SEDIMENT REDUCTION THROUGH WATERSHED REHABILITATION

By Edward L. Noble

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN REGION

SEDIMENT REDUCTION THROUGH WATERSHED REHABILITATION[1/]

Edward L. Noble[2/]

History is replete with stories recounting the failures of man to recognize, control, and conquer the devastating effects of sediments from steep mountainous lands. Learned men have documented the reasons for the tragic downfall of highly developed civilizations in Mesopotamia, Israel, Egypt, and elsewhere. Most agree that it was not conquest of the land by an invader, nor the loss of fertile fields which depopulated the land, but that the relentless encroachment of silt into the canals and rivers forced the people to move elsewhere or starve.

We may now say 7,000 years later that such an occurrence could not happen again; that our engineering skills and general knowledge preclude such disasters that befell the ancient civilizations. In part, such an assumption is true for we have expended billions of dollars to construct dams, levees, canals, and intricate irrigation systems. With such developments, we have assured ourselves of a continuing expansion of irrigated agriculture, industry, and attendant municipalities.

There is no question of our awareness of the critical water shortage problem which faces America today. Such awareness was well documented by the voluminous testimony before the Senate Select Committee on National Water Resources. Nor is there a question of the need for continued development of entire river basins to secure water for the growing industrial and population expansion which is so imminent. Such recognition is well reflected by the huge annual appropriation of funds for water development and flood control purposes by both Federal and State Governments.

With such concrete recognition of the water problems and the vast programs now underway and planned, you may reflect that we have or will have the situation under control and that the continued construction of dams and other structural projects will provide the utopia which we are presumably seeking.

There is no argument that such programs are vital and essential to insure an expanding economy and continuing prosperity. However, there is a question of their continued success if we ignore the need for onsite uses of water and fail to recognize the hydrologic conditions on the watersheds themselves.

1/ Paper prepared for the Federal Interagency Sedimentation Conference, Jackson, Mississippi, January 28-31, 1963.

2/ Forester, Intermountain Region, U.S. Department of Agriculture, Forest Service, Ogden, Utah.

The principle of regulatory stream behavior and maintaining soil stability through land management is not new. It was advanced as a guiding principle over 50 years ago by the late geologist, Dr. Thomas C. Chamberlin, who stated, "The key lies in due control of the water which falls on each acre. . . The highest crop value will usually be secured where the soil is made to absorb as much rainfall and snowfall as practical. . . This gives a minimum of wash to foul the streams, to spread over the bottom-lands, to clog the reservoirs, to waste the water power, and to bar up the navigable rivers."

Since the time of Dr. Chamberlin's keen observation, we have learned much regarding the hydrology of watershed lands. Research has probed the depths of the soil and critically examined the inter-relationships between soil cover, precipitation patterns, and water disposal. By so doing, they have established the fact that a very fundamental relationship exists between land condition and hydrologic behavior. We have also learned through experience and the practical application of research results that upstream engineering and improvement of watershed conditions can greatly reduce land erosion and the resultant damages of sedimentation.

Recognizing then, the fundamental relationships between land condition and watershed behavior, we are able to set as our objective the maintenance of both the productive and the hydrologic or water-regulating functions of the land. By achieving this objective, we are able to obtain the greatest quantity of forage and fiber from the land and simultaneously make certain that water is yielded with the greatest possible regularity and with the least possible load of sediment.

In developing a program of sediment reduction through watershed rehabilitation it is necessary to ascertain fundamental facts such as (1) the geologic norm, (2) type of flooding, (3) watershed protection requirements, and (4) adaptability of the site for treatment.

GEOLOGIC NORM

Essential to the formulation of any flood and erosion control program through watershed rehabilitation is an understanding of the relation between current flooding and erosion to the geologic norm (1, 3).[3/] This is necessary as watershed rehabilitation measures are primarily aimed at controlling water runoff and erosion from those areas on which accelerated erosion is occurring.

Watersheds with their soil and plant mantle, topography, and streamflow characteristics have been inherited from the geologic past. Their streams exhibit great natural variation in erosion and flood

3/ Numbers in parentheses refer to Literature Cited.

behavior. Some streams are usually clear and flow with a relatively constant volume, but the regimen of other streams is marked by great variance in volume and time of flow and vast differences in sediment content. Each stream is the resultant of such normal factors and forces as climate, topography, geology, and the plant and soil mantle. All these factors and forces have operated through the ages to give use to definite land forms, specific soils, vegetation complexes, and characteristic stream channels, streamflow, and sediment loads. Erosional processes at varying rates on the watershed slopes and in the channels are also part of the norm. We know, for example, that erosion is proceeding so slowly in some areas that soil is being formed and accumulated more rapidly than it is being removed. Streams from such areas carry only negligible loads of sediment. We know, too, that in other areas climatic and geologic conditions limit soil formation, plant growth, and fixing of the land surface. From these drainages runoff has always been rapid and erosion pronounced, giving rise to muddy and highly fluctuating streams. Moreover, we know that between these extremes are all gradations of watershed and sedimentation rates (6). Variation in sediment production in relation to watershed conditions are shown in Figure 1.

Figure 1.--A. Morris Creek Watershed, Utah, north-facing basin whose average slope is 48 percent with extreme gradients of more than 80 percent. Precipitation averages 30 inches annually which is completely infiltrated. Dense vegetation provides protection against erosion. Sediment production from this watershed is only 0.0025 acre-foot per square mile per year and represents a low geologic norm. (6)

Figure 1.--B. Lost Creek Watershed, Utah; 85 percent of area comprised of steep barren slopes. Active erosion and periodic flooding are characteristic of this basin giving it a high geologic norm. Small islands of soil protected by vegetation show no evidence of overland flow and erosion. Erosion removes soil material as rapidly as it forms from unvegetated slopes. (6)

From some knowledge of the geologic norm, a study of the condition of the watershed, and a determination of the history of runoff from a flooding stream, we can determine whether erosion is accelerated or normal. If accelerated, an opportunity for rehabilitation exists.

TYPE OF FLOODING

Flooding from high mountain watersheds usually occurs as wet mantle floods due to rapid snowmelt runoff or from dry mantle floods resulting from high intensity summer rainstorms.

Although watershed rehabilitation measures have proved valuable in preventing serious damage from both types, they are primarily used to control surface runoff of water and erosion from floods classed as dry mantle. Accordingly, a knowledge of the characteristics of dry and wet mantle floods is necessary in order to design appropriate treatment measures.

Some Characteristics of Dry Mantle and Wet Mantle Floods (7)

Factor	Dry Mantle Flood	Wet Mantle Flood
Soil mantle condition	Dry--high water storage capacity	Wet--storage capacity exhausted
Precipitation	Short intense rainfall	Prolonged rain-fall, snowmelt or both
Storm area	Usually small--may be only 5 to 10 percent of flood-ing drainage	Relatively large, usually all of flooding drainage
Volume of water	Relatively small--may be only a few acre-feet	Relatively large--thousands of acre-feet
Manner of flow to stream channels	Over surface	Mainly seepage or "bleeding" of saturated soil mantle
Sediment carried	High--may reach 60 percent of volume	Low--in relation to water volume

WATERSHED PROTECTION REQUIREMENTS

During the past 40 years, much research work has been done on high mountain watershed lands to determine the relationship between groundcover (including plants and litter), precipitation, surface runoff, and erosion.

Following floods, field investigations have been made to determine flood-source areas, their condition, and their specific contribution to runoff and sedimentation. From these many analyses it has been determined that heavy flooding has occurred when the hydrologic balance on as little as two to ten percent of the watershed has become deteriorated. It has also been noted that such deterioration is primarily due to a reduction of cover to the extent that each area of land was unable to receive and dispose of water through the process of infiltration.

TABLE 1.--Summer storm rainfall and resultant overland flow and soil losses from Parrish Plots, Davis County Experimental Watershed, Utah

Storm dates	Total rainfall	Nonflood-source area		Flood-source area		Artificially denuded	
		Overland flow	Soil eroded	Overland flow	Soil eroded	Overland flow	Soil eroded
	In.	Pct.	Cu.ft./A.	Pct.	Cu.ft./A.	Pct.	Cu.ft./A.
7/10/36	1.14	0.7	0	42.8	181.5		
7/16/36	.89	.4	0	43.4	153.6		
7/28/36	1.21	.2	0	33.0	83.2		
8/18-20/45	3.09	.5	0	24.3	92.8		
7/10/50	.70	.9	0	12.6	Tr.	61.3	215.3
8/19/51	1.15	.6	0	8.4	Tr.	46.6	186.2
8/4/54	1.17	.4	0	3.8	Tr.	31.3	91.3
8/19-20/59	.98	.6	0	2.3	Tr.	43.7	98.4
9/3/60	.63	-	-	-	-	31.0	110.0
8/25/61	.64	-	-	-	-	28.6	89.2
7/13-14/62	2.59	-	-	-	-	39.0	401.3

Research efforts have covered a wide variety of soil conditions and vegetal types. Results indicate that in the Intermountain West, a minimum of 60-70 percent groundcover is needed to effectively control surface runoff of water and erosion occasioned by torrential summer rainstorms. The same studies have also indicated that when groundcover has been reduced below these amounts, overland flow and soil losses increased at an extremely rapid rate. The relationship of groundcover to surface runoff and eroded soil for different soil-vegetation complexes is shown in figure 2.

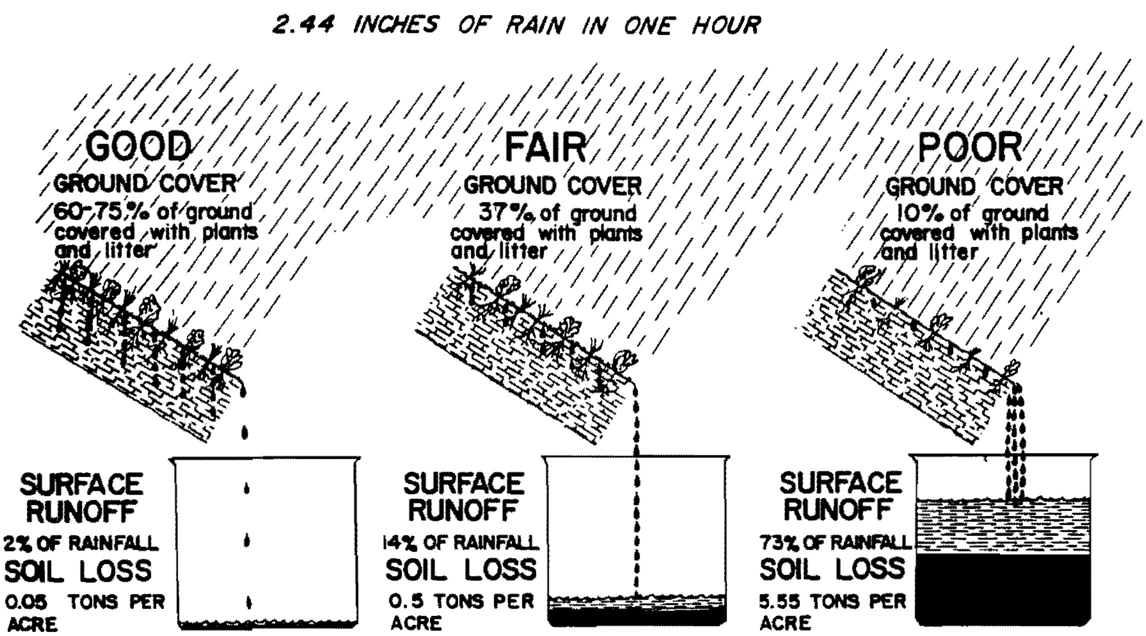


Figure 2.--A. The effect of watershed condition on rainstorm runoff and erosion, Subalpine Range Ephraim Watershed, Utah.

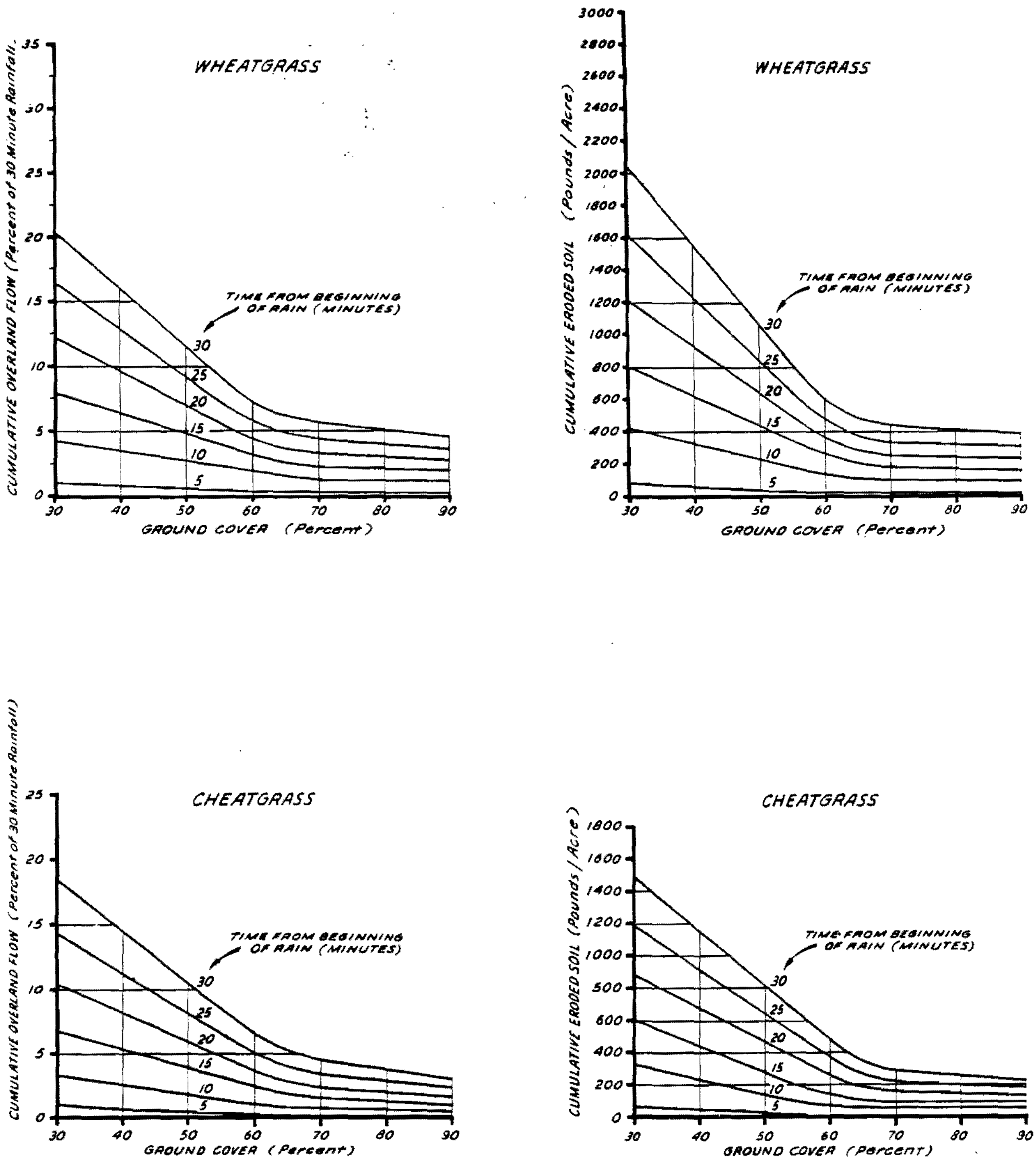


Figure 2.--B. Cumulative overland flow and soil erosion from wheatgrass and cheatgrass sites on soil derived from granite at different groundcover densities by successive five-minute periods. Based on a simulated rainfall of 1.87 inches for 30 minutes. (12)

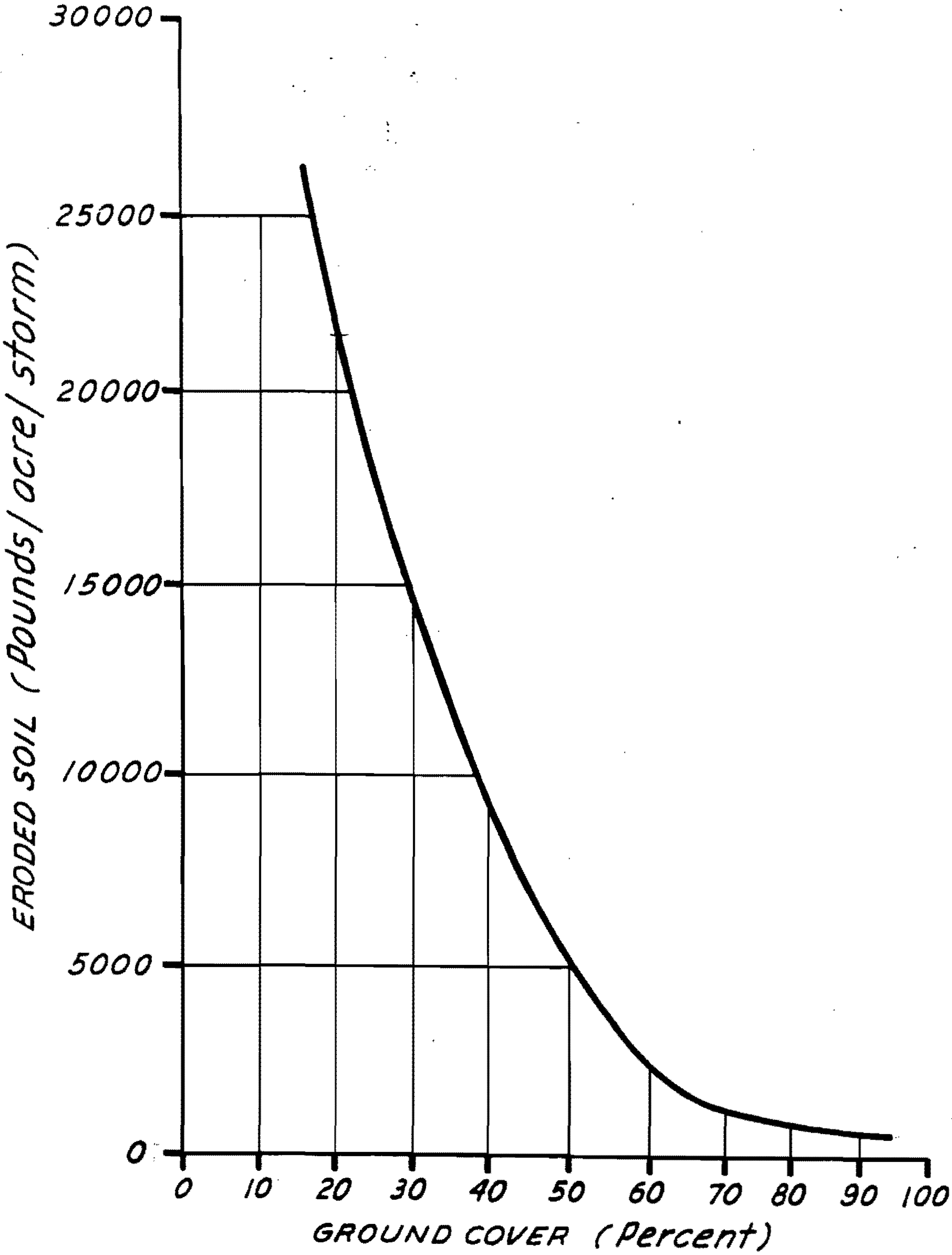


Figure 2.--C. Relation of eroded soil to groundcover density on experimental watershed A, subalpine - herbaceous range, Utah. Based on a simulated rainfall of 1.5 inches per hour for 20 minutes. (10)

DETERMINING TYPE OF WATERSHED REHABILITATION

Following an analysis of a flood-source area to determine the type of erosion, type of flooding, and groundcover condition, it is then possible to plan the watershed treatment required. In most cases the immediate objective is to restore the watershed site to a condition where precipitation is received and disposed of without the occurrence of oversurface flows of water. Based on several factors, watershed rehabilitation efforts fall into the following general categories:

1. Where sufficient native plants are available to furnish a seed supply, adequately fertile soil is present, groundcover density exceeds 40 percent, and a definite erosion pattern of rills and gullies is not evident, restoration of the hydrologic balance can be obtained by means of natural revegetation. This process may be slow and in most instances, very conservative management practices such as rest-rotation grazing and light use by livestock are required.

2. Where natural revegetation cannot be expected because of lack of seed, where soil is productive, and slopes do not exceed 30 percent gradient, artificial revegetation using approved range seeding methods is necessary to secure needed plant cover. This method of rehabilitation requires careful selection of plant species, intensive farming methods, and complete protection from use following treatment until the vegetation is well established. Often it is desirable to supplement this treatment with the installation of a series of contour furrows to prevent surface runoff.

3. Where both plants and soil fertility have been destroyed, so completely that a protective cover cannot be established by 1 or 2 above, the soil must be stabilized and surface runoff controlled by mechanical devices until the plant cover can be restored. To achieve this a system of contour trenches and gully plugs is constructed and areas of soil disturbed by construction activities are seeded to grasses or planted to trees or shrubs.

Contour Trenching

The principle of contour trenching as a soil conservation measure is very old, but the use of trenches to secure soil stabilization on high mountain watersheds and to prevent floods is relatively new.

In 1933 the Intermountain Forest and Range Experiment Station, U.S. Forest Service, was given the responsibility of devising the most efficient and effective methods for the control of floods and erosion originating on forest and range lands (2). Development of the trenching system to get water into the ground where it falls, thus preventing surface runoff, erosion, and sedimentation has proved most effective. In addition, the application creates favorable moisture conditions in the soil which hasten the restoration of plant cover needed to further stabilize the soil.

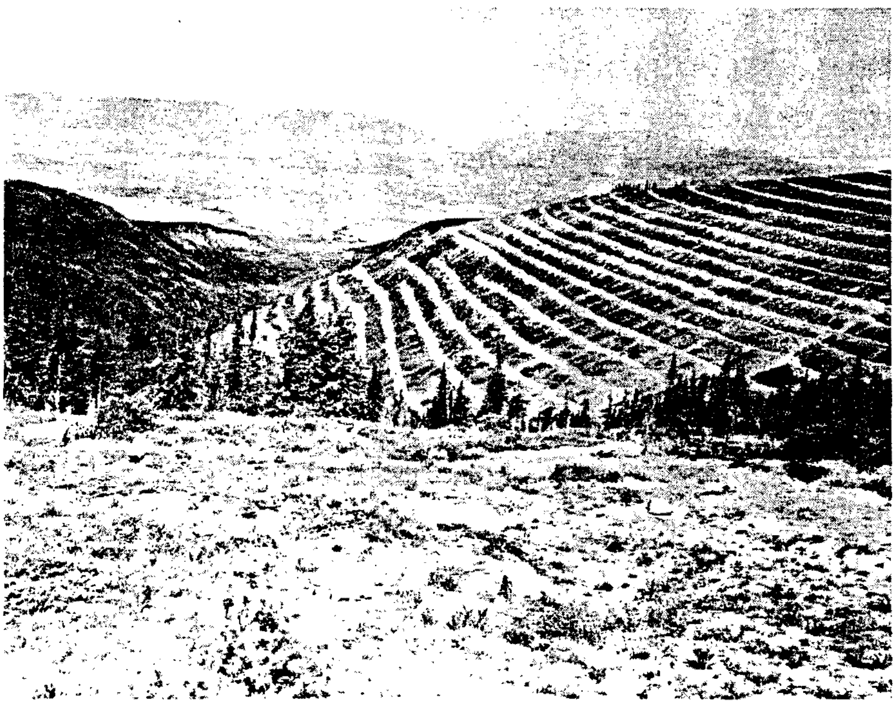
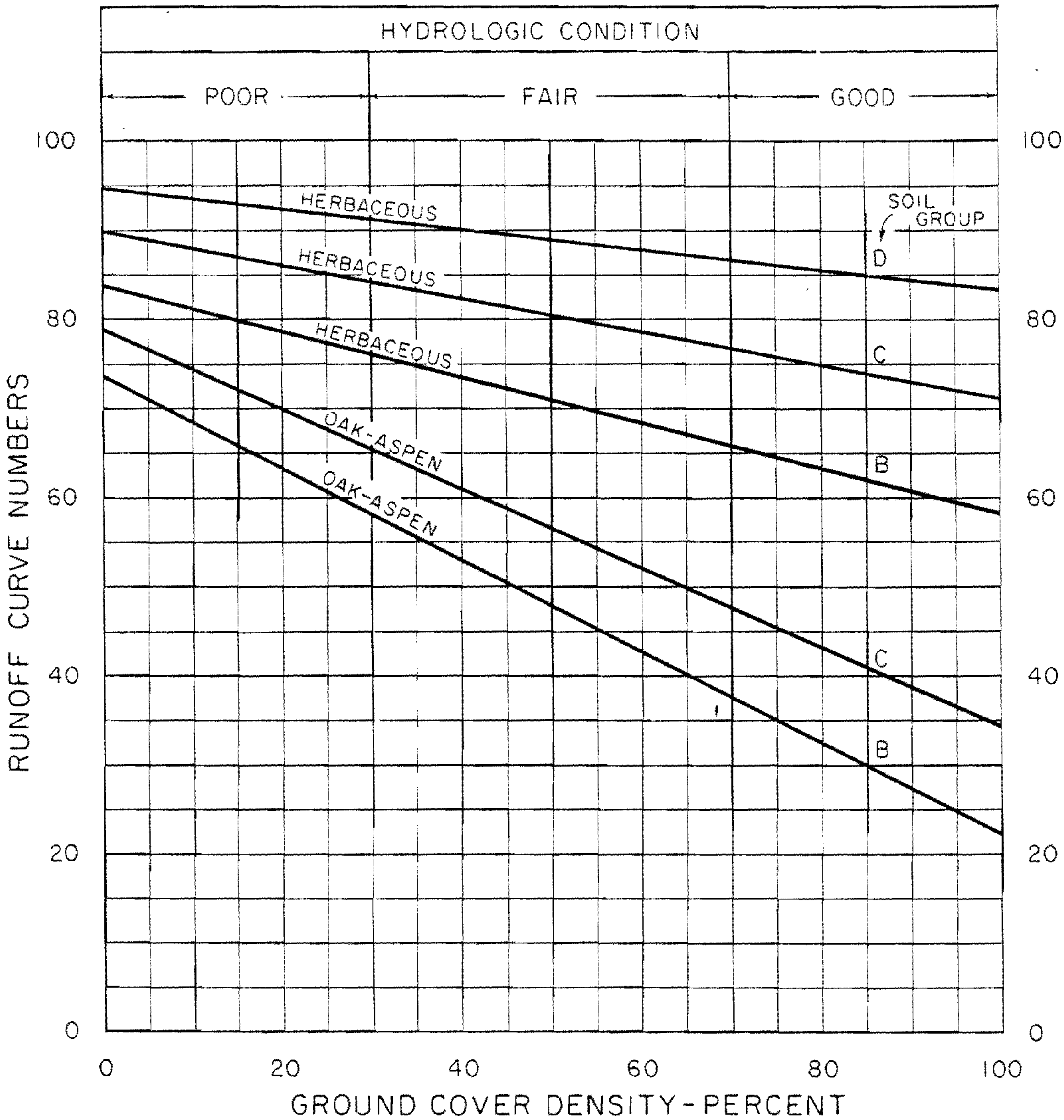


Figure 3.--Contour trench system installed on a deteriorated watershed for flood prevention and watershed protection purposes. Slope gradients vary from 30-70 percent. Evaluations made subsequent to construction indicate the trenching system has materially reduced downstream sedimentation.

The principle of contour trenching has proved so sound and effective that several thousand acres of badly eroded flood-source areas in the Intermountain West have been treated and many more thousands of acres are scheduled for treatment. Since its inception nearly 30 years ago, the criteria guiding application of the contour trenching system and the construction and design techniques have been greatly improved upon. Some of these criteria are discussed here.

Contour trenching is a precision-type job which requires a combination of close analysis of potential surface runoff, recognition of site adaptability, and careful construction. Failure to recognize or give full consideration to any one of these three items can cause failure of the work. Careful consideration of them can provide complete control of surface runoff and erosion from treated areas occasioned by high intensity summer rainstorms.

The contour trench system consists of a series of zero-grade insloping-type trenches spaced sufficiently close to hold a predetermined amount of surface runoff. Small check dams or baffles are constructed across the trenches at intervals of about 35 feet to segment them. These baffles are slightly lower than the fill-dike to allow water to flow along the trench without overtopping the trench. Runoff calculations are obtained by using runoff curves developed for different vegetation and soil types (figure 4).



HYDROLOGIC SOIL-COVER COMPLEXES AND ASSOCIATED CURVE NUMBERS FOR FOREST-RANGE IN WESTERN UNITED STATES FOR AVERAGE WATERSHED CONDITIONS

(MOISTURE CONDITION II & I_a=0.25)

Figure 4.--A. Based on soil group, vegetal type, and ground-cover density, curve number (figure 4--B) is selected for solution of the runoff equation.

HYDROLOGY: SOLUTION OF RUNOFF EQUATION

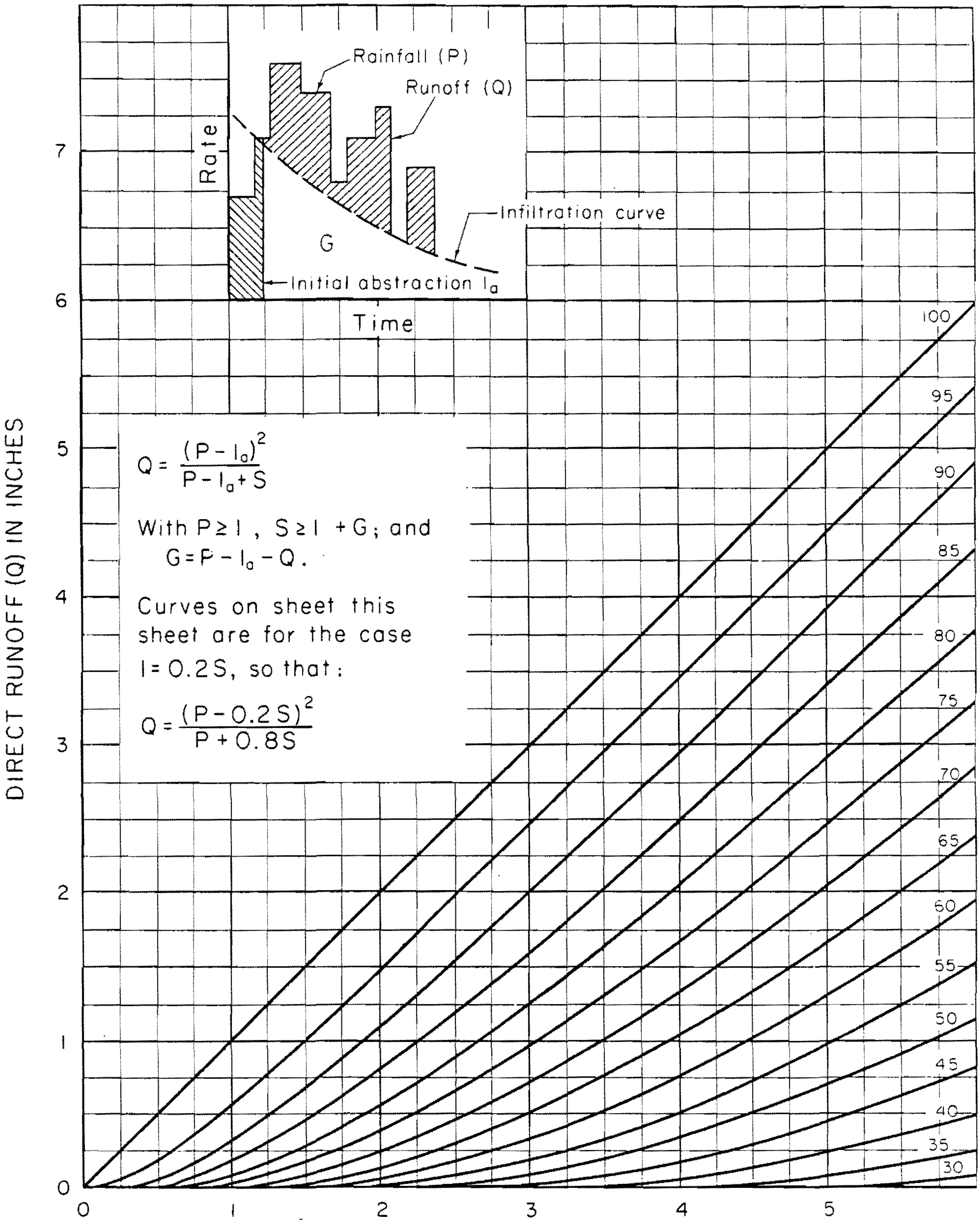


Figure 4.--B. Using runoff curve number selected from figure 4--A, surface runoff can be computed for various rainfall intensities. (13)

The following formula relating rainfall, trench spacing, and capacity aids in designing contour trench systems for various conditions:

$$\text{Rainfall X } \frac{\text{Estimated runoff (Percent)}}{100} \text{ X } \frac{\text{Trench interval}}{12} \text{ (ft.) =}$$

Trench capacity (cu. ft./lineal ft.)

Considerable care is needed in selecting sites which are adaptable to the contour trench system. Soil depth, mass stability of soils, rock outcroppings, and slope gradient all influence the decision of whether to trench or not.

Because the trenching system is a device to hold water until it can be disposed of by infiltration, a minimum of soil depth is necessary. Also, soil is necessary to provide a favorable seedbed for the establishment of vegetation on the soils disturbed by trench construction.

Normally, areas which have 24-30 inches of soil development above the unaltered parent material can be trenched successfully.

Mass stability of the soil is another factor determining the applicability of the trenching system. Areas with a history of mass soil movement or slumping should be avoided. Likewise, sites having a substratum of impervious clay soils should be avoided even though slumping is not obvious.

The pattern and disposition of rock outcroppings within the headwaters of a drainage also exert an influence on the decision to trench. Since each trench of the system is in itself a reservoir, the trench pattern should be continuous across the slope and extend to the upper limits of the flood-source area. If rock outcroppings at the head of a drainage are contributing to oversurface flows of water and such outcroppings preclude trench construction, there is a possibility that runoff from the upper slope will exceed the capacity of the trench, causing the trench to fail. A similar situation can occur when working across the slope and rock outcroppings prohibit a continuous run of the trench.

Many areas containing rock outcroppings have been successfully trenched. The main point to remember is that each trench must be capable of storing and disposing of the water deposited into it from the land above. Under no circumstance should water from an upper trench be diverted into a lower trench nor should water from a trench be diverted to a natural channel.

Once it has been determined that a site is adaptable for the contour trench system, construction can begin. Stages of the construction process are shown in figure 5.

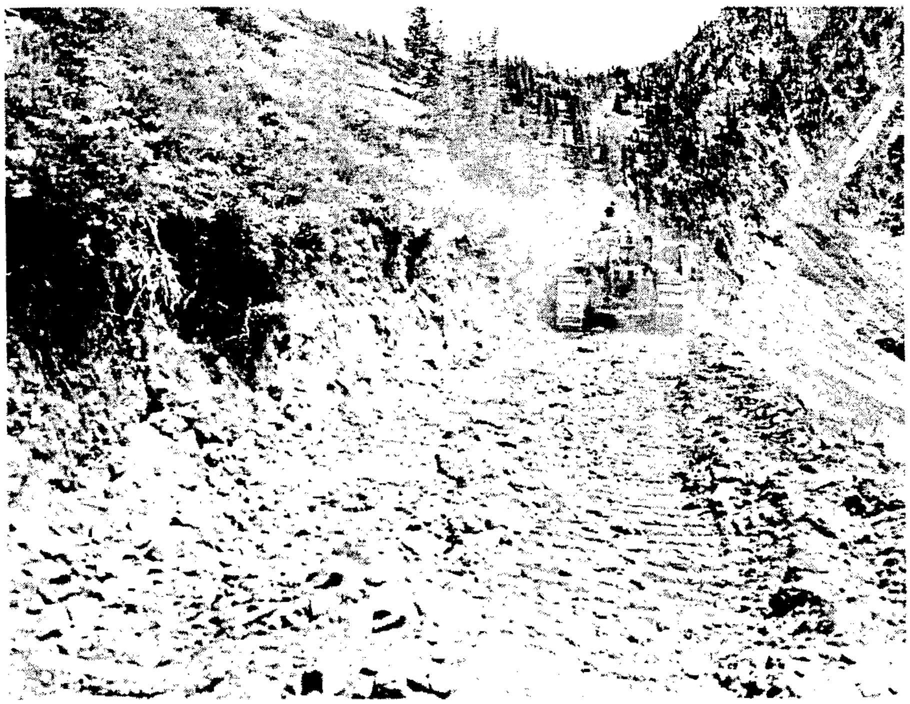


Figure 5.--A. On steep terrain, the first step of contour trench construction is building a level work platform on which the tractor operates. The platform need be no wider than necessary to safely accommodate the equipment.

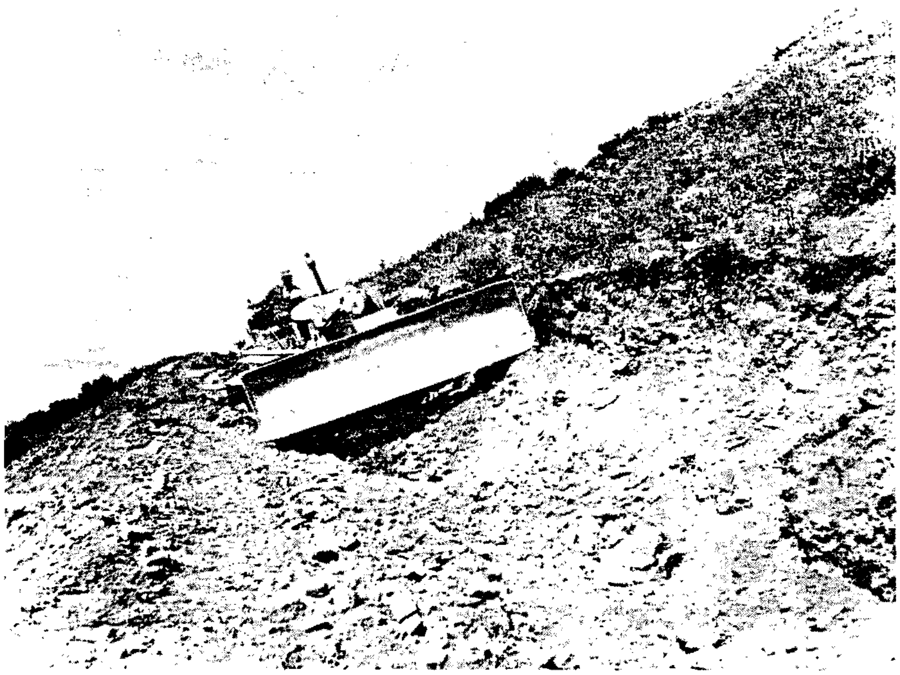


Figure 5.--B. After the platform is constructed, the upper two feet of the steep vertical cutbank are knocked down to aid in backsloping.

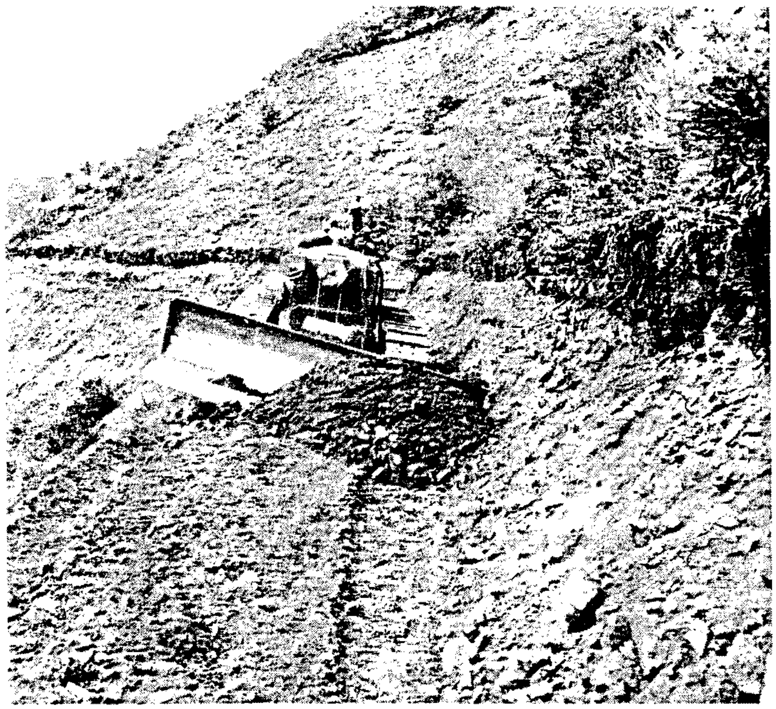


Figure 5.--C. The trench is constructed along the platform by a cut and fill operation. Using full angle and tilt of the blade, excavated dirt spills under the outer track of the machine where it is packed to form the outer dike of the trench.

Figure 5.--D. Trench on 70 percent slope completed to standard except for cross-dams or baffles which are constructed as the tractor backs out.

Figure 5.--E. Completed trench after construction of cross-dams or baffles. Trench has a storage capacity of 7-10 cubic feet per lineal foot of trench. Cross-dams are lower than trench-dike to allow equalization of stored water in trench and to prevent spill over the trench.

The construction process, although not complex, requires an understanding of certain facts involving a knowledge of several skills and disciplines. Failure to apply these skills and disciplines to the specific characteristics of the site to be treated can result in an unsatisfactory job. On the other hand, skillful application can result in a satisfactory job which will provide permanent flood control measures. Some of the more important facets of the construction job are enumerated below:

1. Contour trenching is a precision job and each trench must be on a zero grade. Accordingly, each trench must be laid out on the contour using a hand level and common builder's lath for stakes. Stakes must be placed frequently enough that they can be easily followed by the tractor operation and to keep the machine on level grade across undulating terrain. Each high and low point need be staked to avoid undulations in the trench.

2. The horizontal spacing interval as determined from the formula should be fairly constant. To prevent trenches from converging because of increasing slope gradients, staking should commence on the steepest slope to be treated. If slope gradient lessens and the trench interval increases beyond 30 percent, short trenches will be needed to fill in the gap.

3. Powerful crawler-type tractors with full-angle and tilt dozer blades are essential to successful contour trench construction. If the work is in rocky terrain or in tight soils, a rear-mounted hydraulic ripper is recommended. Because most work is done at high elevations where equipment efficiency is less, tractors with over 140 drawbar horsepower are advisable. Experience gained from high elevation work indicates a lower unit cost per lineal foot of trench when larger size equipment is used.

4. Well trained and competent equipment operators and job supervisors are essential for a successful operation. Several days of training to new crews from personnel experienced in trenching work are advisable. Inexperience and improper job supervision can result in a situation worse than that originally existing.

5. Live water courses and seep areas should be avoided. Contour trenches are designed primarily for collecting and disposing of oversurface flows of water from rainstorms. They will not function properly if continually saturated from live water sources.

6. All areas of soil disturbance caused by construction activities need be revegetated with adaptable plant species. The continued effectiveness of the trenching system depends upon stabilizing the cut and fill slopes caused by construction as well as the establishment of adequate groundcover between the trenches. In most instances, natural revegetation occurs rapidly between trenches since soil movement has been arrested and soil moisture conditions improved.

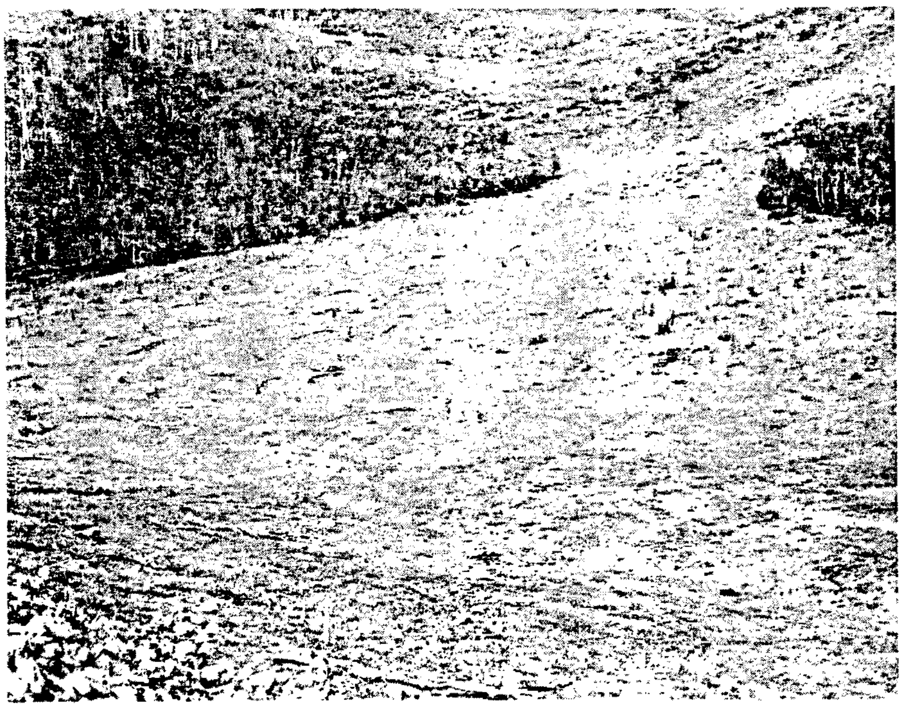


Figure 6.--A. 1957. Severely depleted watershed in Upper Dry Creek. Groundcover density less than 40 percent.

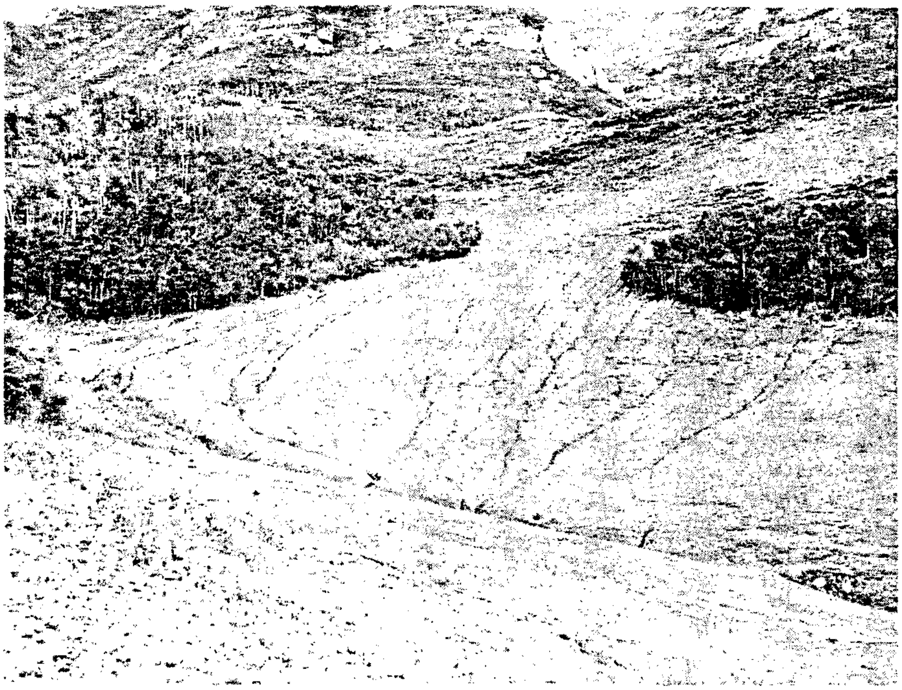


Figure 6.--B. 1958. Dry Creek area after a high intensity summer rainstorm. Oversurface flow of water established gully pattern, concentrated runoff, and contributed to downstream flood and sedimentation.

Figure 6.--C. System of contour trenches constructed on Dry Creek flood-source area in fall of 1958. Trenches break up gully pattern.

Figure 6.--D. 1961. Dry Creek area three years after installation of contour trench system. Seeded grasses well established on soils disturbed by construction activities. Improved soil moisture conditions between trenches have contributed to re-establishment of native vegetation.

Effectiveness of the Contour Trenching System

A few quantitative and many qualitative evaluations have been made to determine the effectiveness of contour trenching to control flooding. Perhaps the most exhaustive and best instrumented study was conducted in the Davis County Experimental Watershed where an intensive system of trenches was constructed in the early 1930's.

The nonflooding behavior of these rehabilitated watersheds has been evaluated (5) and is particularly significant when one considers that during two storms greater rainfall rates were attained than had ever been recorded in the State of Utah. During a rainfall of 1.14 inches on July 10, 1936, a rate of 5.04 inches per hour for a 5-minute period was registered. On the evening of August 19, 1945, when 1.09 inches of rain fell, rates at several of the recording gages exceeded 6.00 inches per hour for a 5-minute period, and at one a rate of 6.80 inches per hour was registered.

The storm on July 10, 1936, produced no floods from the treated watersheds, but the same rainfall caused mudrock floods in four drainages within the area that had not been treated. Rehabilitated watersheds again on August 19, 1945, when subjected to the unusually high rainfall rate of 6.00 inches per hour, disposed of the precipitation without erosion or runoff of flood proportions.

The findings of the Davis County evaluations have been further corroborated by numerous field investigations of comparable watersheds during and immediately following high intensity rainstorms. In all investigations, treated watersheds were compared with contiguous nontreated watersheds. Duration and intensity of precipitation in each watershed were judged to be comparable. In every case it was found that contour trenches significantly reduced surface water runoff into stream channels, reduced peak discharge of streams, and effectively reduced soil erosion and resultant downstream sedimentation.

SUMMARY

Several methods of securing soil stabilization on high mountain watersheds are available to the land administrator. These are (1) intensive management practices, (2) revegetation coupled with intensive management practice, and (3) contour trenching. Each method recognizes the fundamental relationship existing between land cover and hydrologic behavior and reflects the importance of maintaining the productivity of the site for the production of forage, fiber, wildlife, and recreation.

The application of each method requires a careful analysis of the (1) geologic norm, (2) type of flooding, (3) watershed protection requirements, and (4) adaptability of the site for treatment.

Of the methods described, contour trenching has proved most effective in controlling flooding, and sedimentation occurring from badly deteriorated mountain watersheds. The application of this method is not a panacea for all flood-source areas but has proved effective in controlling flooding from badly deteriorated lands occasioned by high intensity summer rainstorms.

LITERATURE CITED

(1) Bailey, R. W.
1941. Land erosion--normal and accelerated--in the semiarid West. Amer. Geophys. Union Trans. Part II: 240-250, illus.

(2) ________
1950. Watershed management: key to resource conservation. Paper presented before 15th North American Wildlife Conference.

(3) ________, and Copeland, O. L., Jr.
1960. Low flow discharges and plant cover relations on two mountain watersheds in Utah. I.A.S.H. Com. of Surface Waters, Pub. No. 51, pp. 267-278.

(4) ________, ________
1961. Vegetation and engineering structures in flood and erosion control. Paper presented before the 15th Congress of International Union of Forest Research Organization, Vienna, Austria, September 10-17, 1961.

(5) ________, and Croft, A. R.
1937. Contour trenches control floods and erosion on range lands. Emergency Cons. Work Forestry Pub. No. 4, 22 pp., illus.

(6) ________, Forsling, C. L., and Becraft, R. J.
1934. Floods and accelerated erosion in northern Utah. U.S. Dept. of Agr. Misc. Pub. No. 196, 22 pp., illus.

(7) Croft, A. R., and Goodwin, V. O.
1956. Some flood characteristics of Sierra Nevada east front watersheds. Proceedings, Tenth Nevada Water Conference, October 18-19, 1956. pp. 12-17.

(8) Lowdermilk, W. C.
1953. Conquest of the land through 7,000 years. U.S. Dept. of Agr. Info. Bul. No. 99, 33 pp., illus.

(9) Packer, P. E.
1951. An approach to watershed protection criteria. Jour. Forestry 49: 639-644, illus.

(10) United States Department of Agriculture
1950. Forest Service annual report. Intermountain Forest and Range Expt. Sta.

(11) ______
1958. Contour trenches and pits. Intermountain Region Watershed Management Training Cir. No. 2, 7 pp.

(12) ______
1960. Forest Service annual report. Intermountain Forest and Range Expt. Sta. 51 pp., illus.

(13) ______
Engineering handbook, section 4, hydrology. Soil Conservation Service, illus.