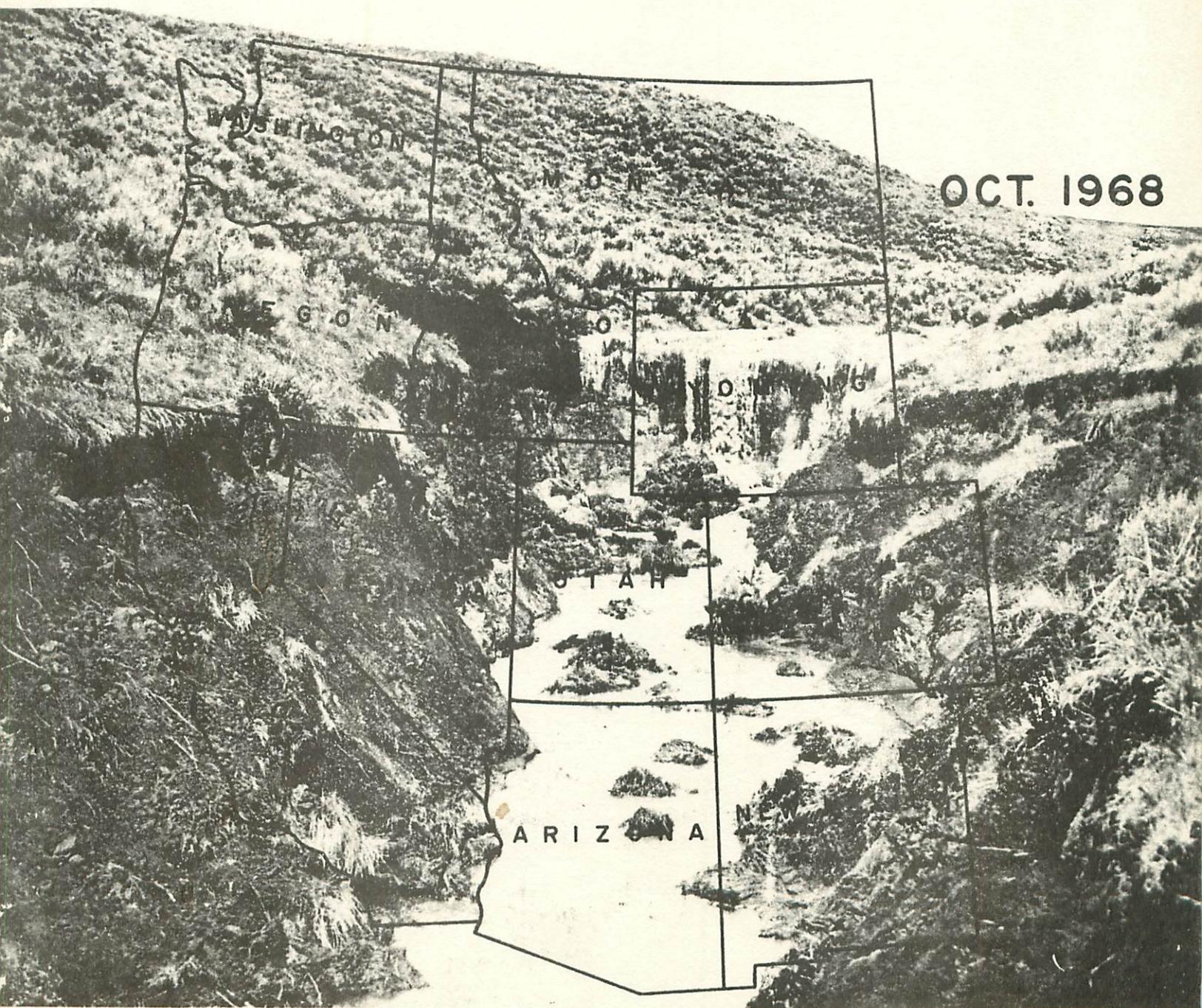


Pacific Southwest **INTER - AGENCY COMMITTEE**

Report of the Water Management Subcommittee



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

FACTORS AFFECTING SEDIMENT YIELD IN THE PACIFIC SOUTHWEST AREA

Recommendations of the Water Management Subcommittee
Sedimentation Task Force, PSIAC
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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 Southwest 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
	2	1.0 - 3.0	" "
	3	0.5 - 1.0	" "
	4	0.2 - 0.5	" "
	5	< 0.2	" "

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:

<u>Rating</u>	<u>Class</u>
> 100	1
75 - 100	2
50 - 75	3
25 - 50	4
0 - 25	5

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.

Topography

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.

Ground Cover

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 artificially 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.