Systematic Watershed Analysis Procedure for Clearwater National Forest

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Natural and man-caused disturbances, including roads, may cause accelerated on-site erosion, increased downstream sedimentation, and changes in channel conditions. A procedure has been developed to estimate the magnitude of these effects on the Clearwater National Forest based on a land systems inventory that uses the "landtype", which is defined as a unit of land that has similar landform, geologic, soil, and vegetative characteristics. The dominant erosion hazards, which include surface erosion and rotational and debris landslides, are evaluated for each landtype in a watershed. The efficiency of a landtype to deliver eroded material into the channel system as sediment is also evaluated for each landtype. Erosion and sedimentation data collected locally or extrapolated from nearby areas with similar characteristics are used to estimate the erosion and sedimentation responses of road construction, timber harvest, and forest fire. Predictions can be made for undisturbed conditions and also to determine the effects of past or proposed management alternatives. Predictions are sensitive to changes in erosion over time. A relation based on analyses of 65 watersheds makes it possible to define allowable increases in sediment production based on channel equilibrium conditions. The procedure is useful to transportation planners because it provides a means to evaluate the effects of alternative road locations and road design features and allows scheduling construction over time to minimize unwanted effects.

There has been considerable interest in recent years in the effect of alternative cultural practices on water quality. On forest lands, the pollutant of primary concern is sediment, and the primary cultural practice that causes accelerated sediment is road construction (1). This is particularly true in the western United States, where accelerated sedimentation following road construction commonly results from both surface and mass erosion processes (2).

Various procedures have been developed to estimate the effects of alternative soil-disturbing practices on erosion. Most of these were developed on agricultural lands (3,4) and have subsequently been adapted to other types of soil disturbances, including construction sites and roads (5,6). Unfortunately, these methods have limited application for evaluating road erosion in much of the mountainous West because they are not adapted to snowmelt conditions, they do not consider gulley and mass erosion, and they make no provision for subsurface flow intercepted by roadcuts.

We have developed a procedure for predicting the effects of alternative watershed disturbances, which include road construction, timber harvest, and forest fire. The procedure uses a systems approach based on the landforms found in the basin, empirical data to estimate the effects of disturbance on annual surface and mass erosion, and the resulting response in both annual sediment yields and channel equilibrium conditions. By using the Clearwater National Forest procedures, responses are measured in terms of changes in annual sediment yields and channel equilibrium conditions and are usually evaluated over a period of less than 20 years.

ROLE OF LANDTYPE

The "landtype" is one stratum of the hierarchical land systems inventory described by Wertz and Arnold (7). The higher-level strata, which include physiographic provinces, sections, and subsections, are all delineated on the basis of climatic and geologic differences and are roughly classified by size as greater than 1000 $mile^2$, 100-1000 $mile^2$, and 25-100 $mile^2$ for each level, respectively. Further stratification requires the evaluation of additional factors, including landform, soils, and vegetation. The landtype association reflects a common genesis for a group of lands and can range in size from 10 to 25 $mile^2$. The basic land unit used for the watershed analysis procedure is the landtype itself, and it is defined as an area of land with similar landform, parent material, soil, and vegetation characteristics. Landtypes range from 40 to several hundred acres in size and average about 150 acres. Guidelines and additional background information on the delineation of landtypes are available elsewhere (8-11).

Landtypes and Slope Hydrology

Landtypes are used as the basic component for describing the watershed system because factors used to delineate landtypes are the same factors that influence the hydrologic function of slopes. Characteristics that describe slope hydrology, or how a slope handles water, include (a) slope shape, (b) slope length, (c) slope gradient, and (d) surface drainage characteristics (12).

When analyzing slope hydrology, it is helpful to consider how a slope disposes of water and how the above-mentioned factors influence runoff timing, as follows:

1. Slope shape: Slope shape influences whether water is dispersed or concentrated. Slope shape classes mapped include the following: (a) class 1--slopes that are convex horizontally disperse water movement in all directions; this tends to discourage concentration and decreases contributing area to streams that originate on the slope; (b) class 2--straight slopes accumulate water in straight flow paths down the slope; and (c) class 3--horizontally concave slopes concentrate water movement to common points; this increases the contributing area of streams that originate on the slope.
2. Slope length: Longer slopes tend to accumulate more water on the lower portions of the slopes.
3. Slope gradient: Steeper slopes decrease the time of concentration of slope water movement and increase flow velocities.
4. Surface drainage characteristics: Slope dissection, stream density, stream length, and entrenchment all affect time of concentration and contributing area of slope water movement.

Soil and parent material characteristics used to delineate landtypes include soil mantle depth, soil texture, soil structure, soil consistency, bedrock type, bedrock weathering, and bedrock jointing and fracturing. Each factor modifies mantle drainage and, subsequently, the subsurface water movement on slopes. Soil and bedrock characteristics can vary within a landtype but occur in a predictable pattern; thus, differences are reflected in the overall slope hydrology.

The last basic criterion that describes the landtype is vegetative habitat type (13). This also indicates basic slope hydrology by expressing relative soil moisture regimes over the slope throughout the year. Vegetative habitat types are used to define soil mantle stability through correlation with vegetative cover and vegetative recovery potential.

Delineation and Description of Landtypes

The actual landtype delineation process requires, first, delineation by landform, which is a morphological descriptor. Landform is described by slope shapes, slope length, slope gradient, etc., and landtypes are classified and mapped by aerial photograph interpretation. Field traverses that cross representative areas of each mapping unit are then taken to provide detailed site information. Patterns of landform, soils and vegetative habitat types, and general parent material characteristics are described and extrapolated over the mapped areas. The mapping units are then transferred from the aerial photographs to 1:24 000 scale topographic maps. A final, detailed landtype description is developed for each unique mapped unit and includes a general description and setting, physical landform characteristics, slope hydrologic properties, parent material, soil, and vegetation characteristics.

Landtype Erosion Hazards

Interpretations of the hazards for various kinds of erosion, including rotational mass wasting, debris avalanche, and overland flow erosion, are made for each landtype in order to define the relative sediment production potential for each area of land. Ratings for each attribute are classified relatively from very low (class 1) to very high (class 5).

Rotational Mass Wasting Hazard

Rotational mass wasting is defined as movement that occurs along internal slip surfaces (usually concave and upward) with backward tilting common. Movement is usually deep seated in response to increased subsurface water concentrations in the vicinity of the slide plane (14). Hard bedrock surfaces do not constitute the slippage plane. Criteria used in evaluating the hazard are incidence of subsurface water concentration, mantle depth, soil and bedrock characteristics, and evidence of past rotational failures. These factors are interrelated, but they are discussed individually.

Slope hydrologic characteristics describe an incidence of subsurface water concentration. Factors considered are slope shape, slope gradient, drainage density, lower-order stream characteristics, and mantle drainage characteristics. Areas with a high incidence of subsurface water concentration include stream headlands with convex-shaped slopes that change to concave shapes where large numbers of first-order streams originate. Also, subsurface water concentrates in deep-mantled, weakly dissected, over-steepened slopes (streambreaks) where almost all slope drainage is subsurface, which causes water concentrations in middle and lower slopes. An example of an area with a low incidence of subsurface water concentration would be low relief lands with a well-developed, high-density, dendritic drainage pattern.

Soil cohesive strength of the mantle also affects rotational mass wasting potential. This is evaluated by using pertinent soil and geologic characteristics such as type of bedrock and soil textural properties. For example, sandy soils developed from quartzites with large percentages of coarse fragments have much lower cohesion strength than silt loam and silty clay loam soils developed from micaceous shists.

Debris Avalanche Hazard

Debris avalanches are defined as rapid and usually sudden sliding of usually cohesionless mixtures of soil and rock material that range in depth from several inches to 4-5 ft (14). Criteria used to assess the hazard are slope gradient, slope shape, aspect, surface soil creep hazard class, and evidence of past debris avalanches such as slide scars, talus slopes, and colluvial cones or fans at the toe of the slopes.

Debris avalanches are most common on steep, concave slopes with soils susceptible to surface creep. On the Clearwater National Forest, most debris avalanches occur when the heads of draws are overloaded with sediment eroded from adjoining slopes through dry surface creep. The occurrence of a large, high-intensity hydrologic event (often rain on snow) triggers the debris avalanche.

Surface creep is the gravitational movement of solid particles dislodged by various processes such as raindrop splash, wind, frost action, and animal movement. Criteria used to assess surface creep are slope gradient, aspect, soil cohesion and coefficient of friction, soil particle size, and vegetative cover potential. Surface creep is a gravity process; therefore, slope gradient is a dominant factor. Aspect influences the frequency of freeze-thaw cycles that occur during the spring. Soil cohesion and particle size refer to surface soil properties. Loose, noncohesive soils with large particle sizes are much more susceptible to gravity movement than fine-grained cohesive soils. Vegetative cover greatly reduces surface creep by reducing surface temperature fluctuations and protecting the soil surface from particle movement.

Overland Flow Erosion Hazard

Overland flow erosion refers to erosion caused by tractive forces developed by water running over undisturbed natural surfaces bared of vegetation. This erosion occurs as sheet erosion and rilling. Factors used to rate surface erosion hazard are based on the detachability of soil particles and the potential for occurrence of overland flow and are very similar to those used for rotational mass wasting: slope shape and slope gradient, mantle depth, and soil particle detachability. Raindrop splash or overland flow is required to detach and move particles. Slopes that concentrate water have the greatest potential for overland flow (for example, steep concave slopes that concentrate runoff from a larger area into a smaller area). Landforms that exhibit this property include breaklands, stream headlands, and glacial cirque basins. Broad convex ridges have a lower potential for overland flow because runoff is dispersed over the slope.

Thin soil mantles are more likely to have overland flow than thick soil mantles that occur on similar slopes because of more limited water storage capacity. Soil particle detachability is a function of the apparent cohesion of individual soil particles within the soil matrix. For example, coarse-textured, single-grain soils are more susceptible to particle detachment than cohesive soils with strong structures.

Slope Delivery Efficiency

On-site erosion is only manifest at downstream locations as sediment if the eroded material is delivered to the stream. Thus, the ability of a given landscape to deliver sediment downslope (termed slope delivery efficiency) is an important concern. Specifically, slope delivery efficiency describes rates at which water and sediment are transported from different slopes to the water system, including ephemeral draws. Slope delivery efficiency defines the role the landtype plays in sediment production in a watershed and refers to the ratio of sediment delivered into the water system over a 5- to 10-year period.

Slope delivery efficiency for mass erosion is based on data that quantify downslope delivery of landslide material collected on more than 600 landslides on the Clearwater National Forest (15). Slope characteristics used to interpret slope delivery for each landtype are slope gradient, slope shape, slope dissection density, and internal relief. Ratings for slope delivery efficiency are made similar to erosion hazard ratings that range from very low (class 1) to very high (class 5).

SEDIMENT PREDICTION FROM FOREST MANAGEMENT PRACTICES

The hazard ratings derived for each landtype provide the basis for quantification of sediment yields from watersheds in both the undisturbed state and following alternative kinds of land use practices. The simulation technique generates probable sediment rates caused by accelerated mass erosion on each landtype from roading, logging, or fire. It also generates sediment caused by induced surface erosion from road prisms, logging, or fire. A natural sediment rate is generated to interpret the magnitude of effects with respect to a specific watershed system and its water resource values.

Basic assumptions involved in the sediment prediction process include the following:

1. Sediment yields can be simulated and used as expected annual volumes per unit area of the system routed to the mouth of the system.
2. Natural sediment yields are generated by in-channel erosion of banks and stored sediment in beds. This material is supplied principally by long-term mass movement (slumps and slides; debris avalanches, flows, and torrents; and creep) and, to a lesser degree, by natural surface erosion that is a function of catastrophic wildfires.
3. Mass erosion and surface erosion can be treated as separate processes, although in fact they are often interactive and interelated. Essentially, mass erosion is assumed to be accelerated by management activities, while surface erosion from wildfires, roads, and logging is induced or created by activities. The erosion products are delivered to the channel system by distinctly different processes: mass erosion is a colluvial or gravity process while surface erosion is moved principally by flowing water. Many of the same landtype properties are used to determine delivery efficiency for the two types of erosion processes, but the influence of those properties is different.

Natural Sediment Rate

The natural sediment rates, expressed as tons per square mile of watershed area per year, are derived from a composite on-site erosion hazard based on a weighted average of the individual on-site erosion hazards developed for each landtype. The composite on-site erosion hazard is calculated as follows:

Composite on-site erosion hazard = (0.4 x rotational mass wasting hazard) + (0.4 x debris avalanche hazard) + (0.2 x overland flow erosion hazard) (1)

The weighting factors are based on the fact that most natural sediment production on the Clearwater National Forest is caused by mass erosion that feeds material directly to stream channels. However, some overland flow erosion occurs following natural wildfires. Megahan and Molitor (16) found a total of 700 tons/mile² of soil loss from surface erosion after a wildfire on landscapes similar to those on the Clearwater National Forest. Soil losses were highest immediately after the burn and decreased to zero within five years in response to vegetative regrowth. The average wildfire frequency for vegetative types on the Clearwater National Forest is estimated to be about 140 years (17). Based on a wildfire erosion rate of 700 tons/mile² in 5 years and a fire frequency of 140 years, the average overland flow erosion from natural wildfire over a fire cycle is 5 tons/mile²/year. Megahan (18) reported an average annual sediment yield of 25 tons/mile²/year for undisturbed drainages similar to those on the Clearwater National Forest. About 5 tons/mile²/year or 20 percent of this is caused by long-term surface erosion from fire on the Clearwater National Forest. The remaining 80 percent is divided about equally between rotational mass wasting and debris avalanche, hence the weighting factors of 0.4 for rotational mass wasting and debris avalanche and 0.2 for surface erosion.

Watersheds with landtypes similar to those on the Clearwater National Forest have been shown to yield average annual sediment volumes that range from about 10 to 100 tons/mile²/year (18,19). Values within this range were assigned to each landtype identified on the forest based on the landtype's relative composite on-site erosion hazard. Each landtype's contribution is summed and weighted by area to account for potential sediment from all the lands in the watershed system.

This value provides an estimate of the total potential sediment for basins of similar size to the basins where the original data were collected. These study basins ranged from 0.15 to 2.5 mile² in size and averaged about 1.0 mile² (18). In order to estimate sediment yields for larger basins, it is necessary to correct for losses caused by channel storage. This is done by multiplying by a channel routing coefficient. The coefficient (C) is obtained from a relation developed by Roehl (20) by using a water shed area (A) in square miles. Roehl's original relation is adjusted to provide a coefficient of 1.0 at 1 mile² as follows:

$$C = A^{-0.18} \tag{2}$$

The procedure to estimate natural sediment yields from composite erosion hazard used on the Clearwater National Forest is adapted from a general procedure in use by the Forest Service, U.S. Department of Agriculture, in the northern Rocky Mountains (21).

Sediment from Accelerated Mass Erosion

The basic premise for quantifying sediment from mass erosion processes is that management activities accelerate natural mass erosion potential. The amount of increase is based on the landtype mass erosion hazard rating developed by using the rotational mass hazard, the debris avalanche hazard, and the slope delivery efficiency determined for a landtype, as follows:

Landtype mass erosion hazard = (rotational mass wasting hazard) + (debris avalanche hazard) x (slope delivery efficiency) (3)

Acceleration factors derived from studies in the Idaho Batholith (15) and modified by work on the Clearwater National Forest (22) are used to predict the increased risk of mass erosion due to roading, logging, or fire as a function of parent material and time after disturbance. The sediment from accelerated mass erosion is simply the landtype mass erosion hazard multiplied by the applicable acceleration factor, the area of the disturbance, and a coefficient to account for mitigation measures for roads and logging or fire intensity. The following illustrates the relation used for roads; similar relations are used for fire and logging:

Increased sediment = 20 x (landtype mass erosion hazard) x (road acceleration factor) x (area disturbed by road) x (mitigation) - 20 (4)

Sediment from Surface Erosion

Sediment derived from surface erosion is similated as an independent process with respect to mass erosion. The basic premise here is that roads, logging, and fire create, rather than accelerate, surface erosion. The methodology was developed by the Forest Service interregional task force and is documented in their report (21).

Surface erosion rates are assigned for each type of land disturbance activity, including road construction, logging, and wildfire. Assigned erosion rates are defined for each kind of disturbance and modified as needed if the disturbance is not in keeping with the definition. For example, the erosion rate for roads is based on the "basic road", which assumes a road with a 16-ft subgrade width, no surfacing, balanced construction, and no ditch.

Erosion rates are modified as the road deviates from this standard. Likewise, erosion rates are modified to account for differences in logging practices and wildfire intensity. Erosion rates also vary by landtype, elapsed time since disturbance (in years), and mitigation measures designed to reduce road erosion. Data for this effort come primarily from research conducted in Idaho (15,16, 18,23,24) supplemented by data from the West Coast (25-27). Erosion rates are in terms of tons per unit area of disturbance; therefore, the rates are multiplied by disturbed area to get total erosion for each landtype.

As with mass erosion, all soil losses caused by surface erosion are not delivered to streams because of enroute storage. A modification of a procedure developed by the Forest Service (21) is used to estimate delivery of surface-eroded material. Three variables are used to determine delivery:

1. Slope shape determines the ability to produce water for movement of sediment in the channel efficiently,
2. Slope gradient defines energy availability, and
3. Stream density represents slope length and proximity of the erosion source to the water system.

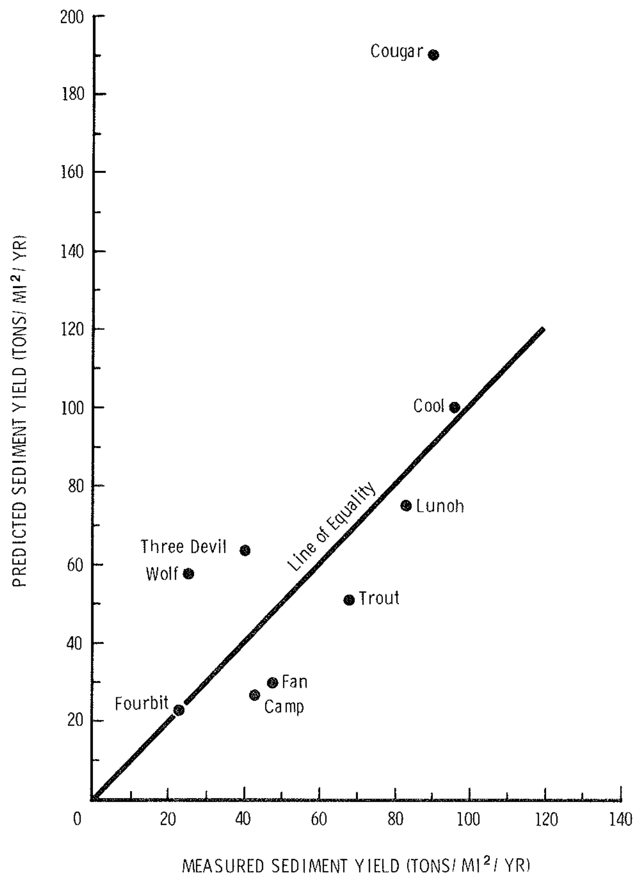
The relation used to predict surface erosion from roads is shown below; similar relations are used for fire and logging:

Increased sediment from road prism = (road base rate) x (mitigation) x (parent material erosion hazard) x (area disturbed by road) x (landtype slope delivery efficiency) (5)

PREDICTED VERSUS ACTUAL SEDIMENT YIELDS

The sediment yield prediction procedure is designed to provide average annual sediment for both natural and disturbed watersheds. This level of precision is analogous to the average annual sheet and rill erosion predictions for agricultural lands provided by the universal soil loss equation (4). In both cases, predictions for a specific year can be considerably different than actual, simply because of deviations in climatic conditions from the average.

Figure 1. Predicted versus measured average annual sediment yield.



Comparisons between actual and predicted values must be made for the average of a number of years of data to be valid.

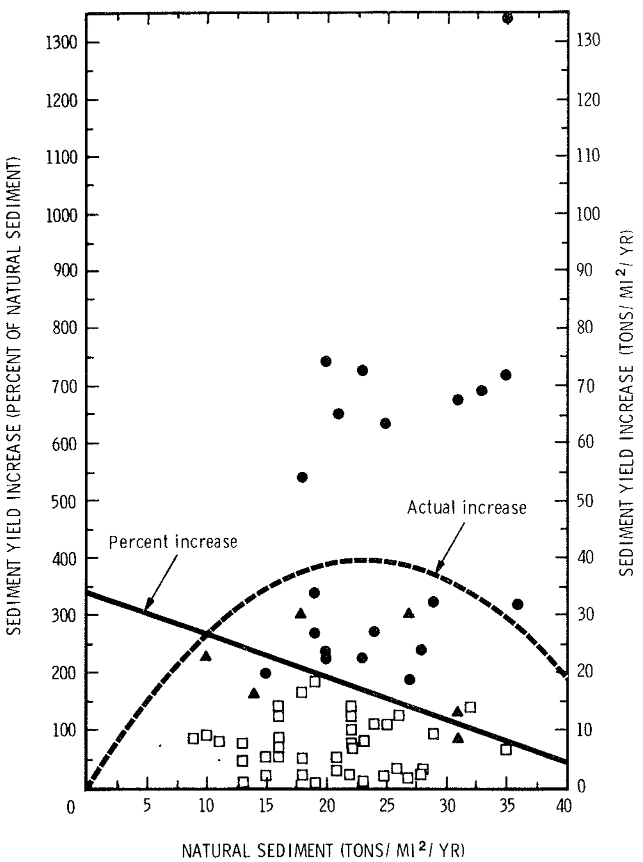
We do have relatively long-term sediment yield data for nine watersheds on the Clearwater National Forest that can be used for comparison purposes. Data consist of suspended and bed-load samples collected at irregular intervals during the year. Each annual data set ranged from about 10 to 16 samples. Individual sediment samples were prorated by time between samples to estimate annual sediment yields. A total of from six or seven years of sediment yield data are available for each watershed.

The actual versus predicted average annual sediment yields are shown in Figure 1. Most streams show relatively close agreement with little bias except Cougar Creek, where predicted values exceed actual by about 100 tons/mile²/year. The Cougar Creek drainage contains many old roads that did not exhibit as much mass erosion as was predicted. On-the-ground inspection indicated that mitigation measures had been applied at a number of high erosion hazard situations but had not been accounted for in the prediction process. Although this comparison hardly provides a validation of the sediment estimation procedures, it does suggest that the estimates are reasonable in most cases.

CHANNEL EQUILIBRIUM

Predictions of annual sediment yields provide a convenient means for comparing watersheds and for comparing the effects of alternative land management practices over time. However, predicted sediment yields do not, in themselves, provide a means to

Figure 2. Sediment yield increase versus natural undisturbed sediment yield.



evaluate changes in channel conditions. Most streams in mountain lands in the western United States are supply limited (28). This means that more energy is available for sediment transport than there is sediment. Consequently, streams are characterized by coarse-textured beds commonly with rubble and boulder-sized materials dominating. There is limited bar development in such streams and bed forms consist primarily of nondescript accumulations of gravel and rubble materials that form the riffle and run areas found in such streams. Stream channels tend to maintain this characteristic appearance with increasing sediment loads for as long as the system is supply limited. However, eventually, sediment yields are accelerated to the point that sediment supply begins to approach transport capability. When this happens, finer bed materials begin to accumulate, as evidenced by accumulated sand particles between the coarser bed materials, development of bars, and other bed forms. Continued acceleration of sediment yields aggrades the bed further and may induce increased bank cutting, altered flow patterns, and major changes in bed forms such as formation of sand dunes, etc. Change in channel conditions are no doubt reflected in the health of the aquatic ecosystem as well.

Analyses of annual sediment yields have been made for a total of 65 watersheds on the Clearwater National Forest for both natural (undisturbed) and disturbed watershed conditions. Predictions for disturbed conditions were made by using the kinds and timing of disturbances that actually occur on each watershed. Values for the predicted maximum increase in annual sediment yield (expressed as a percentage of natural) were then plotted against the natural sediment yield (Figure 2). Channels at the mouth of each watershed were then subjectively evaluated for evidence of loss of equilibrium. Criteria used included accelerated deposition of bed materials (e.g., sand bars, dune bed forms, sand terraces along banks), loss of channel capacity (e.g., bank cutting, channel braiding), and change in substrate particle-size distribution (e.g., sand accumulations that surround gravel, rubble, and boulder material).

Each watershed represented by a point in Figure 2 was classified according to whether it was definitely out of equilibrium (solid circles), at or near equilibrium (solid triangles), or within equilibrium (open squares). An obvious grouping of data is apparent in this figure. The line shown represents the approximate envelope curve for channel equilibrium: Sediment supply exceeds available energy for watersheds above the line, whereas available energy exceeds sediment supply for watersheds below the line.

This curve provides a geomorphic basis for defining response levels of sediment increases in watersheds. Interestingly, the line is not horizontal but rather indicates that larger percentage increases in sediment can occur for watersheds with low natural sediment yields as compared with high sediment yield watersheds. This relation is clarified when the percentage changes in sediment are expressed in absolute units of tons per square mile per year (dashed curve on Figure 2). On this basis, maximum increases in sediment production can occur on watersheds where natural sediment yields equal about 20-25 tons/mile²/year. Apparently, watersheds with natural sediment yields greater than this can stand progressively less sediment increases because they are progressively nearer to equilibrium in the natural state. In contrast, watersheds with natural sediment yields less than 20-25 tons/mile²/year can stand progressively less increases in sediment because they are less capable of cleaning themselves due to limited transport energy.

PROCEDURE APPLICATIONS

These procedures make it possible to test the results of alternative land use practices on erosion, sediment yield, and channel equilibrium conditions. Erosion and sediment yield estimates are an important concern because they provide an index of potential effects on both on-site vegetation productivity and damage to downstream developments, respectively. Likewise, estimates of changes in channel equilibrium are useful because they provide an index of change to the aquatic ecosystem. By varying the kinds of practices, the time sequence of application of practices, and the various kinds of mitigation measures, we can define a mix of activities that optimizes land use benefits without causing large environmental alterations. The primary application is for project-level planning of forest management practices in a watershed system. It is an excellent tool for developing and comparing alternatives, identifying trends and recovery, scheduling activities, and recognizing potentially damaging situations.

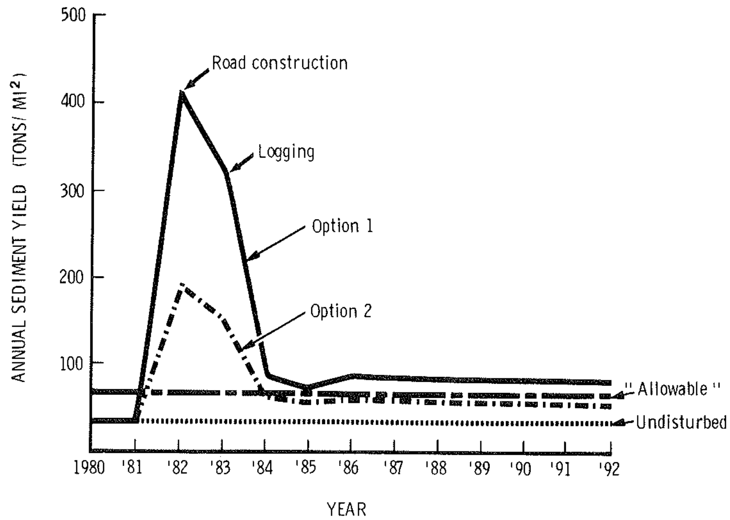
Example of Model Application

A simplified example of the application of the analysis procedures has been developed by using a representative watershed situation and landtypes found on the Clearwater National Forest. The 1000-acre watershed was developed on an old erosion surface by downcutting of the major drainage system in the area. Elevations range from 4000 to 4900 ft, and the bedrock on the watershed is granitic. Five

Table 1. Nature and amount of disturbance by landtypes for alternative timber harvest access routes.

Option	Road Length (miles)	Road Subgrade Width (ft)	Side Slope (%)	Calculated Area Disturbed by Road or Cutting Unit Area (acres)	Landtype	Type of Road Prism
1	1.0	15	25	2.4	22-G03	Balanced
	1.0	15	25	2.4	22-G03	Balanced
	0.5	15	70	1.4	61-G08	Full bench
	1.0	15	50	4.1	60-G11	Balanced
				100	22-G03	
				125	22-G03	
2	1.5	15	25	3.7	22-G03	Balanced
	1.0	15	25	2.4	22-G03	Balanced
	1.0	15	40	3.2	32-G02	Balanced
				100	22-G03	
				125	22-G03	

Figure 3. Percentage change in sediment yields for alternative road and logging practices.



different landtypes are found on the watershed.

Two options are considered in this example. Both required 3.5 miles of road construction in 1982 and logging of 225 acres of timber by using clearcutting and tractor skidding in 1983. Option 1 requires accessing the area from the bottom of the watershed and crossing the steep, high erosion hazard breaklands. Option 2 provides access from the top of the watershed and crosses the lower erosion hazard terrain. The amount and type of disturbances by landtypes are given in Table 1.

The example data were analyzed for a 10-year period following disturbance (Figure 3). The time dependence of the sediment responses is apparent. Sediment yields increase in 1981 in response to road construction. Rates decrease in 1982; however, the rate of decrease is reduced somewhat because of the logging activities. Additional decreases in sediment yield occur over time but not back to predisturbance levels because of long-term accelerated erosion on roadcuts.

According to Figure 3, increases in annual sediment yields up to about 90 percent over natural will not cause apparent channel deposition. Option 2 is clearly preferred to option 1 in terms of total increase in sediment production and duration of effects. However, other considerations may be important, depending on the nature of the uses elsewhere, the value of the water resource, and the juxtaposition of the example watershed over time and space with other watersheds in the area.

Application Elsewhere

This procedure is empirical and, as such, has limited application elsewhere. However, we feel that the principles involved can be extrapolated anywhere. An analysis procedure of this type can be designed in areas with minimal local erosion and sedimentation data by using basic principles to define relative erosion hazard ratings. These evaluations can then be used to design erosion and sediment monitoring programs that serve to update the prediction procedure. Basic requirements for implementing the watershed analysis system are as follows:

1. The dominant landforming and erosional processes of an area must be recognized,
2. The relative role of processes must be understood,
3. Landtypes or land stratification units must be designed to rate the dominant erosion processes,
4. Landtypes or land stratification units must be designed by using criteria essential to making slope delivery efficiency interpretations, and
5. The watershed system must be supply limited in the natural state.

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