad planning purposes.

To briefly indicate the interdependence of the factors discussed separately, ground cover is used as an example. If there is no vegetation, litter or rock fragments protecting the surface, the rock, soil, and topography express their uniqueness on erosion and sediment yield. If the surface is very well protected by cover, the characteristics of the other factors are obscured by this circumstance. In similar vein, an arid region has a high potential for erosion and sediment yield because of little or no ground cover, sensitive soils and rugged topography. Given very low intensity rainfall and rare intervals of runoff, the sediment yield could be quite low.

Each of the 9 factors shown on the table are paired influences with the exception of topography. That is, geology and soils are directly related as are climate and runoff, ground cover and land use, and upland and channel erosion. Ground cover and land use have a negative influence under average or better conditions. Their impact on sediment yield is therefore indicated as a negative influence when affording better protection than this average.

It is recommended that the observer follow a feedback process whereby he checks the sum of the values on the table A through G with the sum of H and I. In most instances high values in the former should correspond to high values in the latter. If they do not, either special erosion conditions exist or the A-G factors should be re-evaluated.

Although only the high, moderate and low sediment yield levels are shown on the attached table, interpolation between these levels may be made.

Surface Geology

Over much of the southwest area, the effect of surface geology on erosion is readily apparent. The weaker and softer rocks are more easily eroded and generally yield more sediment than do the harder more resistant types. Sandstones and similar coarse-textured rocks that disintegrate to form permeable soils erode less than shales and related mudstones and siltstones under the same conditions of precipitation. On the other hand, because of the absence of cementing agents in some soils derived from sandstone, large storms may produce some of the highest sediment yields known.

The widely distributed marine shales, such as the Mancos and shale members of the Moenkopi Formation, constitute a group of highly erodible formations. The very large areal extent of the shales and their outwash deposits gives them a rank of special importance in relation to erosion. Few of the shale areas are free from erosion. Occasionally, because of slope or cover conditions, metamorphic rocks and highly fractured and deeply weathered granites and granodiorites produce high sediment yield. Limestone and volcanic outcrop areas are among the most stable found within the western lands. The principal reason for this appears to be the excellent infiltration characteristics, which allow most precipitation to percolate into the underlying rock.

In some areas all geologic formations are covered with alluvial or colluvial material which may have no relation to the underlying geology. In such areas the geologic factor would have no influence and should be assigned a value of 0 in the rating.

Soils

Soil formation in the Pacific Southwest generally has not had climatic conditions conducive to rapid development. Therefore, the soils are in an immature stage of development and consist essentially of physically weathered rock materials. The presence of sodium carbonate (black alkali) in a soil tends to cause the soil particles to disperse and renders such a soil susceptible to erosion.

There are essentially three inorganic properties--sand, silt, and clay--which may in any combination give soil its physical characteristics. Organic substances plus clay provide the binding material which tends to hold the soil separates together and form aggregates. Aggregate formation and stability of these aggregates are the resistant properties of soil against erosion. Unstable aggregates or single grain soil materials can be very erodible.

Climate and living organisms acting on parent material, as conditioned by relief or topography over a period of time, are the essential factors for soil development. Any one of these factors may overshadow or depress another in a given area and cause a difference in soil formation. For instance, climate determines what type of vegetation and animal population will be present in an area, and this will have a definite influence or determine the type of soil that evolves. As an example, soils developing under a forest canopy are much different from soils developing in a grassland community.

The raw, shaley type areas (marine shales) of the Pacific Southwest have very little, if any, soil development. Colluvial-alluvial fan type areas are usually present at the lower extremities of the steeper sloping shale areas. Infiltration and percolation are usually minimal on these areas due to the fine textured nature of the soil material. This material is easily dispersed and probably has a high shrink-swell capacity. Vegetation is generally sparse, and consists of a salt desert shrub type.

There are areas that contain soils with definite profile development and also stony soils that contain few fines which constitutes an improved physical condition for infiltration and plant growth over the fine textured shaley areas. These areas usually occur at higher and more moist elevations where bare, hard crystalline rocks provide the soil parent material. Vegetation and other ground cover, under these circumstances, provide adequate protection against the erosive forces and thus low sediment yield results.

In arid and semi-arid areas an accumulation of rock fragments (desert pavement) or calcareous material (caliche) is not uncommon. These layers can offer substantial resistance to erosion processes.

The two extreme conditions of sediment yield areas have been described. Intermediate situations would contain some features of the two extremes. One such situation might be an area of predominately good soil development that contains small areas of badlands. This combination would possibly result in an intermediate classification.

Climate and Runoff

Climatic factors are paramount in soil and vegetal development and determine the quantity and discharge rate of runoff. The same factors constitute the forces that cause erosion and resultant sediment yield. Likewise, temperature, precipitation, and particularly the distribution of precipitation during the growing season, affect the quantity and quality of the ground cover as well as soil development. The quantity and intensity of precipitation determine the amount and discharge rates of runoff and resultant detachment of soil and the transport media for sediment yield. The intensity of prevailing and seasonal winds affects precipitation pattern, snow accumulation and evaporation rate.

Snow appears to have a minor effect on upland slope erosion since raindrop impact is absent and runoff associated with snow melt is generally in resistant mountain systems.

Frontal storms in which periods of moderate to high intensity precipitation occur can produce the highest sediment yields within the Southwest. In humid and subhumid areas the impact of frontal storms on sediment may be greatest on upland slopes and unstable geologic areas where slides and other downhill soil movement can readily occur.

Convective thunderstorm activity in the Southwest has its greatest influence on erosion and sedimentation in Arizona and New Mexico and portions of the adjoining states. High rainfall intensities on low density cover or easily dispersed soils produces high sediment yields. The average annual sediment yield is usually kept within moderate bounds by infrequent occurrence of thunderstorms in any one locality.

High runoff of rare frequency may cause an impact on average annual sediment yield for a long period of time in a watershed that is sensitive to erosion, or it may have little effect in an insensitive watershed. For example, sediment that has been collecting in the bottom of a canyon and on side slopes for many years of low and moderate flows may be swept out during the rare event, creating a large change in the indicated sediment yield rate for the period of record.

In some areas the action of freezing and thawing becomes important in the erosion process. Impermeable ice usually forms in areas of fine textured soils where a supply of moisture is available before the advent of cold weather. Under these conditions the ice often persists throughout the winter and is still present when the spring thaw occurs. In some instances water tends to run over the surface of the ice and not detach soil particles, but it is possible for the ice in a surface layer to thaw during a warm period and create a very erodible situation. Spring rains with ice at shallow depth may wash away the loose material on the surface.

In some areas of the Pacific Southwest, particularly those underlain by marine shale, freezing and thawing alters the texture of soil near the surface, and thus changes the infiltration characteristics. These areas generally do not receive enough snow or have cold enough temperatures to build a snow pack for spring melt. Later in the year soil in a loosened condition is able to absorb a large part of the early rainfall. As rains occur during the summer, the soil becomes compacted on the surface, thus allowing more water to run off and affording a greater chance for erosion.

<u>Topography</u>

Watershed slopes, relief, floodplain development, drainage patterns, orientation and size are basic items to consider in connection with topography. However, their influence is closely associated with geology, soils, and cover.

Generally, steep slopes result in rapid runoff. The rimrock and badlands, common in portions of the Pacific Southwest, consist of steep slopes of soft shales usually maintained by the presence of overlying cap rock. As the soft material is eroded, the cap rock is undercut and falls, exposing more soft shales to be carried away in a continuing process. However, high sediment yields from these areas are often modified by the temporary deposition of sediment on the intermediate floodplains.

The high mountain ranges, although having steep slopes, produce varying quantities of sediment depending upon the type of parent materials, soil development, and cover which directly affect the erosion processes.

Southerly exposed slopes generally erode more rapidly than do the northerly exposed slopes due to greater fluctuation of air and soil temperatures, more frequent freezing and thawing cycles, and usually less ground cover.

The size of the watershed may or may not materially affect the sediment yield per unit area. Generally, the sediment yield is inversely related to the watershed size because the larger areas usually have less overall slope, smaller proportions of upland sediment sources, and more opportunity for the deposition of upstream derived sediments on floodplains and fans. In addition, large watersheds are less affected by small convective type storms. However, under other conditions, the sediment yield may not decrease as the watershed size increases. There is little change in mountainous areas of relatively uniform terrain. There may be an increase of sediment yield as the watershed size increases if downstream watersheds or channels are more susceptible to erosion than upstream areas.

<u>Ground Cover</u>

Ground cover is described as anything on or above the surface of the ground which alters the effect of precipitation on the soil surface and profile. Included in this factor are vegetation, litter, and rock fragments. A good ground cover dissipates the energy of rainfall before it strikes the soil surface, delivers water to the soil at a relatively uniform rate, impedes the flow of water, and promotes infiltration by the action of roots within the soil. Conversely, the absence of ground cover, whether through natural growth habits or the effect of overgrazing or fire, leave the land surface open to the worst effects of storms.

In certain areas, small rocks or rock fragments may be so numerous on the surface of the ground that they afford excellent protection for any underlying fine material. These rocks absorb the energy of falling rain and are resistant enough to prevent cutting by flowing water.

The Pacific Southwest is made up of land with all classes of ground cover. The high mountain areas generally have the most vegetation, while many areas in the desert regions have practically none. The abundance of vegetation is related in a large degree to precipitation. If vegetative ground cover is destroyed in areas where precipitation is high, abnormally high erosion rates may be experienced.

Differences in vegetative type have a variable effect on erosion and sediment yield, even though percentages of total ground cover may be the same. For instance, in areas of pinyon-juniper forest having the same percentage of ground cover as an area of grass, the absence of understory in some of the pinyon-juniper stands would allow a higher erosion rate than in the area of grass.

Land Use

The use of land has a widely variable impact on sediment yield, depending largely on the susceptibility of the soil and rock to erosion, the amount of stress exerted by climatic factors and the type and intensity of use. Factors other than the latter have been discussed in appropriate places in this guide.

In almost all instances use either removes or reduces the amount of natural vegetative cover which reflects the varied relationships within the environment. Activities which remove all vegetation for parts of each year for several years or permanently are cultivation, urban development and road construction. Grazing, logging, mining, and fires artifically induce permanent or temporary reduction in cover density.

High erosion hazard sites, because of the geology, soils, climate, etc., are also of high hazard from the standpoint of type and intensity of use. For example, any use which reduces cover density on a steep slope with erodible soils and severe climatic conditions will strongly affect sediment yield. The extent of this effect will depend on the area and intensity of use relative to the availability of sediment from other causes. Construction of roads or urban development with numerous cut and fill slopes through a large area of widespread sheet or gully erosion will probably not cause a change in sediment yield classification. Similar construction and continued disturbance in an area of good vegetative response to a favorable climate can raise yield by one or more classifications.

Use of the land has its greatest potential impact on sediment yield where a delicate balance exists under natural conditions. Alluvial valleys of fine, easily dispersed soils from shales and sandstones are highly vulnerable to erosion where intensive grazing and trailing by livestock have occurred. Valley trenching has developed in many of these valleys and provides a large part of the sediment in high yield classes from these areas.

A decline in vegetative density is not the only effect of livestock on erosion and sediment yield. Studies at Badger Wash, Colorado, which is underlain by Mancos shale, have indicated that sediment yield from ungrazed watersheds is appreciably less than from those that are grazed. This difference is attributed to absence of soil trampling in the ungrazed areas since the density of vegetation has not noticeably changed since exclusion began.

Areas in the arid and semi-arid portions of the Southwest that are surfaced by desert pavement are much less sensitive to grazing and other use, since the pavement affords a substitute for vegetative cover.

In certain instances the loss or deterioration of vegetative cover may have little noticeable on-site impact but may increase off-site erosion by acceleration of runoff. This could be particularly evident below urbanized areas where accelerated runoff from pavement and rooftops has increased the stress on downstream channels. Widespread destruction of cover by poor logging practices or by brush and timber fires frequently increases channel erosion as well as that on the directly affected watershed slopes. On the other hand, cover disturbances under favorable conditions, such as a cool, moist climate, frequently result in a healing of erosion sources within a few years.

Upland Slope Erosion

This erosion form occurs on sloping watershed lands beyond the confines of valleys. Sheet erosion which involves the removal of a thin layer of soil over an extensive area is usually not visible to the eye. This erosion form is evidenced by the formation of rills. Experience indicates that soil loss from rill erosion can be seen if it amounts to about 5 tons or more per acre. This is equivalent in volume per square mile to approximately 2 acre-feet.

Wind erosion from upland slopes and the deposition of the eroded material in stream channels may be a significant factor. The material so deposited in channels is readily moved by subsequent runoff.

Downslope soil movement due to creep can be an important factor in sediment yield on steep slopes underlain by unstable geologic formations.

Significant gully erosion as a sediment contributor is evidenced by the presence of numerous raw cuts along the hill slopes. Deep soils on moderately steep to steep slopes usually provide an environment for gully development.

Processes of slope erosion must be considered in the light of factors which contribute to its development. These have been discussed in previous sections.

Channel Erosion and Sediment Transport

If a stream is ephemeral, runoff in traversing the dry alluvial bed may be drastically reduced by transmission losses (absorption by channel alluvium). This decrease in the volume of flow results in a decreased potential to move sediment. Sediment may be deposited in the streambed from one or a series of relatively small flows only to be picked up and moved on in a subsequent larger flow. Sediment concentrations, determined from field measurements at consecutive stations, have generally been shown to increase many fold for instances of no tributary inflow. Thus, although water yield per unit area will decrease with increasing drainage area, the sediment yield per unit area may remain nearly constant or may even increase with increasing drainage area.

In instances of convective precipitation in a watershed with perennial flow, the role of transmission losses is not as significant as in watersheds with ephemeral flow, but other channel factors, such as the shape of the channel, may be important.

For frontal storm runoff the flow durations are generally much longer than for convective storms, and runoff is often generated from the entire basin. In such instances, sediment removed from the land surfaces is generally carried out of the area by the runoff. Stream channel degradation and/or aggradation must be considered in such cases, as well as bank scour. Because many of the stream beds in the Pacific Southwest are composed of fine-grained alluvium in well defined channels, the potential for sediment transport is limited only by the amount and duration of runoff. Large volumes of sediment may thus be moved by these frontal storms because of the longer flow durations.

The combination of frontal storms of long duration with high intensity and limited areal-extent convective activity will generally be in the highest class for sediment movement in the channels. Storms of this type generally produce both the high peak flows and the long durations necessary for maximum sediment transport.

Sediment yield may be substantially affected by the degree of channel development in a watershed. This development can be described by the channel cross sections, as well as by geomorphic parameters such as drainage density, channel gradients and width-depth ratio. The effect of these geomorphic parameters is difficult to evaluate primarily because of the scarcity of sediment transport data in the Pacific Southwest.

If the cross section of a stream is such as to keep the flow within defined banks, then the sediment from an upstream point is generally transported to a downstream point without significant losses. Confinement of the flow within alluvial banks can result in a high erosional capability of a flood flow, especially the flows with long return periods. In most channels with wide floodplains, deposition on the floodplain during floods is often significant, and the transport is thus less than that for a within bank flow. The effect of this transport capability can be explained in terms of tractive force which signifies the hydraulic stress exerted by the flow on the bed of the stream. This average bed-shear stress is obtained as the product of the specific weight of the fluid, hydraulic radius, and energy gradient slope. Thus, greater depth results in a greater bed shear and a greater potential for moving sediment. By the same reasoning, steep slopes (the energy slope and bed slope are assumed to be equivalent) also result in high bed-shear stress.

The boundary between sediment yield classifications in much of the Pacific Southwest may be at the mountain front, with the highest yield designation on the alluvial plain if there is extensive channel erosion. In contrast, many mountain streams emerge from canyon reaches and then spread over fans or valley flats. Here water depths can decrease from many feet to only a few inches in short distances with a resultant loss of the capacity to transport sediment. Sediment yield of the highest classification can thus drop to the lowest in such a transition from a confined channel to one that has no definition.

Channel bank and bed composition may greatly influence the sediment yield of a watershed. In many areas within the Pacific Southwest, the channels in valleys dissect unconsolidated material which may contribute significantly to the stream sediment load. Bank sloughing during periods of flow, as well as during dry periods, piping, and bank scour generally add greatly to the sediment load of the stream and often change upward the sediment yield classification of the watershed. Field examination for areas of head cutting, aggradation or degradation, and bank cutting are generally necessary prior to classification of the transport expectancy of a stream. Geology plays a significant role in such an evaluation. Geologic controls in channels can greatly affect the stream regimen by limiting degradation and headcuts. Thus, the transport capacity may be present, but the supply of sediment from this source is limited.

Man-made structures can also greatly affect the transport characteristics of the stream. For example, channel straightening can temporarily upset the channel equilibrium and cause an increase in channel gradient and an increase in the stream velocity and the shear stress. Thus, the sediment transport capacity of the stream may be temporarily increased. Structures such as debris dams, lined channels, drop spillways, and detention dams may drastically reduce the sediment transport.

SELECTION AND EVALUATION OF MEASURES FOR REDUCTION OF EROSION AND SEDIMENT YIELD IN THE PACIFIC SOUTHWEST

Introduction

The following material is intended to provide guidance in the selection and evaluation of measures for erosion and sediment reduction in the Pacific Southwest. The recommendations are for broad planning purposes only and not for specific projects where detailed evaluations would be required.

The evaluation of treatment needs considered in this report are for purposes of erosion and sediment reduction without regard to other benefits that may or may not be gained by the improvements. While it is true that several purposes are frequently achieved by the same treatment, priorities of need and opportunities for success in treatment may not coincide for the alternative purposes. The highest priority for sediment control is, of course, the application of erosion control measures to the major sources. However, in the case of some grazing lands, treatment of low contributing or non-contributing sediment source areas having the potential for increased forage production may be of benefit in reducing the stress exerted on adjacent high sediment contributing areas.

For purposes of identifying erosion and sediment sources, reference is made to the report of the Water Management Subcommittee, PSIAC, titled "Factors Affecting Sediment Yield in the Pacific Southwest Area". When the erosion and sediment source areas have been determined, erosion sites are broadly classified as to whether they are the uplands or channels. In the former instance the measures that are applicable are easily identified as "management" and "land treatment" and the latter as "structural measures" and associated vegetative controls. Management measures include proper uses of the land and related resources to minimize erosion and sediment yield. Land treatment measures usually include the purpose of holding the soil in place by whatever means, including a reduction in rainfall impact and runoff, and by increasing the resistance of the soil. The general purposes of structural measures are to retard erosion at the site (head cutting, bank cutting, degradation) and to provide a trap for sediment moving into the reach from upstream.

Measures which Include Erosion and Sediment Control Purposes

Management and Land Treatment Measures

The following list of measures and their definitions include most of those now being used in the Pacific Southwest.

Measures for Range and Forest

<u>Brush Control</u> - Eradication of pinyon-juniper, sage, and other brush, and replacement with more desirable vegetation.

<u>Contour Furrowing and Trenching</u> - Making furrows and/or trenches on the contour at intervals varying with the precipitation, slope, soil, and cover.

<u>Contour Terracing</u> - Development of water storage capacity along the contour by excavation and placement of soil as an embankment along the downstream side. Intervals vary with the precipitation, slope and soil.

<u>Critical Area Planting</u> - Stabilizing severely eroded areas by establishing vegetative cover.

<u>Fire Prevention and Suppression</u> - Employment of a variety of measures for the control and prevention of fires on range and forest land, including personnel, roads, trails, fire breaks, water facilities, aircraft and other equipment.

<u>Livestock Exclusion</u> - Excluding livestock from any area where grazing is harmful or otherwise undesirable.

<u>Pitting</u> - Making shallow pits or basins of suitable capacity and distribution to retain water and increase infiltration.

<u>Proper Grazing Use</u> - Grazing at an intensity which will maintain adequate cover for soil and maintain or improve the quantity and the quality of desirable vegetation.

<u>Range Seeding</u> - Establishing adapted plants by seeding.

<u>Rotation - Deferred Grazing</u> - Grazing under a system where one or more grazing units are rested at planned intervals throughout the growing season of key plants, and generally no unit is grazed at the same time in successive years.

<u>Tree and Shrub Planting</u> - Planting tree or shrub seedlings or cuttings to establish desirable cover.

<u>Trespass Control</u> - To prevent unauthorized uses detrimental to the land.

<u>Measures for Cultivated Land</u>

<u>Chiseling and Subsoiling</u> - Loosening the soil, without inversion and with a minimum of mixing of the surface soil, to shatter restrictive layers below the normal plow depth that inhibit water movement or root development.

<u>Contour Farming</u> - Conducting farming operations on sloping cultivated land in such a way that plowing, land preparation, planting and cultivating are done on the contour.

<u>Contour Terracing</u> - Development of water storage capacity along the contour by excavation and placement of soil as an embankment along the downstream side. Intervals vary with the precipitation and slope.

<u>Cover and Green Manure Crop</u> - A crop of close-growing grasses, legumes, or small grain used primarily for seasonal protection and for soil improvement.

<u>Critical Area Planting</u> - Stabilizing severely eroded areas by establishing vegetative cover.

<u>Crop Residue and Mulching</u> - Utilizing and managing crop residues for soil protection on a year round basis or when critical erosion periods usually occur.

<u>Field Diversion</u> - An interception channel near the contour to carry runoff to a waterway. Intervals vary with the precipitation, slope and cropping.

<u>Grassed Waterway or Outlet</u> - A natural or constructed waterway or outlet shaped or graded and establishment of suitable vegetation as needed for the safe disposal of runoff.

<u>Proper Cropping and Use</u> - The use of close growing crops on erodible land.

<u>Strip Cropping</u> - Growing crops in a systematic arrangement of strips or bands across the general slope or on the contour to reduce water erosion. Strips approximately at right angles to the prevailing winds to reduce wind erosion.

<u>Structural Measures</u>

The following list of measures and their definitions include most of those now being used in the Pacific Southwest.

<u>Channel Lining</u> - Protection of the channel bottom and banks with concrete or riprap.

<u>Debris Basins</u> - Storage for sediment provided by a dam with spillway above channel grade; by excavation below grade, or both. Water retention is not an intended function of the structure.

<u>Diversions and Dikes</u> - Devices used to divert water away from eroding areas.

<u>Drop Structures</u> - Concrete, masonry, sheet piling or earth structures placed in eroded channels below the top of the bank to control grade, prevent further erosion and provide sediment storage.

<u>Jacks and Jetties</u> - Projections built in the stream channel to divert currents away from a vulnerable bank.

Reservoirs - To provide for permanent storage of sediment and either temporary or permanent water storage.

Revetments - Materials placed on the stream bank to protect it from erosion by stream flow.

Sills - Structures of rock, masonry, rails, etc., placed at channel grade to prevent stream downcutting.

Disturbed Area Protection - This measure may include any of the above treatments and structures. In addition, it often includes stabilizing steep slopes, lining road ditches, etc.

Applicability of Management and Land Treatment Measures for Erosion and Sediment Control

The soils, climate, topographic and other factors which tend to create the most severe erosion and sediment problems also increase the difficulty of control. Similarly, many measures are usually more successful under conditions of low or moderate erosion and sediment yield than they are under high yield. The broad trends in the principal factors affecting erosion indicate the reasons for this. Vegetative measures are dependent on favorable moisture conditions and proper grazing control. Although there are some notable exceptions in the Pacific Southwest, the more humid sections usually show less sediment yield than more arid sections, as more favorable moisture furnishes greater support to vegetation. Similarly, the mechanical treatment measures which require disturbing, molding, or reshaping the soil are most successful where the soils have properties which inherently make them resistant to erosion. The other factors operate in much the same way and in an interdependent fashion. As the slope increases, for instance, problems of establishing and maintaining vegetation, applying mechanical treatment and obtaining proper grazing use also increase.

Figure 1 shows the climatic environments of the Pacific Southwest. The indicated large variations are most pronounced in the mountains and valleys of the region where the mountain peaks may be humid and the valley bottoms arid. This variation causes many planning problems.

The measures that are used for erosion and sediment control in the Pacific Southwest may be classified by purpose into several groups: (1) to intercept and/or conserve moisture; (2) to increase infiltration capacity; (3) to reduce or eliminate stress on existing cover; (4) to preserve existing cover regarded as adequate or in the process of becoming adequate with time; (5) to increase the protection of the soil by a change in the type as well as density of vegetation.

1. In this group are such measures as contour furrowing, contour terracing, diversions, pitting, and chiseling or subsoiling. Contour terracing is frequently used in semi-arid and sub-humid climatic environments under high hazard site conditions and low to moderate soil hazard. The measure has been most useful and effective in breaking up gully patterns on steep slopes. Field diversions are used in semi-arid and sub-humid environments on sites having high to moderate soil hazards and moderate to low topographic hazard. In order to maintain an effective capacity on cultivated land, vegetative strips for interception of sediment are needed on moderate slopes above the diversions. Furrowing and pitting are being tested under arid and semi-arid conditions with soils ranging from low to high erosion and sediment yield potential and topographic sites in the low to moderate topographic hazard. Their success in arid climates with high and moderate hazard soil conditions has not yet been established.

2. Crop residue use and stubble mulching are widely used under a variety of soil, topographic site and climatic conditions. They are effective for erosion control as a soil binder and for increased infiltration capacity, particularly in semi-arid and sub-humid climatic environments and under moderate and high topographic and soil hazards. Contour furrowing, trenching, chiseling and subsoiling aid indirectly in improving or increasing total infiltration into the soil.

3. Measures to reduce or eliminate stress on existing cover are used under all site, soil and climatic conditions. Proper grazing use, rotation-deferred grazing, exclusion, trespass control and other management practices have the effect of increasing the density of cover or reducing eroding runoff by improvement of the soil infiltration capacity. Under arid conditions, vegetative cover improvement by range (grazing) management alone usually does not have sufficient impact on existing conditions to reduce erosion significantly unless a slight or moderate change in cover is critical to a site. However, livestock exclusion under arid or semi-arid climatic environments and high soil erosion potential has shown a substantial reduction in soil loss. Where plant density under observed conditions has not noticeably increased, it is presumed that reductions in soil loss are due to absence of continued compaction due to trampling.

4. Measures which are for preservation of existing adequate cover or cover which will become adequate with time include those for fire suppression, proper grazing use, and trespass control. These measures are used in a variety of topographic, site, soil and climatic conditions. They are most effective under semi-arid to sub-humid climatic environments and high hazard soil and topographic conditions. They are usually measures of low priority under arid and humid climatic environment with gentle to moderate slopes and low to moderate hazard soil conditions.

5. Revegetation is one of the most widely applied land treatment measures. It usually consists of seeding adapted grasses where natural cover has deteriorated, such as where juniper and pinyon pine occupy or have

encroached upon soils suitable for grasses. In the latter instance eradication precedes revegetation. Fine textured soils which may be in the high erosion potential classification are more favorable for this purpose since they retain moisture in the shallow root zone. Greater ground cover density is achieved by replacing brush and small trees with grasses. In arid and semi-arid areas seeding has in some cases been effective on low hazard topographic sites. Its effectiveness for reducing erosion on high hazard sites in these climatic environments has not been established. It is recommended for sub-humid and humid climatic environments, high and moderate hazard site conditions and moderate hazard soils, particularly where quick cover protection is needed following a brush or forest fire.

Table I lists some of the more specific management and treatment measures for erosion and sediment control under various site conditions. Climatic environments are listed first, being the key to the success or effectiveness of vegetation which is intimately related to all land treatment measures.

Structural Measures for Erosion and Sediment Control

Structural measures as those described below have met with more uniform effectiveness than land treatment measures. Achievement of the purpose for which they were designed is not dependent upon nature. Their design, construction and maintenance have a variable flexibility to meet demands of the local situation.

The structural measures as defined are primarily intended for use where channel erosion and sedimentation are the major problems. Debris basins are constructed to prevent sediment, usually coarse textured, from entering a downstream reach where damages may occur because of its accumulation. The degree of control over the sediment problem depends upon the available capacity relative to the sediment yield and on the stability of the channel downstream. The latter must be able to resist scour where the erosion potential is renewed by debris retention.

Reservoirs usually provide storage capacity for sediment likely to enter the reservoir during the project life in addition to the capacity needed for the design flood. Sediment storage is a secondary purpose unless the damsite is chosen so as to reduce stress on a downstream eroding channel. In the Pacific Southwest where valley trenching in fine grained alluvium is common, erosion and sediment transport is frequently limited only by the magnitude of the discharge. Reduction of discharge by controlled release above an extended reach of valley trenching can have a substantial influence on channel erosion and sediment yield.

Drop structures are widely used in dissected alluvial channels and mountain channels to prevent continued unraveling of the bottoms and sides. They are also used near or at a headcut to prevent its further movement. Chutes and drop inlets are used for the same purpose. Drop structures are frequently used in a series. Scour below structures can most effectively be controlled by appropriate spacing in the series. Isolated drop structures in a reach with extensive erosion are not very effective except to control the problem at the specific site.

Channel lining is used to protect the bed and/or banks when it has been determined that excessive erosion will occur without this protection. This measure is usually effective in preventing erosion to the level of the flood frequency for which it is designed.

Sills have little impact on sedimentation except to prevent additional sediment from being derived from channel degradation. Their single purpose is to prevent further degradation or a new cycle of erosion.

Jacks are used roughly parallel to and in front of the bank to direct the flow to a specific width and direction and to furnish protection to the bank. In some instances deposition behind a series of jacks provides a coating to the bank and encouragement to the development of levees.

Jetties, in projecting usually at an angle into the stream flow, are intended to protect only a local segment of the bank. The artificial change in direction of flow may tend to create a similar problem at another place unless it is part of an integrated plan.

Revetments protect the specific site where the installation is made. They are most appropriately used when adjacent banks are stable, such as in a vulnerable bend or where the revetments will provide a comprehensive treatment of all banks in the reach.

Structural measures for erosion and sediment control should be evaluated individually on the basis of purpose, site suitability and on the projected benefits as related to costs.

Evaluation of Management and Land Treatment Measures

The elements of a recommended conservation program pertaining to erosion and sediment control may be very broad or fairly specific. Some of the more specific measures which have been defined above and that are included in Table I may need to be combined or modified to match the scope of the recommendations. On Table I are given some of the management and land treatment measures considered favorable for application on land with site conditions listed.

In estimating the probable effect of individual or groups of measures on erosion for any one delineated area, the following steps are recommended:

(1) identify the major source or cause of sediment; i.e., land use, upland erosion, channel erosion, by referring to columns G, H, and I in the table on "Factors Influencing Sediment Yield in the Pacific Southwest"; (2) from the aforementioned table, extract the topographic and soils characteristics listed in columns E and B for upland erosion areas; (3) determine from Figure 1 the climatic environments for the area on the broad basis of arid, semi-arid, sub-humid, and humid. If the treatments listed in Table I are checked as appropriate for each of the variables of climate, soils and topography for the area considered, the treatment would likely reduce erosion in the area.

Those areas which may be identified geographically as "cliffs" or "badlands" should not be considered suitable for land treatment measures. All areas are affected by geologic erosion, the amount depending upon the geologic, topographic and climatic conditions peculiar to the site. This is a "background" rate of erosion unaffected by man's level of use either directly or indirectly. High geologic erosion sites are characterized by an arid environment and/or by periods of exceptionally heavy rainfall and runoff. Detached or easily dispersed soils on very steep slopes in an unfavorable climate furnish an unstable medium for vegetative growth. In humid or sub-humid areas landslides and land slips may be the characteristic expression of geologic erosion, although land use can be a contributing or even major cause.

Management measures applied alone are termed an extensive treatment. When these are combined with land treatment measures, they are termed intensive treatment. (See Table 2). Whether or not extensive and intensive measures are recommended depends on treatments indicated as appropriate on Table I and on other possibly limiting factors, including economics.

Evaluation of Structural Measures

The scope and method of evaluating structural measures is similar to that for treatment of the land in that off-site and on-site benefits may accrue by application of some of the measures. For example, prevention of continued bank erosion by a stabilization structure can reduce the sediment yield as well as prevent the loss of more land along the bank. On the other hand, land treatment measures usually apply to broad areas whereas structural measures for the purposes herein described are placed in stream systems where specific sites may be involved. Evaluation is thus more on a specific site basis.

Debris basins are designed for specific purposes. These may include prevention of land destruction or deterioration by overwash, reduction of cleanup costs, prevention of channel aggradation, and resulting overbank flooding. A reduction in sediment yield based on debris basin construction is justified only when coarse sediment is the major constituent.

Detention or multi-purpose reservoirs retain all sizes of sediment behind the structure and sediment yield downstream is dependent on the trap efficiency of the reservoir. Reservoirs may be placed above a valley trench to reduce stress on the eroding channel by a reduction in flood peaks. However, long duration low flow releases may render a channel more vulnerable to erosion. Such a condition can exist when fine, lightly cemented or cohesive soils lose their resistance to erosion with the extended wetting.

A system of drop structures and bank revetments can reduce sediment yield when channel erosion is a major source. However, it is unlikely that one or a small number of measures installed in channels will result in a substantial reduction unless a particularly favorable situation occurs. This might include a drop structure located to stop a headcut from trenching an extensive valley.

Evaluation of Land Treatment and/or Structural Measures

Considered here are the potential off-site benefits from treatment under high or moderate yield potential for both Upland Erosion and Channel Erosion and Sediment Transport, Columns H and I in the report "Factors Affecting Sediment Yield". When both are in the high classification, treatment of uplands but not channels is less likely to result in a significant reduction in total yield. The reason is that material is readily available in the channel and the stream may become loaded to capacity from this source without regard to contributions from hill slopes.

Measures applied to one of the other combinations of upland and channel erosion conditions should have a greater impact on sediment yield with the possible exception of the treatment of high channel erosion but not that on the upland. The topography, cover and precipitation patterns determine to a large degree what sediment load the upland eroding areas furnish when the flow reaches the channel.

Procedure for Evaluating Effect of Application of Measures on Erosion and Sediment Yield

Table 2 presents numerical values for estimating the effect of measures on sediment yield. As in Table 1, climatic environment is subdivided into four types to facilitate classification in accord with more or less favorable vegetative response to varying moisture conditions. (See Figure 1).

The factors which can be affected by treatment are Ground Cover, Land Use, Upland Erosion and Channel Erosion. Table 2 reflects changes in the numerical ratings on the chart attached to the report on Factors Affecting Sediment Yield in the Pacific Southwest. Based on the treatment to be applied, the new rating uses the same numbers as given on the chart for factors A through E and new values in accord with Table 2 for columns F through I.

The following example is given, using the same watershed in western Colorado as given on page 18 of the report cited above in which factors A through E total 42 points. According to Figure 1 this area has an arid environment. With the easily dispersed soils and moderate slope, Table 1 shows that the appropriate treatment can include brush control, livestock exclusion, rotation-deferred grazing and proper grazing use, all measures except brush control characterized as extensive. Since the majority of treatment possibilities are extensive, this level of treatment and of effectiveness are assumed. According to the numerical rating system on the chart of Factors Affecting Sediment Yield, the ratings in factors F, G and H are at the high sediment yield levels.

On the basis of Table 2, the rating of this watershed following treatment would be as follows:

Factors	Rating	
	Without Treatment	With Treatment
A. Surface geology	10	10
B. Soils	10	10
C. Climate	7	7
D. Runoff	5	5
E. Topography	10	10
F. Ground cover	10	8
G. Land use	10	8
H. Upland erosion	25	20
I. Channel erosion	5	5
Total	92	83

This total rating of 83 with treatment indicates that a management program would place sediment yield in the lower levels of classification 2 where the sediment yield rating is 1.0 - 3.0 acre feet per square mile.

The time factor is not a part of the numerical rating system of Table 2. However, a realization of when the appraised reductions in erosion and sediment yield will accrue is important. As a general rule, the more arid the climatic environment, the longer the period between application of measures and the achievement of evaluated results. The elapsed time may range from only a year or two at favorable locations to decades under unfavorable site conditions.

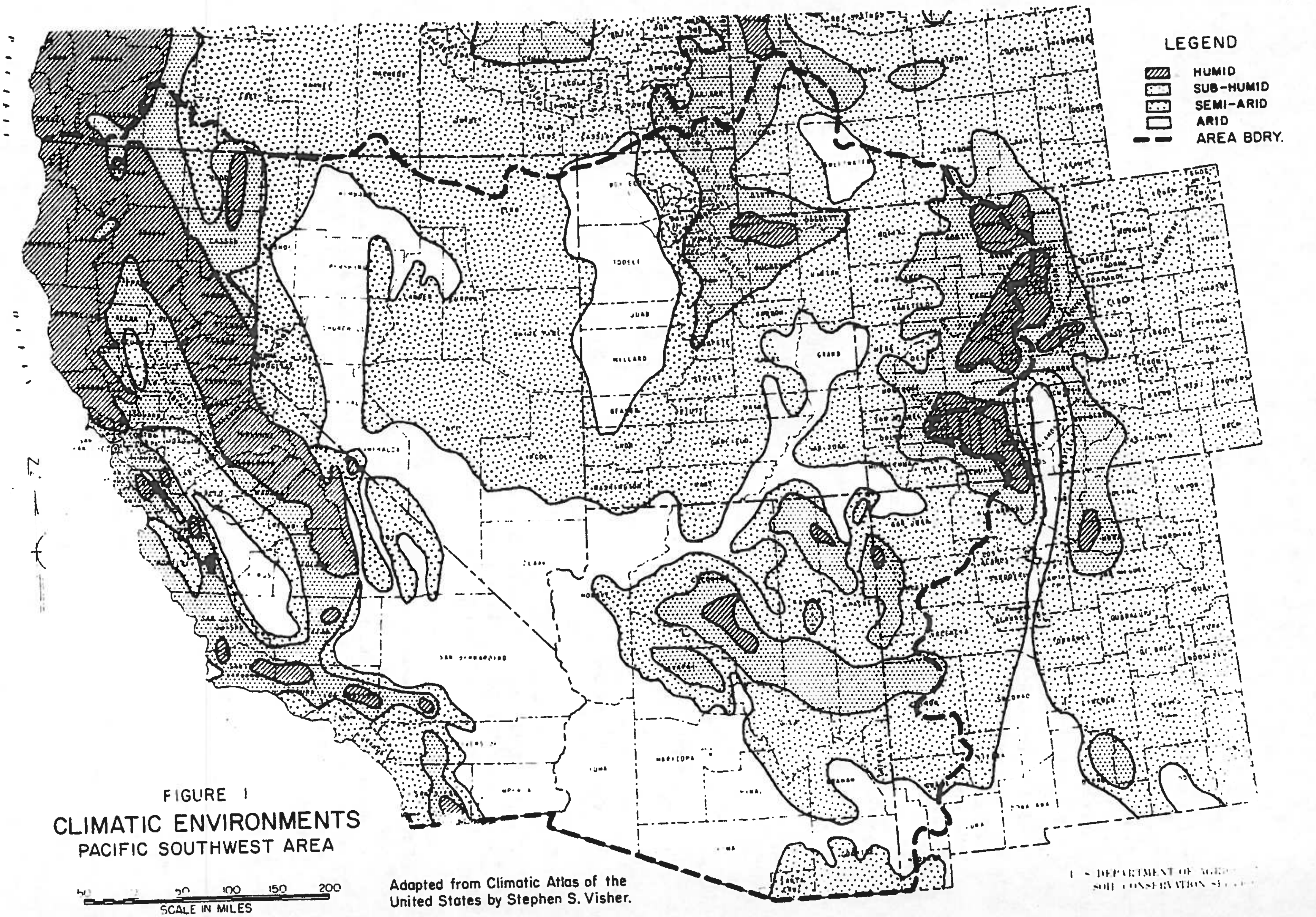


FIGURE I
CLIMATIC ENVIRONMENTS
PACIFIC SOUTHWEST AREA

Adapted from Climatic Atlas of the United States by Stephen S. Visher.

TABLE I - MANAGEMENT AND LAND TREATMENT MEASURES RECOMMENDED FOR REDUCTION OF EROSION AND SEDIMENT YIELD UNDER VARIOUS SITE CONDITIONS

Measures	Climatic Environment				Soils *			Upland Slope Topography		
	Arid	Semi-Arid	Sub-Humid	Humid	Fine Textured	Medium Textured	Coarse Textured	Steep	Moderate	Gentle
	A	B	C	D						
Forest and Range Lands										
Brush control	x	x			x	x	x		x	x
Contour furrowing and trenching		x	x		C	B		x	x	
Contour terracing		x	x			x	x	x	x	
Critical area planting		x	x	x	x	x		x	x	
Fire prevention and suppression		x	x	x	x	x	x	x	x	
Livestock exclusion	x	x	x	x	x	x	x	x	x	x
Proper grazing use - trespass control	x	x	x	x	x	x	x	x	x	x
Range seeding		x	x		C	B			x	x
Rotation-deferred grazing		x	x		x	x	x	x	x	x
Tree and shrub planting		x	x	x		x	x		x	x
Cultivated Land										
Chiseling and subsoiling			x	x		x			x	x
Contour farming		x	x	x	x	x	x		x	x
Contour terracing		x	x	x	C-D	x			x	x
Critical area planting		x	x	x	x	x		x	x	
Crop residue and mulching		x	x		x	x		x	x	x
Field diversion		x	x		x	x			x	x
Proper cropping and use		x	x	x	x	x	x		x	x
Strip cropping		x	x		x	x	x		x	x

* Mechanical treatments are not applicable on shallow soils.

TABLE 2 - EVALUATION OF MEASURES

Sediment Yield Levels	Climatic Environment	F. GROUND COVER Extensive Treatment	F. GROUND COVER Intensive Treatment	G. LAND USE Extensive Treatment	G. LAND USE Intensive Treatment	H. UPLAND EROSION Extensive Treatment	H. UPLAND EROSION Intensive Treatment	I. CHANNEL EROSION & SEDIMENT TRANSPORT Extensive Treatment	I. CHANNEL EROSION & SEDIMENT TRANSPORT Intensive Treatment
High	Arid	8	5	8	5	20	15		
	Semi-arid	5	0	5	0	15	10		
	Sub-humid	0	-5	0	-5	10	5		
	Humid	-5	-10	-5	-10	5	0		
								20	5
Moderate	Arid	0	-3	0	-3	10	7		
	Semi-arid	-3	-5	-3	-5	7	5		
	Sub-humid	-5	-7	-5	-7	5	3		
	Humid	-7	-10	-7	-10	3	0		
								5	0