*Forest and Range Management in Flood and Sediment Control**

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THERE IS a growing consciousness of flood and sedimentation hazards. The criticality of sedimentation is being emphasized by the silting of reservoirs and canals, a threat to the projected billion dollar irrigation program in the arid West. At the sedimentation conference in Denver in 1947 it was recognized that sedimentation constituted the greatest threat to the permanence of control structures in rivers.

Never before has the importance of forest, range, and farm management been recognized more in the control of floods and sedimentation than it is today. There are, however, too many trained men, some in high places, who are still unwilling to consider the proper use of land an important factor in flood and sediment control. There are those who fail to appreciate the part man has played in creating our flood and sedimentation problem.

The idea that there have always been floods and therefore that floods are normal indicates a misconception of the part that land management plays in the production and control of floods and sedimentation. It has been observed that in certain places in the West erosion and sedimentation are usually high and, therefore, the conclusion has been drawn that all erosion and sedimentation are normal.

On the other hand, the case for land management has sometimes been over-stated. Friends and advocates of conservation, although not actually over-

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emphasizing the gravity of soil erosion and floods, often give man too much credit for the erosion that is going on and for too many of the floods that are occurring. They sometimes have been overoptimistic regarding man's ability to control erosion and abate sedimentation and prevent floods. Control of sedimentation and floods is too important and too critical at this stage of our civilization to permit prejudice and misunderstanding to stand in the way of any program the validity of which has been proved by research and experience.

These extreme points of view are illustrative of some of the confusion that prevails in the minds of many people regarding watersheds and watershed management. This confusion seems to stem from an incomplete understanding of the critical factors involved in the processes of soil stability, sedimentation, and stream flow. Although climate, topography, soil, and cover are generally recognized as being involved in these processes, the relative importance and inter-relationship of these elements of the landscape are often ignored or misinterpreted. Much of this confusion can be dispelled by a better understanding of what watersheds are, how they function hydrologically, the extent to which man is capable of speeding up erosion and runoff in excess of normal, and the limits of his capacity to control these phenomena through treatment of the land.

Watershed Mantle and Sediment Potential

Each watershed has definite characteristics of stream flow and yields of sediment. These characteristics are the result not only of the present climate but also of past climates. They are the result of features of the landscape, including topography, soil, and plant cover, all of which have been inherited from the past. Of these inherited watershed features, the soil mantle and plant cover are of major importance because they exert a dominant influence on stream flow regimen and sediment loads, and because they are the two components of the land which are used by man and can be greatly altered by that use.

The soil mantle on watersheds is known to be a product of rock weathering and biotic activity. Disintegration and decomposition of rock of the earth's crust into soil-sized particles is a very slow process. The succession of plant and animal communities, and the incorporation of organic matter in the soil also is a long process. A soil mantle with its humic horizons is truly a product of the ages.

The soil mantle in some places is formed *in situ* from the underlying rock; in others, from materials that have been transported by gravity, wind, glaciers, and water. Regardless of the mode of origin, the presence of soil on a site today means that the processes of soil development and accumulation have proceeded at a rate greater than the rate of soil removal.

Soil and rock waste that has accumulated on mountain slopes under the formative and protective influence of vegetation constitutes a high sedimentation hazard. On a given slope, the more water from precipitation that infiltrates into the soil mantle, the deeper the soil due to an increase in rock weathering, the denser the vegetative cover, and the finer and richer the soil. With this development there arises a high erosion potential and consequently a greater and greater source of potential sedimentation. The sediment potential on these soil-covered slopes is much higher than on slopes where soil has not developed.

That the plant cover is the key to the development and maintenance of a soil mantle in the face of the forces of removal and that high sediment potentials accompany soil formation can best be appreciated by consideration of stable soils on steep slopes.

Numerous examples of stable soil on slopes greatly in excess of the angle of repose for loose, nonvegetated soil materials, occur in many mountainous areas. Soil mantles well clothed with vegetation and litter have been observed in Utah and Idaho on slopes as steep as 173 per cent whereas the maximum steepness of adjacent, bare talus slopes was generally less than 70 per cent. These over-steep slopes have developed and exist today in spite of the extremes and vicissitudes of climate to which they have been subjected throughout the long period of their formation. The only way the soil mantle could have been formed and retained on these over-steep slopes or held in place today against the force of gravity, the impact of rain, the loosening effect of alternate freezing and thawing and the erosive action of wind and surface run-off was through inter-dependent development of the plant cover. This plant cover contributed to the body of the soil. It aided the infiltration of water and bound the soil in place.

Any land surface having a soil and plant cover, regardless of its degree of slope, is a product of all of the elements of the weather and of other natural influences such as fire, rodents, and game which have operated through the period of slope formation. Such slopes, by reason of protection afforded by the vegetation, have existed in spite of the cyclic changes of the climate as well as extreme variation within these cycles. All soil-covered slopes, in other words, exist because of an adjustment between aggradational and degradational forces in which the plant cover is the key to stability. With the reduction or destruction of the vegetal cover the balance is broken, and soil removal takes *place, charging streams with sediment. This occurs because the site hydrologic conditions prevailing during soil formation have been radically changed —precipitation which formerly percolated into the mantle is made to flow* over the surface of the soil with power to erode and transport soil.

Hydrologic Functions of the Soil and Plant Mantle

The degree of soil stability on watershed slopes is largely dependent upon the manner in which precipitation is disposed of by the plant and soil mantle. This hydrologic function also has an important bearing on the nature and usefulness of run-off.

Watersheds may yield run-off either as seepage flow or as overland flow, or both. The former is water that reaches channels after infiltrating into, and percolating through, the soil mantle. Overland flow, as the name implies, is run-off that reaches channels by moving over the surface of the land.

Seepage flow can take place from a watershed only after the soil mantle is saturated to its field capacity. Mountain soils are known to hold from 2 to 3 inches of water per foot of depth against the force of gravity. Thus, a mantle 4 feet deep must receive from 8 to 12 inches of water before it will yield any seepage run-off. This retention-storage function of the mantle prevents run-off to the extent of the storage opportunity. Even when the mantle is at field capacity, the movement of additional precipitation as free water through the soil, to lower levels and on out to channels proceeds slowly as compared to the movement of overland flow. This detention-storage function is so effective in many watersheds that streams continue to flow for a year or even longer after having been charged with water. Because seepage flow run-off is delayed in delivery to channels and is generally free of sediments, it is the most useful water yielded by watersheds.

Overland flow is generally destructive run-off. It can occur whether the mantle is wet or dry, and starts whenever rain falls or snow melts at a rate that is faster than the water can get into the ground. Because it flows over the land surface, it is capable of eroding the soil and of gathering quickly into channels to produce discharges of great violence. Peak flow discharges of this

type of run-off are known to exceed those from seepage flow by as much as 100 times.

Whether run-off occurs as seepage flow or overland flow hinges primarily *on the infiltration capacity of each watershed site. We have learned from many tests that there is much natural variation in the capacity of sites to infiltrate water due in part to the structure and porosity of soils, but more particularly to* the kind and amount of plant and litter cover. We have also learned that the infiltration capacity of a site can be materially decreased by reducing the density of the plant and litter cover on the surface of the ground and by trampling and packing the soil. It is not unusual, for example, for sites with an undisturbed soil and a natural cover of plants and litter to absorb rainfall at rates in excess of 6.00 inches per hour, and for the same sites to absorb water at only 2.00 inches per hour or less after the plant and litter cover has been removed or drastically reduced by fire, land clearing, overgrazing, and other improper land-use practices. Such reductions of the plant cover can also change the rates of soil loss from nil or negligible amounts to many tons per acre per storm. Thus, erosion of soil is accelerated, because precipitation which formerly entered the soil becomes overland flow.

Geologic Norms and Potentials for Erosion and Floods

When man entered a drainage basin to build his home or to exploit its resources, he found streams with definite characteristics of discharge, quality, and sediment load. These hydrologic end-products represent the sum of the effects of several factors or components of the watershed including its climate, relief, rock formation and structures, soils, and plant cover. Due to natural differences in one or more of these components, there is great variability in normal hydrologic behavior not only between watersheds but also within some drainage basins. Differences in these factors which are responsible for normal variations in hydrologic behavior also create different potentials for the production of abnormal run-off and sediment loads when the natural vegetation or the soils are altered.

As man extended his activities, first locally, then regionally, he not only encountered major normal differences in run-off, but soon discovered also that treating all land in the same manner would not cope with the variable erosion and flood hazards. He found, in other words, that some streams were frequently in flood stage while others were not, and that some always carried much sediment while others ran clear. He is also discovering that treatment of the watershed resources in some cases has little effect on run-off and erosion whereas, in other cases, the same land treatments result in discharges and sediment loads greatly in excess of normal.

Floods are a normal event in parts of all climatic and physiographic regions. In the humid southern and eastern portions of the United States, for example, as well as in the Pacific Northwest, watersheds are frequently subjected to copious rains or to heavy snowfall and rains. In many parts of these regions, well vegetated plant cover and soil mantles are capable of infiltrating virtually all of the rain as it falls, and there is therefore but little overland flow. Frequently, however, more precipitation passes into the mantle than it can hold, and, when sufficiently available, large volumes of water drain from the soil into channels to create great flood discharges.

The possibility of increasing the frequency and severity of floods is high in humid regions, whether precipitation occurs as rain or snow. The normal storage capacity of the mantle on these lands can be reduced by destroying or diminishing the litter and other organic matter in the soil. Water storage capacity can also be decreased through the removal of the soil by erosion. Each increment of water storage loss increases the amount of run-off. As storage capacity is lost, smaller storms are capable of producing flood discharges, and large storms will produce bigger floods.

The potential for increased sediment loads is also great in the humid regions, particularly where precipitation occurs as rain. The exposure of normally stable soils to the direct impact of these rains, through the removal or thinning of the plant and litter cover by fire, cultivation, or other disturbances, greatly speeds up erosion rates. Moreover, the proportion of the run-off that occurs as overland flow is increased. This increases the volume and velocity of stream flow and its power to scour materials from the channels.

Floods are also a normal event in so-called arid regions. Much of the western United States, for example, is subject to torrential summer storms. Though these are generally of short duration and sometimes of limited extent, the rain falls in large drops with great impact, and at very high rates. This type of rainfall is a powerful eroding agent, particularly on areas where the soil surface is exposed.

In those parts of the West where the plant cover is sparse or non-existent and the soils are shallow or absent, violent, debris-laden floods are a normal occurrence during torrential rains. Typical of such areas where the geologic norm of erosion, flood frequency, and sediment loads is high, are Bryce Canyon in southern Utah and the Badlands of the Dakotas.

On the other hand, there are extensive areas in the West, particularly the high mountains and plateaus, on which a plant cover and soil mantle have developed, capable of absorbing virtually all torrential rainfall. The normal incidence of flooding on these areas is low, and the geologic normal rate of erosion on watershed slopes is very slow, in many places the losses of soil being imperceptible. The consequences of disturbing the plant cover and soil mantle on these watersheds may be spectacular. Such induced changes, even when confined to a small portion of a watershed, can result in discharges 100 or more times the normal and in a tremendous acceleration of erosion and sedimentation.

Thus, through differences in climate, topography, soil, and plant cover, the watersheds we have inherited from the geologic past exhibit great natural variations in erosion and flood behavior. In some places the plant cover and soil mantle have not developed sufficiently to exert much influence on hydrologic behavior. In such places the geologic normal rate of erosion, sedimentation, and flooding is high. On more extensive areas of watershed lands, on the other hand, a plant cover and soil mantle have developed that exert a high degree of control on the reception and disposition of precipitation, resulting in relatively low normal rates of erosion, in normally moderate stream discharges, and in normally small sediment loads. These geologic norms, whatever they are, are susceptible to great change by depletion of the plant cover and soil disturbance.

Columbia River Flood of 1948

Consideration of the precipitation, watershed conditions, and history of flooding brings into focus causes and suggests remedies. Natural limitations of control of sediment and floods through forest and range management are determined by the geologic norm.

Meteorology.—The major cause of the flood was no doubt the occurrence of a combination of extraordinary meteorological conditions operating over most of the basin. Prolonged heavy fall rains, abnormal snow accumulation, late spring rains and snow, and a delayed snow melt followed by unseasonably high temperatures sent high water streaming from all snow-covered elevations and from practically all parts of the basin in such a manner as to effect unusual synchronization of run-off.

This weather combination overshadowed or by comparison made the influence of forest conditions small on the Columbia River flood. The condition of the forest lands, however, did affect importantly the magnitude of the headwater floods and the damages they did locally. It made differences in the amount of erosion, particularly channel cutting, produced by run-off from various tributary watersheds.

Hydrology.—Water came from all elevations and from all parts of the basin except the Willamette and upper Snake rivers.

Physiographic factors.—The combination of steep gradient mountain tributaries and low gradient main streams (Kootenai, Clarks Fork, Blackfoot, and others) gave the effect of pouring mountain torrents into a lake.

Effect of forest cover.—The soil was kept in place, with practically no slope erosion, irrespective of forest condition. Run-off from slopes occurred as seepage flow. There was almost complete infiltration.

Alpine zone.—This high area normally receives more snow and retains it long after the spring floods have passed. In the spring of 1948 the melting temperatures extended well up into these areas in all parts of the basin. The resulting snow melt added to the volume of discharge.

Retention of snow in timbered areas is a striking feature. June 14, fifteen days after the flood peak, snow was observed in forests, while adjacent burned areas were barren. Snow is estimated to occur 1000 feet lower in elevation in the timbered areas than in the denuded areas. On some ridges and thin-soil areas in the high alpine region, surface run-off did occur, causing soil erosion.

Fire damage had been very extensive in the sub-alpine zone. The retention of a snow cover in the timber of the sub-alpine area and its absence on the burns made it obvious that had the devastated areas been forest covered considerably more water would have been held back until after the flood peaks.

Effect of fire.—Flood waters came from both burned and unburned tributary watersheds. Channels of tributaries in both conditions were extensively eroded, indicating the large volume of run-off. However, burned tributaries yielded peak discharges up to ten days sooner than the unburned and produced peaks on the average of 50 per cent higher.

The average ratio of peak discharge over the discharge after the peak flow for well timbered areas was 4, while for burned areas it was 2.4. Burned tributaries also discharged more debris, producing more damage.

Fire destroys humus, litter, and duff. Experiments indicate that, on the average, 1 inch of humus material will hold ½ inch of water. Because of the extensive and frequent burns in the headwaters of the Columbia River, little humus is left on the forest floor.

A limited number of observations were made which, though not conclusive, are suggestive: In a second-growth forest burned 20 years ago, about 1 inch of humus had accumulated. In a second-growth forest burned 60 years ago, 3 inches of humus accumulated. By contrast, a virgin forest, one that had not been burned in historical times, had 20 inches of humus.

Watershed management.—In flood and sediment control in the Columbia River Basin watershed management can provide for: (1) tested information on influences—relationship of forests and water; (2) more adequate protection from fire; (3) significant data on the alpine areas in flood and sediment control; (4) logging operations that produce a minimum of soil disturbance and allow a continuous protective plant cover; (5) roads that are designed and maintained with a minimum of soil disturbance and surface run-off from storms; (6) grazing systems and practices that will maintain a vegetal cover sufficient to keep soil in place.

If the forest and range cover is kept in optimum condition, soils can be kept in place; thus sedimentation and, no doubt, flood peaks can be reduced and many of the minor floods that do considerable damage under present conditions may be completely controlled. However, preventing all fires and locking up the timber resources will not prevent floods of the kind experienced in the spring of 1948.

Wasatch Front Floods

THERE ARE A NUMBER of contrasting features between Wasatch Mountain and Columbia River Basin floods. In the Wasatch Front there are torrential summer storms of high intensity and short duration, characterized by surface run-off floods and mud-rock flows.

Six of seven watersheds ranging in size from about 1200 to 6000 acres in the Farmington-Centerville portion of Davis County, Utah, have produced such floods. Here, in 1923 and again in 1930, mud-rock flows issued from the short, steep canyons and deposited boulders, weighing as much as 200 tons, and debris on valuable community property at the base of the mountains.

This area offered unusual opportunities for the study of the history of flooding and for measuring the effects of watershed management and the lack of management on run-off, erosion, and sedimentation. The fact that the ancient Lake Bonneville left deltas, terraces, and other deposits at the mouths of the canyons made it possible to differentiate between pre-Bonneville, Bonneville, and post-Bonneville deposition.

Geological observations revealed that the recent floods in several canyons of this area cut to extraordinary new depths into previously undisturbed sands and gravels of the deltas and terraces of ancient Lake Bonneville. They also deposited quantities of debris and sediment on the former bottom of the old lake far in excess of the previous normal rate of deposition, thus indicating these new floods to be unprecedented in modern times.

By following the freshly scoured channels, the sources of these floods were found to be areas of from a few acres to less than one acre in extent in the headwaters at elevations of from 7500 to 9000 feet, and on which the plant and litter mantle had been drastically reduced by very heavy overgrazing and to some extent by fire. That these areas were the source of the flood run-off was evidenced by an efficient system of gullies freshly cut in the soil mantle. In the aggregate these deteriorated and gullied flood-source areas covered less than 10 per cent of the mountainous catchment areas.

Surrounding and intermingled with these flood sources were well-vegetated areas on which there was no evidence of surface run-off or of soil loss. Here the litter was undisturbed and there were no rill marks or freshly incised gullies. Examination of the soil mantle immediately following flood-producing storms revealed that these areas received as much rainfall as the gullied, flood-producing areas, but were able to absorb and hold it. Moisture penetrated to depths of 6 to 10 inches on the non-flood sources, whereas on the deteriorated areas, penetration of moisture was generally less than 2 inches.

This same relationship between vegetation and erosive run-off has been demonstrated many times by measurements on plots representative of the flood- and nonflood-source areas on these watersheds since 1934. During several of the heaviest rains experienced in this area, for example, the denuded areas yielded from 24 to 43 per cent of the rainfall as surface run-off, whereas run-off on the nonflood-source areas has been less than 1 per cent. The flood-source areas have lost the equivalent of from 83 to 181 cubic feet of soil per acre during individual storms, whereas on the nonflood-source areas there has been no measurable amount of soil lost.

The measured run-off and erosion behavior described above is not peculiar to the watershed lands of Davis County. Comparable behavior has been measured by means of plots and small watersheds over wide areas and conditions. For example, 97 different sites representing a cross section of grass, sagebrush, and mountain brush ranges from central to southern Utah were measured. These show that on areas where the plant and litter cover was approximately normal for the site, usually less than 5 per cent of the first 1.5 inches of rainfall ran off. On the other hand, run-off increased sharply with successively decreased amounts of plant cover with areas of virtually denuded soil yielding up to 75 per cent or more of the applied rainfall as run-off.

One of the most serious aspects of the erosion and sedimentation problem on western range lands is that once plant cover depletion progresses to the stage where the soil mantle becomes broken, less and less rainfall is required to produce destructive run-off. The situation in Ford Canyon in Davis County, Utah, illustrates this point.

This canyon had produced violent floods as a result of headwater denudation. The run-off producing these floods eroded a system of gullies in the steep slopes. With the watershed in this condition a storm of only 0.47 inch occurred on July 4, 1934, which produced storm flow sufficient to carry boulders 9 feet in diameter out of the canyon. There was run-off only from the areas on which the soil mantle had previously been broken.

The often advanced assumption that debris floods in this region are always the product of exceptionally heavy rainfall and a saturated mantle have no support in fact. On the contrary, destruction of plant cover, resulting in reduction of infiltration capacity and of detention-retention storage, can change a watershed slope from one capable of absorbing and retaining virtually all high-intensity summer rainfall to one that may yield, as storms flow, 75 per cent or more of the same rainfall.

Restoration by watershed management.—Recognizing these relationships, a watershed program was designed to reestablish the plant cover and to stabilize the soil on deteriorated portions of the flood-producing watersheds in the Davis County, Utah area. The two main features of this program were: (1) closure of the area to grazing and intensification of fire control to prevent further depletion of the plant cover; (2) construction of contour trenches and artificial reseeding on about 1300 acres of flood-source areas. Contour trenches were installed to break up the gully system, to store and force infiltration of precipitation where it fell and thus prevent surface run-off and erosion, and to create favorable conditions for revegetation. Artificial reseeding was done to hasten the recovery of the vegetative cover.

The watersheds have responded remarkably to the improvement measures. The depleted and eroded slopes are being rapidly reclothed with vegetation and gullies have largely disappeared.

The effectiveness of this rehabilitation program has been tested by numerous summer storms since work was begun in 1933, and in no case has surface run-off eroded the slopes, or have floods generated on the treated area. That the protective functions of these watersheds have been restored was especially demonstrated during two storms when 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 rainfall occurred, rates at several of the recording gages exceeded 6.00 inches per hour for a 5-minute period and at one a rate of 6.84 inches per hour was registered. Previous to these two storms the maximum rate of record was a 5-minute rate of 4.80 inches per hour, recorded at Salt Lake City in 1931.

The July 10, 1936, storm produced no floods from the treated watersheds. The same rainfall caused mud-rock floods in four drainages within the area which had not been treated. The treated watersheds on August 19, 1945, when subjected to the unusually high rainfall rate of 6.00 inches per hour, again were able to dispose of the precipitation without erosion or run-off of flood proportions.

Centerville Canyon, one of the experimental watersheds which has not been deteriorated and which has never produced a mud flow in recent times, received the same amount and intensity of rainfall as the adjacent fully treated Parrish Canyon. There was no evidence of surface run-off reaching the stream channels in either of these basins during the record-breaking rains on July 10, 1936, and August 19, 1945. The only storm flow from these basins was that which came from precipitation that fell in the stream channels.

In contrast, on the same evening of August 19, 1945, a mud-rock flood issued from a deteriorated watershed immediately adjacent to the treated experimental watersheds. Another flood—the first of its kind since the Pleistocene—issued from an overgrazed watershed at Ogden, 15 miles to the north. Another flood, heavily laden with debris, occurred at Salt Lake City, 15 miles to the south. This flood originated in a 600-acre burn on a 1000-acre foot-hill watershed and caused damage amounting to $346,000 in Salt Lake City.

The behavior of the improved watersheds during the period from 1936 to the present time marks a radical departure from their behavior when in deteriorated condition in 1923 and 1930. This change from one of violent flooding and very high debris-content to one of virtually regulated flow and low sediment load is in keeping with the basic principles of watershed management which have developed from wide experience and experimentation.

THE JOB AHEAD

THERE ARE MANY WATERSHED AREAS in the West which are in such deteriorated condition that they will require essentially similar and intensive treatment as the flood-producing areas in Davis County, Utah. However, the great bulk of the forest and range lands in need of rehabilitation in the West must and can be restored by less intensive and costly measures. On these areas the first great need is fire protection. Another which in some instances is more important is an adjustment in the degree and kind of use of the forage and timber resources. Use of these resources must be such as to allow for the natural re-establishment of a plant cover that will more adequately protect the soil. Supplemental artificial reseeding and planting will be required on some areas.

Another major job ahead is the maintenance of satisfactory watershed conditions on the vast area of forest and range lands in order that the tremendous volume of potentially destructive sediments on them is kept in place.

Watershed management will not stop the weathering and erosion of bare rock surfaces. There will always be large quantities of waste material added to certain streams from such areas. Moreover, considerable erosion and sediment yields must always be expected from areas on which aridity precludes the development or maintenance of a fully effective plant cover. There may also continue to be much sediment produced from areas on which accelerated erosion has advanced to such a stage that stabilization is practically impossible. However, on the great bulk of the forest and range lands, watershed management can make a big contribution to the solution of the sediment problem.