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SOME REFERENCES ON WATERSHED MANAGEMENT

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Several of you in the field administrative jobs have asked for a summary of available information from forest influences studies relating to watershed management practices. This paper hits some of the high spots, giving a brief survey of European and American studies and recommendations that may be applicable within our region. Further, it contains a few pertinent recommendations from recent local observations. We hope these notes will give you, the forest managers, some basic information for use in thinking about and discussing the subject, and some principles and methods to adapt to problems that may be present in your areas.

The paper is divided into six parts: First, the general field of forest influences which considers the effects of forest vegetation (trees, shrubs, herbs, and grass) on climate, soil, erosion, runoff, and stream flow. Second, the watershed management aspect, dealing with such things as logging systems, logging methods, use of fire, road location and construction. Third, the details of specific activities often necessary in watershed management, such as road drainage, road bank stabilization, gully control, and curative measures for eroding "sore spots." Fourth, local observations and some recommendations applicable to our conditions. Fifth, a tabulation of the water yields of some of our principal streams, to give a picture of the size of the water crop. Sixth, a list of references for those who want to dig a little deeper.

Some definitions may be in order. Forest influences, one phase of forest ecology, deals with the effect of natural vegetation on climate, water, and soil. Watershed management involves the application of the principles established from forest influences studies. It may have various objectives, such as maximum water production, or control of flood peaks and erosion, or harvest of timber without harm to water supplies, or use of forage without damaging the soil. Research in forest influences is directed toward solving the soil and water problems that develop from the use of forest and range resources; watershed management makes use of these findings in controlling operations on the land.

I. FOREST INFLUENCES

Effects of Forest on Climate

Consideration of forest influences goes back to Biblical times, but modern scientific research in the field began only a century ago. In the mountains of Switzerland, France, and Italy various studies have been made to show the way toward avalanche control and regulation of floods in mountain streams. A good deal of time was spent investigating and discussing the effect of forests on climate. From studies in France it was concluded that forests transpire moisture to the air above and cool it, leading to increased frequency and more regular distribution of rainfall. In Italy, various studies showed rainfall over forest areas to be from two to four percent greater than on deforested areas. Similar conclusions were reached in this country. Comparison of denuded and forested areas in the Tennessee Copper Basin showed that rainfall over the forest was ten percent greater than over the barren area, five percent greater than over grassland. Shantz says that "movements in the direction of desiccation may not indicate a lowering of rainfall, but may be brought about by the partial destruction of the plant cover, followed almost immediately by the loss of the soil mantle. These effects are confined largely to man's use of wild land and the result is always that of throwing the vegetation to a more desert type."

Regarding temperature, the Copper Basin study showed the denuded area to have lower average winter maxima and higher average summer maxima than the forest. Range in soil temperature was three times as great in bare areas as under the forest. A study in Germany showed that at night the forest soil was warmer than the air above it, which again was warmer than the air in the open; but that in daytime the forest soil was cooler than the air above it, which in turn was cooler than the air in the open.

Various workers in this country studying frost occurrence have discovered that frost pockets may develop after heavy cutting or fires in the forest, and persist for years. Areas of greatest frost hazard were found on flats and at the base of steep slopes. Generally, occurrence of frost in the soil is much more likely in the open than under forest cover. In Ohio, studies have shown that woodland cover protects the soil from freezing; and that more porous soils are less subject to freezing. Also, that freezing concentrates soil moisture at the surface; and that three inches of frost in the soil may greatly affect percolation of soil water. Concentration of soil moisture at the surface by freezing was also noted by a California observer.

Wind movement was found to be five to fifteen times greater in the open than in the forest. Similarly, evaporation was shown to be twice as great in the open as in the forest; in partially cut areas, less than in the open but more than in the untouched forest. Evaporation on south slopes was observed to be sixty percent greater than on north slopes. Increased humidity on north slopes was concluded to be as much due to cooling from radiation of ground heat as to freedom from sunlight. There are numerous other observations of interest that might be quoted, but they are not pertinent here.

Forests and Precipitation Losses

With regard to interception of precipitation by forest cover, an Italian observer stated that deciduous forest trees intercepted and re-evaporated about fifteen percent of the rainfall, coniferous trees probably more. One California study showed about twenty percent interception loss from rainfall on undisturbed woodland-chaparral cover, with three-fourths of the amount intercepted reaching the ground by stem ~~stream~~ flow. Another described loss in chaparral ranging from five to eleven percent, varying inversely with total precipitation. Studies in Colorado found that aspen and grass cover intercepted much less than lodgepole pine forest, and that interception was the most important source of moisture loss in the types considered. In the lodgepole forest, net rainfall was found to vary with intensity of cutting, heavily cut areas getting twenty-three percent more than uncut areas. Various investigators showed that forest--both broadleaf and conifer--intercepted on the average about one-fourth of the precipitation in storms of various sizes.

In an Eastern hardwood forest, removal of stream-bank vegetation (affecting about one-eighth of the total watershed area) showed gains up to one-fifth in summer stream flow. Cutting all the vegetation on a watershed and leaving the slash to shade and protect the soil increased the runoff nearly twenty inches, with most of the gain made in the fall period. These significant gains followed reduction of the transpiration draft on soil moisture. Studies in Utah showed that evapotranspiration losses equaled about one-third of the stream flow in late summer. Other observers have reported similar significant losses from stream-side trees and shrubs.

Part of such gains may be due also to reductions in evaporation loss. A California study in woodland chaparral showed that evaporation of intercepted precipitation amounted to five percent of total precipitation, about equaling the transpiration loss, with the total loss greater on undisturbed areas than on denuded areas. In the Copper Basin, total annual evaporation was found to be twenty percent greater in the bare area than in grassland, and two hundred percent greater than in the forest. An Italian observer concluded that forests transpired about one-fourth of the precipitation they got. From the Colorado lodgepole pine study, it was concluded that timber cutting significantly reduced forest water losses, including evaporation and transpiration.

Forests and Snow

Studies relating to snow melt are perhaps of greater interest to us here in the Northwest. Findings of the snow laboratories run by the Weather Bureau and the Army pointed out that while dense vegetation was associated with reduced snow cover, south slopes with dense cover had more snow than south slopes with little cover. An investigator in Germany attributed the bending of tree trunks on steep slopes to snow creep. He found that creeping snow moved and sorted rocks, placing the largest at the bottoms of the slopes; and that on gravelly soils snow creep formed ridges from which mud flows often developed.

Other observers have found that north slopes hold snow up to ten days longer than level or south slopes; that snow evaporation losses may range to more than an inch of water equivalent per month; and that interception of snow in ponderosa pine stands varied from five to thirty percent, increasing with age, size, and density of stand. An open ponderosa forest caught about the same amount of snow as an adjacent meadow; but the forest held the snow from one to three weeks longer than the meadow. An eighth of an inch, or 3500 gallons per acre, of snow water was held in drifts in the forest a week after the meadow was bare.

Griffin in 1917 studied the effects of forest on snow melt in the Upper Deschutes, Wind River, and Upper Yakima areas. He noted that snow remained about seventeen days longer on the average in the forest, though snow was less deep in the forest than in the open because of interception losses. In the latter part of the melt season, there was more snow in the dense forest than in more open stands. Snow remaining in the forest at the time the open area was bare contained over seven inches of water, equal to about thirty percent of the maximum snow blanket. At higher altitudes or in denser forest, the effect was even greater. Snow catch in the open was about a foot deeper than in the forest; and prior to the melt period snow in the open had a greater density than that in the forest.

Fifteen to twenty years later, a continuation of the Wind River study by Hawley and Meagher showed that snow on open cut-over land disappeared a week before that in partially cut stands, and two weeks before the snow disappeared in the untouched old-growth stands. On the open lands, seventy percent of the original snow pack melted in a single week; but under timber cover the snow melt was evenly distributed over a four-week period.

Elsewhere, it was concluded from observations in Nevada that the forest cover most suitable for water yield--from the standpoint of accumulation and melting of snow--would be a young stand with many small openings in the crown canopy. Studies in Idaho showed that old-growth ponderosa pine stands caught seventy to seventy-five percent as much snow as was caught in the open, and young second-growth stands ninety-five percent, but the snow cover lasted several days longer in the forest than in the open. In Utah it was observed that the snow melt period was fifty percent longer in south-facing watersheds though the yield was only sixty percent as great as in north-facing watersheds. On the south-facing areas the soil was saturated from snow melt twenty to thirty days earlier, and peak stream discharge came ten days earlier. Another study in the same area showed that the ground under snow cover was not frozen after the beginning of runoff.

On this matter of soil freezing, observers in Arizona found that while there was freezing in the soil of a ponderosa pine forest it was not as deep as in adjacent open areas, that the frozen soil was discontinuous and patchy by the beginning of the melt period, and that all soil freezing had disappeared well before the end of the melt period. In the open area there was still deep frost that impeded infiltration and left a layer of soft mud at the soil surface. Thick ice layers also formed at the bottom of the snow pack in the open. Most of the freezing in the forest occurred on the shaded north sides of the trees; there was much less freezing on the exposed south sides, and the frost there disappeared before the melt period began.

In a Colorado study, rate of snow melt was found to be most rapid in open areas. Melt rates in the forest were distinctly speeded up by timber cutting; though snow storage was increased in proportion to degree of cutting. While melting was most rapid on heavily cut plots, all areas lost their snow at about the same time. Largest amounts of water in a lodgepole pine forest were found in the larger natural openings. However, the comment was made that absence of interception losses in large open areas may be offset by losses from exposure of the stored snow to evaporation by sun and wind.

Russian observers found a delay in snow thawing within the forest, or in small openings, attributed to reduced air circulation; and noted that the thaw period lasted longer in the forest than in the open. One concluded that snow began melting about two weeks later in the forest than in the open, but that duration of the melt period was about the same because there was usually less snow to be melted in the forest. Further, that melting in the open went on during the day but stopped at night, while melting once begun in the forest went on continuously.

Avalanches are another feature of snow in the forest that make up a subject of importance to us. Many studies of avalanches have been made in Germany and Switzerland. One of their conclusions is that a selection forest composed of many age and size classes gives the best avalanche protection. Another, from a Swiss record of ten thousand avalanches, was that only six percent started on timbered or brush covered areas. In 1911, following the disastrous Stevens Pass avalanches which took more than one hundred lives, Munger made a study which showed that three-fourths of the avalanches occurred on deforested slopes and that nearly all started on deforested or barren slopes. Avalanches which had no well worn slideways to follow occurred after denudation of the steep slopes by fire and logging; the extensive fires of the period 1880 to 1910 were blamed for increasing avalanche prevalence.

Munger concluded that forests promoted climatic conditions less favorable to starting slides, and that chunks of wet snow and drops of water melted from the tree crowns tended to compact and cement the whole snow mass. Further, that trees acted as nails to hold the snow pack on the slope. Patches of timber could slow down or stop avalanches, but trees twenty feet or taller were needed to give significant resistance. Forests were observed to have the greatest influence on avalanches at the place of origin, not after the avalanches gained headway.

In a more recent study of avalanches on a ski area in Utah, it was pointed out that avalanche hazard was related to terrain and climate. Steepness, length, convexity, and exposure of the slope; snowfall, wind, and temperature are the important factors. It was remarked that any vegetation except grass had a restraining effect. Dry powder snow was the least controllable by vegetation, because it flowed readily around barriers such as tree trunks. A German observer stated that most of the damage from fine powder snow avalanches was caused by the tremendous air pressure that developed below them.

Forests, Floods, and Water Supply

Many observers have described the beneficial effects of forest cover in stabilizing stream flow. In North Africa, one pointed out the need for preventing forest destruction by sheep grazing, to reduce flood damage. In Italy, another told of the action of rain on bare soils, gully formation, channel cutting, and the occurrence of disastrous floods after deforestation. Deposits of flood debris and sediments ruined orchards and croplands, plugged the lower river courses, and developed ponds and swamps which became sources of malaria. A Swiss study showed that stream-flow peaks from a fully forested watershed were one-third less than those from a partly forested watershed; every kind of vegetation, especially forest, was found to contribute greatly to reducing erosion and stream debris transport.

Studies in Russia showed that location of forested areas within a watershed may have significant effects on stream-flow peaks, that the most moderating influence is exercised by forest distributed uniformly over an entire drainage basin, and that maximum discharge from basins forested only in the lower parts may exceed that from unforested basins. Further, that flood peaks were lowest where the upper half of the drainage basin was forested, and that the smallest maximum snow melt rises were found in rivers with watersheds only partly forested. This follows from the variation in timing of the snow melt period between forested and open areas. In a Czechoslovakian study total annual runoff from forested watersheds averaged about seven percent less than from unforested. Highest stream flow was five times as great from unforested as from forested areas, but the lowest summer flow was half again as great from the forested as from the unforested areas. Channels in the forest were stable even at peak flow, with very little debris added from banks or slopes; while stream courses in pastured areas were unstable and showed considerable bank erosion.

A comparison in Switzerland of runoff from twenty-three storms on forested and partly forested watersheds showed the advantage of full cover. For the period of highest stream flow, runoff from the fully forested area was only seventy percent of that from the partly forested area. There were several interesting findings from this study. Porosity of forest soils was greater than that of pasture or field soils. Soil moisture content was most constant in the forest; and there was less soil freezing in the forest than in the open. There were fewer slides and less erosion in the forest; and more dry season runoff--both summer and winter--from the forested areas. Water retaining capacity of the forest was very great for high intensity storms of short duration, and increased with age of the stand. Raw humus had an adverse effect, in that it soaked up water which was not transmitted to the soil, and that when saturated it permitted surface runoff. Mixed species forest composition was pointed out as desirable to prevent development of heavy raw humus concentrations. Forest soils yielded surface runoff when saturated by general rains; but the runoff was clear and free of sediment, and the discharge more stable and regular than that from soils in the open areas. Usually, precipitation drained from forest soils by deep seepage, and from soils in open areas by surface runoff.

In this country, the Wagon Wheel Gap study in Colorado showed that peak discharge from a denuded watershed was from one-fifth to one-third greater than from an untouched watershed, and that total water yield was about one-seventh greater. It was concluded that the ratio between high stream flow stage and low stream flow stage is a direct measure of the need for protection of the watershed as a storage reservoir; the higher the ratio the more needs to be done to retard snow melt and to increase absorptive capacity of the soil. Other observers noted that water losses varied according to aspect, soil condition, cover type and condition, and the seasonal distribution of precipitation.

Tests in Utah showed that where litter and plant material were normal for the site, runoff averaged five percent of the rainfall applied. On deteriorated parts of the same area runoff increased as plant density decreased, reaching eighty percent of the rainfall applied on nearly bare areas. In a California study of woodland chaparral plots, surface runoff from areas denuded by repeated burning averaged fourteen percent of precipitation; from areas burned but once, two percent; and from unburned areas, less than a tenth of one percent. Water yield from the undisturbed plots was by percolation; but more than a third of the yield from denuded areas was silt-laden runoff. Underground water flowed for a longer period and in greater amounts from the undisturbed than from the denuded plots.

Forests and Soil Moisture

Percolation tests in the Swiss study mentioned in the preceding section showed that forest soil was from fifteen to seventy times as absorptive as soil of grazed or pasture areas. In California soils with undisturbed woodland chaparral cover, percolation was fifty percent greater than in denuded soils. During the growing season all soils dried out to less than the wilting point down to a depth of forty inches; but the winter season soil moisture remained at a level useful to plants twenty percent longer in the soils with undisturbed cover than in denuded soils.

An Italian observer stated that evaporation from forest soil ranged between one-fourth and one-half that from bare soil. During the snow-melt period when transpiration draft is fairly low, such a reduction of evaporation losses can result in significant soil moisture saving. This is borne out by the findings of an Arizona study in a ponderosa pine forest. The surface soil layers in the forest absorbed and retained for a longer period a greater amount of water from snow melt than did the corresponding soil layers in an open meadow. Within the forest, areas covered with leaf litter and shaded by tree crowns absorbed and retained a greater quantity of soil moisture than did the bare forest openings. In Utah, observers reported that watershed soils became saturated during the high runoff period, and remained so for about two weeks after most of the snow cover had disappeared. One pointed out that winter melting may transfer considerable water from the snow pack to the soil to replenish earlier soil moisture losses. Where soils were saturated by snow melt, rain during the melt period yielded very high runoff.

From a California study, it was concluded that soil freezing drew water upward, drying out the subsoil and causing the surface soil to become and remain very wet during rainless periods. In soils bare of vegetation, freezing greatly increased evaporation losses. Evaporation during freezing periods was three times as great as in similar periods without freezing, and nearly four times as great as evaporation and transpiration combined from brush-covered soils during the same periods.

One American observer summarized the effects of forest cover on soil moisture by pointing out that in level areas forests drain the soil and improve marshy conditions, while in hilly areas forests increase underground water storage. From studies in Europe it was concluded that in general a heavy forest stand tends to lower the ground-water table and dry out the soil.

Forests and Erosion

Though this topic has been considered here and there in the preceding sections, some specific findings of interest remain to be given. In the California woodland chaparral study, annual erosion losses averaged twelve tons of soil per acre from denuded plots, one-half ton per acre from disturbed plots, but only two pounds per acre from the undisturbed plots. The surface workings of small animals contributed to erosion on the disturbed areas. In the Intermountain region, it was observed that the amount and severity of erosion varied with slope, vegetation density, and accessibility to livestock; that soils are most stable and erosion least on northerly slopes; and that a vegetation density under thirty percent had little appreciable effect in retarding erosion. Another study in the same region indicated that soil freezing led to serious erosion. Where vegetation was sparse, steep slopes were eroded by frost action and snow melt combining to cause miniature mud flows. Brush-covered slopes were generally resistant to mud-flow erosion, while slopes with a sparse sagebrush and grass cover were susceptible.

Summer cloudburst storms cause much more spectacular erosion damage on areas with depleted cover. Heavy rains on saturated soils during the snow melt period may have similar disastrous effects. We can see plentiful evidence of erosion from both sources, particularly in the eastern part of our region, wherever the cover has been removed. Croplands, bare of cover in the winter season, show the most; but on many range areas, overused by livestock or by game animals, the signs of sheet and rill erosion are prominent. Below the eroded slopes, small waterways are gullied out, their crumbling vertical banks showing their instability. In the forest, the damages are less obvious. Where cover is denser, erosion is usually lower; though logging skid trails often become accessory channels contributing to the sediment and debris load of streams below. In undisturbed forest, erosion is limited to an occasional landslump or to the very slow processes of soil creep on the steeper slopes.

A study of erosion on watersheds predominantly brush-covered showed one-third of the area to suffer from significant erosion losses. Areas with deep friable soil had very little severe erosion. Where soils were shallow, with tight subsurface layers, erosion was widespread. Such soils generally supported only a sparse vegetation which was easily overgrazed and depleted. Even with moderate use, these areas tended to erode readily; they require at best careful management, and if badly eroded, they need positive control measures in addition to removal of grazing use in order to prevent continued deterioration.

II. WATERSHED MANAGEMENT CONSIDERATIONS

Logging and Stream Flow

Forest operations and management practices have considerable effect on runoff and erosion. In the Rocky Mtn. lodgepole pine forests observations indicate that mechanical disturbance of the soil by logging leads to erosion of the humus. However, heavy cutting was found to make about thirty percent more water available for stream flow, the increase being attributed largely to differences in interception. In the southern Appalachian hardwood forest, clear-cutting increased annual water yield sixty-five percent, while cutting only the stream-bank vegetation increased the yield twenty percent. Stream turbidity and sediment loads were increased by the usual logging methods which greatly disturbed the watershed soils. Old logging roads continue to erode and may add sediment to streams below for many years. European observers found clear-cutting detrimental because of the compaction and degeneration of denuded soils.

In our own region, Rapraeger noted that on partially cut tractor logging chances in Douglas-fir, over forty percent of the area had the ground cover changed by the addition of slash or from crushing by tractors and logs, while about five percent of the area was taken up by skid trails. Other observers have reported up to ten percent of logged areas taken up by skid trails, with the skid trail soil disturbed and compacted. Tarrant's studies indicate a probable reduction in site quality as well as an increase in runoff and erosion on the altered soils in skid trails.

On the East side in ponderosa pine forests Garrison and Rummell found that logging denuded twenty-two percent of the cutover area. Shrub density losses in the understory of as much as sixty percent were observed. Skidding disturbance increased with slope, and was greatest on the light-textured soils. Where skid trails were long and heavily used, they often were dug out to depths of as much as four feet and showed severe soil displacement. Where arches were used for skidding, there was much less soil disturbance.

Grazing and Stream Flow

European observers early recognized grazing damages on watersheds. They recommended that mountain pastures be limited to areas not subject to injury by grazing use; and that grazing be prohibited on soil stabilization and torrent control projects. On the latter point, similar recommendations have been made in this country.

Soils on grazed pasture (converted from hardwood forest) were found to have less than half the infiltration rate of soil with an undisturbed forest cover. On Western ranges, infiltration rates were observed to be reduced as grazing pressure increased. Moderate grazing use increases surface runoff, but has little effect on erosion; while heavy grazing greatly increases both runoff and erosion. Light grazing on bunchgrass range in Colorado increased surface runoff forty percent; heavy grazing increased runoff nearly ninety percent. Similar effects have been noted on brush and forest ranges, also.

Floods from summer cloudbursts in the Intermountain region have been correlated with the degree of grazing on the watersheds producing the high flows. Removal of the cover vegetation and compaction of the soil by grazing animals led to high rates of runoff and severe erosion on the slopes, and produced disastrous boulder-laden floods in the channels below at times of heavy rain. From undisturbed watersheds, peak flows were much lower and carried little debris load.

Road Construction and Stream Flow

Concerning road construction, a Swiss observer stated that forest roads must be drained so that water will flow in the forest soil rather than in surface channels. In Czechoslovakia it was observed that discharge from forest roads ran off rapidly and was loaded with sediment. In California, erosion losses from a mountain road in a deeply weathered granitic formation amounted to one-eighth of the original fill, during a single high-intensity storm. In North Carolina, it was pointed out that road-bank erosion choked ditches and culverts, cut out fills, increased accident hazards, cost up to $300 per mile for extra maintenance annually, and added to stream sediment loads. Observations in California showed considerable damage done by road erosion sediments to stream channels, reservoirs, irrigation works, agricultural lands, and mountain recreational areas. The damage below a storm-gullied road may be less conspicuous but is often greater than that to the road itself; further, such accessory damage frequently is irreparable.

Fire, Soil Conditions, and Stream Flow

The effects of burning are summarized by Shantz as follows: "A third of the natural vegetation of the earth's surface was affected by fire. In each case the vegetation is thrown back to a less luxuriant type, a dryer or less productive type.... Some of the most desert areas in the world lie in a region of ample rainfall.

"A plant cover, a duff cover, accompanied by a myriad animal forms, and an equally rich bacterial and fungal flora keeps the surface in a constant state of biological activity. This activity involving the upper inch or more of soil, and the inches of animal and plant cover is totally destroyed by fire. That fire enriches the soil chemically might be true; but there is little evidence that soil is enriched through a series of burnings, and considerable evidence that it is not.... Another effect of removal of vegetation by fire is that the duff and the mycorrhizal content so necessary for many forest trees is largely destroyed."

It was concluded from studies in Sweden that burning decreased the acidity of humus, and so improved growing conditions for plants, though the effect varied according to the particular soil. The composition of ashes changed rapidly, but basic elements were taken up by humus and held for several years. Acidity remained low for some time, and gradually returned to original levels. Burning was most effective in cases of podsols with heavy raw humus. From observations in Colorado it was inferred that thirty to forty years after burning were needed to develop an appreciable humus and litter layer in lodgepole pine forest; and that to develop the three- to six-inch depth of litter humus such as found in old stands took over two hundred years.

The infiltration capacity of woodland chaparral areas denuded by burning was found to be reduced eighty percent at the first burning, ninety percent at the second, and ninety-five percent with continued reburning. Thereafter, seventy-five percent of the rainfall on the denuded area produced runoff. In another study, annual burning of hardwood forest flood reduced infiltration thirty-eight percent, whereas mechanical removal of litter gave only an eighteen percent reduction.

In the mixed forests of the Alleghenies, burning was pointed out as a cause of frost pockets. Openings in the stand made by either fire or clear-cutting persisted because of unfavorable seed-bed conditions due to freezing; such frost pockets were not found in the undisturbed old-growth stands.

Removal of the litter, as by a ground fire, in young ponderosa pine stands caused severe erosion and doubled the runoff rate, according to a Colorado study. Seven years later, even though a normal amount of litter was again accumulated, the treated area still had not returned entirely to the normal runoff rate.

Fire, where it is the only agent affecting cover, as in the chaparral of California, is the second chief contributing factor in floods. (Precipitation is of course the first.) Watershed runoff and erosion rates are increased many times over in the first season after burning. Erosion rates as great as one hundred and fifty tons of sediment per acre have been measured from newly burned watersheds. Runoff rates up to six hundred second-feet per square mile have also been measured under these conditions. The effects of fire are reduced slowly; thirty years may be needed to bring the cover back and lower the runoff and erosion rates to normal.

Miscellaneous Considerations

Returning to the subject of avalanches: One of the lesser known but quite important avalanche damages is that of destruction of the productive capacity of fairly large forest areas. Protecting avalanche hazard areas from fire is of prime importance. In the high elevation avalanche source areas, tree planting may be necessary. European authorities recommend stone walls and terraces to anchor snow packs that may become avalanches.

Changing the forest cover has its effects on wildlife. Openings in the old-growth Douglas-fir forest tend to improve the habitat for deer. Other animals, however, may be adversely affected. As the timber harvest has proceeded in this region, trees shading the streams have been removed and channels have been plugged with logging debris. Lack of shade causes water temperatures to rise, debris jams prevent upstream travel by spawning fish, and decomposition of organic matter released in the streams cuts down the oxygen supply for many forms of aquatic life in addition to furnishing material sometimes directly poisonous. Erosion sediments, whether from cut-over areas, heavily used range, or cropland, foul the streams and ruin spawning grounds. At times of high water, heavy loads of fine sediment choke the fish themselves.

Recreational aspects other than those involved in hunting and fishing are also important. Two and a half million people visit resorts and camps and picnic grounds on the national forests of our region each year; and three times that many more see the forests while traveling through. Those that are looking for berries enjoy visiting burned and cut-over lands; but the majority of the travelers prefer green-clad mountains for scenic enjoyment. Where and how the timber is cut may seriously affect this intangible but valuable resource. On the other side of the picture, recreational use itself may cause damage to the forest, because of soil compaction where many people gather, and because of increased fire hazards.

III. WATERSHED MANAGEMENT ACTIVITIES

Management to Control Erosion and Runoff

A number of authorities have given suggestions for watershed management toward control of slope erosion and runoff. One recommended partial cutting and scattered openings to prolong the snow melt period on densely forested watersheds. Another pointed out that part of stream-flow losses could be eliminated by cutting down the vegetation along channels. In Colorado, it was stated that differences in interception largely determined the value of watershed cover types; and that aspen and grass were satisfactory where water yield was more important than timber production. Transportation by wire has been described as a method of getting logs out of the forest without skid-trail damage and erosion.

Concerning grazing lands, Ellison says a cover that is patchy is shot through with small problem areas. It is the open spaces that remain unproductive year after year, from which most of the soil loss takes place, and which limit the efficacy of the land as watershed. Moderation in grazing is necessary so that vigor of established plants not be impaired, to permit adequate seed production, and to furnish control by vegetation over the microenvironment. Providing soil stability and favorable microclimate is essential for rehabilitation of deteriorated range watershed lands, and mulching can help toward these objectives.

With regard to seriously deteriorated watersheds, an Italian forester said control requires reforestation of slopes and regeneration of alpine meadows. Some slopes may be so bad that terracing is needed before planting can be successful. In severely eroding channels, dams and revetments are needed to reduce flood flow energies, to collect flood sediments, and to provide stabilization until the vegetation cover on the slopes above is fully reestablished. He recommended temporary barriers of dry masonry or bundles of wood for secondary gullies; paving channels of large gullies and covering the side banks with layers of branches; sloping steep cut banks; terracing steep eroding slopes; and installing drains to eliminate landslides. He stressed the importance of reforesting with species adapted to the particular site. In describing torrent control in Jugoslavia, another observer mentioned the need for checkdams, lateral terraces, and reforestation, including continued maintenance.

Terrace and Contour Trench Installation

A Czechoslovakian stated that the sole feasible means of reducing flood peaks on mountain streams was the use of forest, planting bare slopes where water retentive capacity has been lost and which are exposed to the danger of erosion. He described the use of small stone dams and wattle revetment and planting for channel stabilization. An Italian recommended contour terraces from $1\frac{1}{2}$ to $4\frac{1}{2}$ feet wide, having inward slopes of 30 percent to collect litter and debris from above, with the soil loosened to a foot depth to promote plant growth, prior to reforesting denuded slopes in dry areas. Some 2000 lineal feet of terrace are needed per acre on the average, with the terraces from 16 to 20 feet apart. On badly eroded soils in the Southern States, where conditions do not permit effective use of checkdams, it has been mentioned that trenches dug $1\frac{1}{2}$ feet deep and $1\frac{1}{2}$ feet wide may be substituted satisfactorily. These trenches should be at right angles to and across drainage channels, and excavated soil material should be piled on the lower sides. As the trenches become filled with loose outwash materials, they provide planting sites for trees.

In Utah, recommendations for stabilizing soil and controlling runoff on flood source areas included the use of contour trenches 25 feet apart. The trenches are built with cross checks at 20- to 40-foot intervals, to break up the gully system, impound rain, and create soil moisture conditions favorable to plant establishment. Treated areas are then broadcast seeded with grass and closed to grazing. More specific recommendations developed from another study called for cut and fill slopes of $1\frac{1}{2}$:1 in the contour trenches and digging the trenches $1\frac{1}{2}$ feet deep and a foot wide on slopes to 40 percent. Trenches of greater capacity were needed on areas of lesser slope but with excessive snow melt. On slopes from 40 to 65 percent it was found that trench cut and fill slopes should be 1:1. Water checks four inches lower on top than the outer dike of the trench were found necessary; with dams to the top of the trench dikes when ending trenches at gullies. Tractors were used on easy slopes, but on steeper slopes horses and plows were needed to build the trenches, which were then finished by hand labor. Trenches were seeded in early spring, or transplanted to forest trees and shrubs if in forest or chaparral areas.

Road Erosion and Drainage Control

About road construction, reports on a North Carolina study show that careful road planning avoids heavy cutting and leaves the banks sloped back ready for the naturalization treatment. Good drainage is necessary, with headwalls at culvert inlets and aprons at outlets. Top soil should be stockpiled as the road is built, or obtained for old banks by rounding off the upper shoulder; then raked down over the banks. The limiting factors for plant growth on road banks are soil instability, soil moisture deficiency, and inadequate soil fertility.

Most successful operations in this study included resloping banks where necessary, to blend with the natural topography, scarifying the bank surface, and applying a protective weed mulch held down by poles and stakes. On slopes of less than $1\frac{1}{2}$:1 a light mulch alone was adequate to promote natural plant growth. On steep ($1\frac{1}{2}$:1) dry slopes, step terraces with a two-inch top-soil dressing and a heavy mulch were needed with the slope screened by trees planted below or vines planted above.

The mulch cut down frost-heaving soil loss, furnished shade, and provided catchment for seeds. Weeds cut for mulch in the fall usually furnished their own seed supply. Ryegrass, orchard grass, bent grass, and blue grass were found useful for seeding to form a sod. Seed was applied at a rate of 20 to 30 pounds per acre, right onto the mulch in wet weather. Stakes two feet long were set a foot and a half in the ground and two feet apart; then a mulch of both fine and coarse weeds was laid out two to four inches deep; and finally poles were placed resting against the upper sides of the stakes to hold the mulch in place.

In California, instead of overcasting, end-hauling excess material to basins above fills was recommended, with drop-inlet culverts used for drainage. Retaining walls of native rock or cribbing of concrete or metal were stated as useful to hold fill slopes and cut banks to reduce overcasting. It was recommended that top soil be held to spread on top of fill slopes and end-haul piles. Frequent road drainage was considered necessary; with culverts draining onto rock slopes or into natural channels, by flume (metal half-culverts) if needed. Large culverts which do not readily plug with debris were specified. Installation of drainage on the upgrade side of all deep cuts was recommended to avoid blocking drainage by slides.

Specifications included treating fill slopes by smoothing the surface, providing mechanical anchorage through contour trenching or wattling and staking, sowing grasses or quick-growing annual herbs, and by planting suitable trees and shrubs (including cuttings of sprouting species). Wattling involves packing and partially burying brush in contour rows above supporting stakes. Sprouting shrubs or trees are desirable for stakes. Breakdowns in the treatment measures were required to be repaired as soon as possible. This treatment was used for repairing erosion damage on the Palomar Mountain road, and though road costs were increased about 20 percent it was pointed out that the cost would have been much less had the erosion-control work been done at the time of the original road construction.

In Summary

The basic principle in watershed management and in erosion and runoff-control treatments is nicely summarized by Shantz. He concludes that forest and the condition of the soil surface profoundly influence the microclimate and that is what immediately affects the growing plant, and the animals and people that live in a region. Ellison in considering watershed restoration says that moisture near the soil surface and soil instability are important factors in explaining association of new plants with established vegetation and absence of new plants in openings. Temperature is less extreme under vegetation, frost-heaving of the soil is less common, and moisture in the surface soil persists longer. The favorable influence of vegetation on microenvironment outweighs its influence in competition; association is more marked as exposed bare spaces are more eroded, or more unstable, or as current rainfall is more deficient.

IV. LOCAL OBSERVATIONS AND RECOMMENDATIONS

Logging Practices

Recent observations in this region bring out certain points with respect to watershed management. Though the problems of the west-side Douglas-fir country with respect to stream flow and erosion may not be as obvious as those of the east-side ponderosa pine, they do exist and they are serious. More and more demand is being made on the water of our west-side streams, for domestic use, for industry, and for irrigation. More and more concern is being expressed by the water users as to possible harmful effects of timber harvest on their watersheds. It is as much our job to provide a continuing supply of clean usable water as it is to provide a continuing supply of timber. The two jobs are compatible.

Opening up the forest by timber harvest may increase somewhat the total water yield. But at the same time, protecting the streams against sediment damage requires control of the harvesting job. There are cases of going timber sales, visited last year, where access roads and skid trails followed along or in natural channels, where logs were skidded across channels, where excavated soil and rock from the roads and slash and culls from the logging were dumped into flowing streams, where logging on the steep stream-bank slopes opened up eroding scars, where burning after the logging has denuded stream banks and contributed more debris to the channels.

Protection can be provided. Burning can be controlled along the streams. Removal of timber on steep stream banks is often an unrewarding or even costly part of a logging job, particularly where the site is poor and the stand low in volume; it need not be done along many reaches. Cutting areas should be located away from channels above such areas where the slope is steep enough that erosion damage will surely follow logging. Use of steep cross-contour skid trails should be avoided, as should skidding across channels. Dumping slash and road debris in channels should be prohibited; as the channel cleanup now required is not always done, and is difficult to do without seriously disturbing the channels. State forest practice regulations also bear on this point,1/ which is important to water supply pollution and to spawning grounds and feeding conditions for trout and salmon.

Soil disturbance is related to the size of equipment used. Skid-trail compaction leads to rapid runoff and gullying, and also affects the site for growing a new timber crop. Where small equipment can handle a logging job, it should be specified; as the larger and heavier equipment increases forest floor disturbance and soil compaction. Total length of roads and skid trails should be held to a minimum, or at least be balanced against the necessary amount of use expected. In some instances it may be better, because of instability of the soil, to have more skid trails but less use on each. Where soils are unstable and readily eroded, care must be taken to avoid deep gouging in the skid trails. In some areas the soils are so unstable that any logging by present methods is hazardous from the erosion and stream sedimentation standpoint.

A certain amount of damage cannot be avoided; but it can be corrected. When the logging job is finished, skid trails can be seeded with grass to hold the soil. On steeper slopes, water bars or checks to divert drainage and catch eroded materials are often desirable. These checks should be large enough to control drainage flow completely, and should divert it safely to the side in places where it will not cause more erosion. Brush alone does not make a good check. If a bulldozer is used to pile up earth checks in the skid trails, the machine should work backwards up the slope and return by a different route, to avoid smashing down the crests of the barriers already built.

1/ Oregon Fish and Game Code, Section 39-603, Oregon Code Supplement 1935;
Oregon Fish and Game Code 1930, Sections 14-8-100 and 14-8-111;
Oregon Commercial Fisheries Code, 1949-50, Section 59(a);
Oregon Compiled Laws Annotated, 1941, Article 1, Section 116-1101.
State of Washington, Laws of 1945, Chapter 216, Section 14.

Throwing logging slash into skid trails on partially cut areas has been recommended, and gives some protection to the skid trail soil as well as serving to reduce slash accumulation. Slash accumulations in channels can be avoided by leaving protection strips equal in width to the average stand height, or by felling trees to drop away from the channels.

Advance planning of all phases of a timber sale and logging job makes it easier to avoid water problems. Access roads and landings can be located up out of the channels. Necessary channel crossings can be designed to minimize stream disturbance. The cutting pattern, for the present and for the future, can be laid out so that great changes are not made in any one watershed unit at any given time. Size of cutting area can be related to topography, soil conditions, and stream flow regime. Logging methods, type of equipment, and limits on size of equipment can be specified for time and place according to the dictates of timber size, soil, and slope.

Many of these points apply also to the east-side ponderosa pine country. Because the stands are more open and livestock are grazed over many of the pine forests, reseeding with grass is much more useful to provide cover for areas bared by logging and burning. Gjertson recommends seeding on any ground that is totally denuded, using timothy, orchard grass, smooth brome grass, and tall oat grass. Seeding should be done within a year of the time the ground is disturbed; and it is desirable to use a mixture to provide species adaptable to a variety of sites. Some control of grazing is needed the first season after seeding to permit the grass to become established.

Road Construction

Erosion and sedimentation problems arising from road construction often go back to the road location. As has been mentioned, building roads away from channels will save considerable trouble in the streams. Where possible roads should be located on the most stable geologic formations. It may not be possible to determine stability of the rock structure in advance; but there are often some indicators at the ground surface, such as seeps, natural slides, talus layers on the slopes, and outcrops of clay layers. Or roads may have to be located in unstable areas because of considerations of topography, etc. However, slide and drainage difficulties can be avoided or minimized by thorough advance planning. Road gradient and straightness can be compromised so that cut and fill may be held to the minimum on unstable sites. Overcasting can be planned for locations where the excess material will not feed sediments to stream channels. Long stretches of uniform grade that permit drainage to concentrate and gather volume and velocity must be avoided.

Drainage from roads should be led off at frequent intervals to avoid large concentrations; and cut banks should be sloped so that they will not slip and plug drainage ditches. Cross drains should be set on a slope great enough to provide free flow and prevent accumulation of sediment. Slightly raised humps on both sides of cross drains will permit trucks to ride over them without smashing them down; and short lengths of pipe used as spreaders will keep the drains open at the top so that they can readily be cleaned out with a hoe. Culvert inlets should be paved, or have headwalls. Culvert outlets need aprons of logs or rocks or concrete or metal to break up and distribute water flow unless they feed directly into natural channels. Culverts must be large enough to carry the increased flow and the sediment and debris load that may be expected after the logging operation. Cannon culverts that shoot drainage out to fall on unprotected fill slopes nearly always lead to active gullying, and should not be used. Open drains down fill slopes need adequate inlet protection to prevent formation of gullies beside the drains; metal inlet troughs are excellent for this purpose. Where possible, drains should be installed upgrade from, rather than on, the fill slopes.

There are other points to watch in road construction. Where the material is available, it is desirable to use heavy rock to stabilize the toes of fill slopes and prevent slumping. The rock should be put in first, as the lowermost part of the fill. It helps fill drainage, in addition to anchoring the fill material. Placing culverts in drainageways under fills should be the first step in fill construction, with the culverts laid out on the natural drainage gradient.

General Statement

Grazing problems have not been accented here. They are already well outlined, and control measures have been prescribed by numerous authorities. Programs are now under way to improve range conditions, both from the forage standpoint and from the watershed standpoint. There is a much greater need for consideration of our timber harvest from the watershed standpoint. It is up to the local administrator to watch for the problems that develop on his area, to anticipate and prevent their occurrence where possible, and to apply corrective treatment as needed. It is the purpose of this paper to furnish a guide for such observation and treatment.

As you look over the areas and jobs for which you are responsible, you may see where improvements in present practices can be made. We would like to have your suggestions, as we do not have much background to furnish detailed advice for the various problems of this region. In particular, we need your help in finding native herb and shrub species that may, by reason of growth habit and rooting characteristics, be adapted to soil stabilization and erosion-control work. You can also help by outlining the problems in watershed management that are facing you, and by recommending them to us for study as our forest influences research gets under way.

V. THE WATER CROP

To give you an idea of the water production from national forests, a table on discharge of some of our streams is included. These records are taken from the U. S. Geological Survey Water Supply Papers. Most of the water flowing in these streams is produced on the national forests; as you can see, it is a sizeable crop. It is also a valuable one; California would undoubtedly be glad to buy it at two dollars an acre-foot!

WATER YIELD OF SOME STREAMS DRAINING NATIONAL FOREST WATERSHEDS

Stream	Drainage Area	Average Yearly Flow	Maximum Yearly Flow	Minimum Yearly Flow	Average Yearly Yield Per Square Mile	
					Total	Inches
Name	Square Miles	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Depth
Rogue	2,020	1,980,500	2,988,000	839,000	980	18
N. Umpqua	1,210	2,257,000	3,101,000	1,360,000	1,860	35
Siletz	204	1,204,000	1,610,000	715,000	5,900	110
McKenzie	930	2,640,500	3,221,000	1,870,000	2,840	53
Santiam	665	2,344,000	3,180,000	1,570,000	3,520	66
Clackamas	665	1,885,000	2,680,000	1,340,000	2,830	53
Deschutes	Undetermined: large springs at sources.	2,995,000	3,744,000	2,600,000	--	--
John Day-	1,640	235,000	434,300	90,100	140	3
Powder	230	77,500	127,000	29,220	330	6
Lewis	483	2,010,000	2,708,000	1,350,000	4,160	78
Cowlitz	1,170	3,726,000	5,216,000	2,210,000	3,180	60
Snoqualmie	605	2,663,000	3,760,000	1,800,000	4,400	82
Skagit	2,700	10,428,000	14,290,000	7,060,000	3,860	72
Quinault	264	1,960,000	2,640,000	1,290,000	7,420	139
Yakima	500	1,369,000	2,026,000	861,000	2,740	51
Entiat	419	356,000	585,000	199,000	850	16
Methow	1,330	852,000	1,509,000	339,000	640	12

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