Protecting Quality of Stream Flow by Better Logging

Good water and good land management go hand in hand. Water supply engineers, foresters, and land use planners are learning more and more that there is an intimate and continuous relation between water and the condition of the land. The whole purpose of watershed management is to maintain this relation so that all the watershed resources may be utilized to their fullest advantage and economic extent.

One of the problems that has arisen in connection with the maintenance of this principle is whether the harvesting of timber would jeopardize a city's water supply. Seattle's Cedar River watershed is a concrete example of this question. There the controversy arose as to whether logging on the watershed should be continued or prohibited for the indefinite future. After detailed study, an expert commission concluded that with the given climate, soils, vegetation, and other circumstances, "there are no inconsistencies in a policy and program which results in protecting the water supply values simultaneously with the conservation and use of the timber resources of the Cedar River watershed." Logging was continued. The commission also pointed out that "For over half a century lay and professional groups have argued with more heat than light about the effect of forest cover and forest practices upon precipitation and run-off. Even at this late date authoritative quantitative data which shed light upon these important effects are exceedingly meager."

The Coweeta Hydrologic Laboratory was established by the U. S. Forest Service to supply this lacking information for the southeastern United States.

Stream Flow Influenced by Cutting

At Coweeta we have been able to separate the effects of tree cutting from the effects of erosion caused by logging. The effect of tree cutting, with minimum disturbance of the soil, was determined on a complete 33-acre experimental watershed. The run-off characteristics of the watershed were established from five years of continuous stream-flow measurement. At the end of this standardization period all major vegetation was cut. To prevent any unnatural soil disturbance, the trees were left lying where felled and were not removed from the area. As a result of this treatment, there was a 65 per cent increase in yield of high quality water from the area during the first year following cutting. Thus it was demonstrated that in this climate the reduction of vegetation was not detrimental to the water supply as long as forest soil conditions were maintained.

Logging Disturbs Soil

When forest soil conditions are seriously disturbed, however, the water supply is adversely affected. From a nearby 212-acre experimental watershed, wood products were removed with the use of typical local logging practices, without any restrictions because of water values. In this case there were decided increases in stream turbidity and sedimentation.

As is typical of the southern Appalachians, this logging chance was characterized by steep, generally rough topography, with the valuable trees in scattered stands. Logs were ground-skidded by horse teams. Steep access roads and skid trails were constructed parallel and adjacent to natural stream channels, and comparatively little thought was given to their location and design. These latter deficiencies subsequently resulted in considerable soil erosion and the transportation of sediment into the stream.

Log on the 212-acre experimental watershed was begun in June, 1942. In early 1946, in order to facilitate the operation, an access road 0.8 miles in length was bulldozed into the area by the logging contractor. In early 1947 he constructed two spur roads, totalling about 1.3 miles in length. To date approximately 1000 cords of extract wood and 200,000 bd. ft. of timber have been taken from the area. No logging or road specifications were set up for the operator and the whole situation is typical and average for the southern Appalachians.

Stream Turbidity Increases

The results of the logging were soon apparent to workers on the experimental forest whose general remark was, "that used to be one of our best..."
drinking places, but it’s too muddy now.”

To measure quantitatively and systematically the changes in water quality associated with the logging operation, water samples were collected from the logged area (Watershed No. 10) and turbidities of these samples were compared with those collected from an adjacent control watershed (Watershed No. 34) on which there was no man-made disturbance. The daily samples from the two watersheds were obtained within a few minutes of each other. An analysis of the turbidity determinations for the period June 10 to September 21 shows that on the area that was being logged, the average turbidity was 93.7 parts per million. More important, the maximum turbidity was 3500 ppm. As was expected, the higher turbidities were recorded when logging disturbance was followed by heavy rainfall.

Sources of Turbidity

Measurements and observations on the watershed readily revealed the sources of this turbidity. In the summer of 1942, during a three-months’ period, 250 cubic feet of eroded material were collected from a portion of skid-road 450 feet long and five feet wide on a 30 per cent grade. This is equivalent to an erosion rate of over 160 cubic yards per acre of road surface. Cross-sections of the access road measured at intervals showed lowering of the road level as much as a foot, with recession of the road bank (due mainly to frost action) of an equal amount. Wheel ruts eight inches to a foot deep and two feet wide were not uncommon. Table 1 shows cross sectional area changes at 10 measured points. It also shows volume change as computed on a basis of one lineal yard of road at each cross section.

Table 1.—Truck access road—Coweeta Watershed No. 10, April 1946—December 1947.

<table>
<thead>
<tr>
<th>Cross Section in Area</th>
<th>Change in Rd.</th>
<th>Volume Moved</th>
<th>Grade Exposure</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cubic yds. per one lineal yd. of road</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>5.4</td>
<td>0.6</td>
<td>17 SE</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>6.3</td>
<td>0.7</td>
<td>25 SE</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>2.7</td>
<td>0.3</td>
<td>20.5 SW</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>6.6</td>
<td>0.73</td>
<td>17.5 S</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>16.7</td>
<td>1.84</td>
<td>19 SW</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>3.1</td>
<td>0.57</td>
<td>17.5 S</td>
<td></td>
</tr>
<tr>
<td>VII Trace</td>
<td>Trace</td>
<td>20 SE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIII Trace</td>
<td>1.3</td>
<td>0.14</td>
<td>18.5 S</td>
<td></td>
</tr>
<tr>
<td>IX Trace</td>
<td>Trace</td>
<td>11.5 W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>Trace</td>
<td>8.5 SW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How a small, local trouble spot may affect a larger stream system was brought out during the storm of April 11, 1947. Following this storm of 1.02 inches in 14 hours, samples were collected from (a) the stream draining Watershed No. 10, where logging was
going on; (b) from the main stream just above Watershed No. 10; (c) from the main stream, draining an area of 1800 acres, at a point below Watershed No. 10; and (d) from another main stream in the experimental forest draining slightly less than 1800 acres, on which there is no logging activity. The turbidities of these samples were as follows:

Watershed No. 10
(212 acres) ............................. 1200 ppm.
Main stream above Watershed No. 10 ...................................... 25 ppm.
Main stream below Watershed No. 10 (1800 acres) .................. 395 ppm.
Another comparable main stream of nearly 1800 acres—(no logging) ............................................. 25 ppm.

Thus it is seen that the origin of high turbidity in a large stream may be traced to a fairly small or localized area.

Better Location and Maintenance Needed

A number of common-sense improvements would go a long way toward lessening the destructiveness of most logging operations in the Southern Highlands. First, considerably more attention should be given to the location and grade of access roads. For instance, on Watershed No. 10, the road is so laid out that slopes as high as 26 per cent alternate with relatively flat stretches. Erosion on the steep sections is much harder to control because of the increased velocity and erosive force of the flowing water. Also, because of these steep slopes the road is highly dangerous in wet weather and in many cases impassable to truck traffic.

In any logging operation, and particularly where integrated multiple use is to be made of the logging area, the road lay-out should be designed to fit the area and the products to be obtained from it. Too often a road is punched in to reach one particular stand of timber without much thought to possible later use. Or one operator will build a road to get out the saw-timber and will be followed by an extract wood operator who may find the first road does not get to all the extract wood and proceeds to construct spurs and additions. In practically all cases these conditions result in more road than is actually required to get all the products. Experience of this sort shows that the location of all the various forest products in the area, together with a procurement and resource management plan, should be known ahead of time so that the road lay-out may be most efficient. Also, the possibility of amortizing the cost of a better road over a period of time rather than paying for a poor road from a single operation should be considered.

Erosion is Active at all Times

On completion of a job, some operators make a practice of diverting water out of roads and skid trails and placing brush on the worst eroding portions. Others do not take these precautions against continued erosion. In any case the most serious erosion and sedimentation may take place during the operation.

Another important factor is the length of time of the operation. It is not only important to the timber operator, but also extremely important to the watershed manager, since turbidities and soil losses are increased proportionately. In many cases where a proposed timber sale or removal contract is supposed to be completed in a year, it is still going at the end of two, three, or four years. Further operations to get out other forest products very often lengthen the time that the road is in use. Thus the widely-held opinion that the sale will be finished in a short time and that the damaging effects of the road or roads can be rectified following the operation is false. It is false also because, as has been pointed out, the greatest erosion, transportation of sediment, and resulting high turbidities occur while the actual logging is in progress on the watershed.

Road and Skid Trail Drainage Pays Off

The matter of road drainage can hardly be overemphasized. The motto of the military road builders is "Keep the water off and the rock on." The first part of this maxim definitely applies to the construction of logging roads. Since the roads are generally unsurfaced, the ever-present wheel ruts nullify the use of crowning or sloping the road surface for drainage. The ruts concentrate water and are frequently sources of serious erosion. This means that water bars or turn-
To measure quantitatively and systematically the changes in water quality associated with the logging operation, water samples were collected from the logged area (Watershed No. 10) and turbidities of these samples were compared with those collected from an adjacent control watershed (Watershed No. 34) on which there was no man-made disturbance. The daily samples from the two watersheds were obtained within a few minutes of each other. An analysis of the turbidity determinations for the period June 10 to September 21 shows that on the area that was being logged, the average turbidity was 93.7 parts per million. More important, the maximum turbidity was 3500 ppm. As was expected, the higher turbidities were recorded when logging disturbance was followed by heavy rainfall.

**Sources of Turbidity**

Measurements and observations on the watershed readily revealed the sources of this turbidity. In the summer of 1942, during a three-months' period, 250 cubic feet of eroded material were collected from a portion of skid-road 450 feet long and five feet wide on a 30 per cent grade. This is equivalent to an erosion rate of over 160 cubic yards per acre of road surface. Cross-sections of the access road measured at intervals showed lowering of the road level as much as a foot, with recession of the road bank (due mainly to frost action) of an equal amount. Wheel ruts eight inches to a foot deep and two feet wide were not uncommon. Table 1 shows cross-sectional area changes at 10 measured points. It also shows volume change as computed on a basis of one linear yard of road at each cross section.

<table>
<thead>
<tr>
<th>Cross Section</th>
<th>Change in Area</th>
<th>Volume Moved</th>
<th>Grade Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sq. ft. road</td>
<td>Cubic yds. per one linear yd. of road</td>
<td>Per cent</td>
</tr>
<tr>
<td>I</td>
<td>5.4</td>
<td>0.6</td>
<td>17 SE</td>
</tr>
<tr>
<td>II</td>
<td>6.3</td>
<td>0.7</td>
<td>25 SE</td>
</tr>
<tr>
<td>III</td>
<td>2.7</td>
<td>0.3</td>
<td>20.5 SW</td>
</tr>
<tr>
<td>VI</td>
<td>6.6</td>
<td>0.7</td>
<td>17.5 S</td>
</tr>
<tr>
<td>V</td>
<td>15.7</td>
<td>1.5</td>
<td>15 SW</td>
</tr>
<tr>
<td>IV</td>
<td>5.1</td>
<td>0.57</td>
<td>17.5 S</td>
</tr>
<tr>
<td>VII</td>
<td>Trace</td>
<td>Trace</td>
<td>20 SE</td>
</tr>
<tr>
<td>VIII</td>
<td>1.3</td>
<td>0.14</td>
<td>15.5 S</td>
</tr>
<tr>
<td>IX</td>
<td>Trace</td>
<td>Trace</td>
<td>11.5 W</td>
</tr>
<tr>
<td>X</td>
<td>Trace</td>
<td>Trace</td>
<td>8.5 SW</td>
</tr>
</tbody>
</table>

How a small, local trouble spot may affect a larger stream system was brought out during the storm of April 11, 1947. Following this storm of 1.02 inches in 14 hours, samples were collected from (a) the stream draining Watershed No. 10, where logging was
going on; (b) from the main stream just above Watershed No. 10; (c) from the main stream, draining an area of 1800 acres, at a point below Watershed No. 10; and (d) from another main stream in the experimental forest draining slightly less than 1800 acres, on which there is no logging activity. The turbidities of these samples were as follows:

- Watershed No. 10 (212 acres) 1200 ppm.
- Main stream above Watershed No. 10 25 ppm.
- Main stream below Watershed No. 10 (1800 acres) 395 ppm.
- Another comparable main stream of nearly 1800 acres—(no logging) 25 ppm.

Thus it is seen that the origin of high turbidity in a large stream may be traced to a fairly small or localized area.

Better Location and Maintenance Needed

A number of common-sense improvements would go a long way toward lessening the destructiveness of most logging operations in the Southern Highlands. First, considerably more attention should be given to the location and grade of access roads. For instance, on Watershed No. 10, the road is so laid out that slopes as high as 26 per cent alternate with relatively flat stretches. Erosion on the steep sections is much harder to control because of the increased velocity and erosive force of the flowing water. Also, because of these steep slopes the road is highly dangerous in wet weather and in many cases impassable to truck traffic.

In any logging operation, and particularly where integrated multiple use is to be made of the logging area, the road lay-out should be designed to fit the area and the products to be obtained from it. Too often a road is punched in to reach one particular stand of timber without much thought to possible later use. Or one operator will build a road to get out the saw-timber and will be followed by an extract wood operator who may find the first road does not get to all the extract wood and proceeds to construct spurs and additions. In practically all cases these conditions result in more road than is actually required to get all the products. Experience of this sort shows that the location of all the various forest products in the area, together with a procurement and resource management plan, should be known ahead of time so that the road lay-out may be most efficient. Also, the possibility of amortizing the cost of a better road over a period of time rather than paying for a poor road from a single operation should be considered.

Erosion is Active at all Times

On completion of a job, some operators make a practice of diverting water out of roads and skid trails and placing brush on the worst eroding portions. Others do not take these precautions against continued erosion. In any case the most serious erosion and sedimentation may take place during the operation.

Another important factor is the length of time of the operation. It is not only important to the timber operator, but also extremely important to the watershed manager, since turbidities and soil losses are increased proportionately. In many cases where a proposed timber sale or removal contract is supposed to be completed in a year, it is still going at the end of two, three, or four years. Further operations to get out other forest products very often lengthen the time that the road is in use. Thus the widely-held opinion that the sale will be finished in a short time and that the damaging effects of the road or roads can be rectified following the operation is false. It is false also because, as has been pointed out, the greatest erosion, transportation of sediment, and resulting high turbidities occur while the actual logging is in progress on the watershed.

Road and Skid Trail Drainage Pays Off

The matter of road drainage can hardly be overemphasized. The motto of the military road builders is "Keep the water off and the rock on." The first part of this maxim definitely applies to the construction of logging roads. Since the roads are generally unsurfaced, the ever-present wheel ruts nullify the use of crowning or sloping the road surface for drainage. The ruts concentrate water and are frequently sources of serious erosion. This means that water bars or turn-
outs are almost invariably necessary in order to overcome the erosive concentration of water. Experience at Coweeta has shown that an open top culvert made of sawn timbers and pipe spacers has been entirely satisfactory for this purpose. Although more information about the design and installation of these water bars is needed, it is believed that existing standard open-tops or improvised buried log "thank-you-mams" can be readily used by operators.

Equipment May Have Some Answers
Track-laying equipment and winches are valuable aids in any logging operation. These, however, must be used with the watershed values kept well in mind, because their promiscuous use can very often result in conditions extremely conducive to erosion. The careful use of arches, sulkies, pans, cable systems and other equipment may do much to eliminate or reduce destructive erosion and sources of turbidities.

Many logging men are of the opinion that the introduction of simple, standard equipment in the southern Appalachians is entirely feasible and would make for a more efficient and cost-reducing operation, in addition to helping in the conservation of watershed values.

Important Road Design Consideration
Some of the design factors which are important in reducing erosion are as follows:

1. Grade and alignment.—Sustained grades above 12-15 per cent become difficult erosion control problems. In some cases it may be preferable to have a little more road and cut down on the grade. In most cases, however, a properly designed job will result in less road because of the elimination of spurs.

2. Road surface drainage.—Adequate surface drainage must be provided and maintained. Crowning, in-sloping, out-sloping, etc., is of little use on an unsurfaced road.

3. Stream crossing and location near streams.—Very often at stream crossings the water at high flows is diverted into the road. To avoid this, the approaches to the crossing should on both sides be downgrade into the stream so that at high flows the water merely rises on the portion of road immediately adjacent to the stream, instead of flooding a long section. Bridge and culvert openings should be of adequate size to accommodate flow. When the road runs parallel to a stream, effort should be made to stay at least 100 feet—and preferably 200 feet—away from the stream.

Other items, such as location of skid trails to avoid both the concentration of skidding and the formation of gullies, also deserve thought and attention.

Probably the most important general consideration in a properly designed and operated job is the question of maintenance. For the sake of the efficiency of the operation as well as a guard against a reduction in water quality, adequate maintenance of roads and skid trails must be continuously stressed. As already mentioned, much of the damage occurs during the operation, so it is faulty management to neglect the maintenance for any period of time and hope to catch up later on.

Ultimately, the problems and their solutions are related to economic considerations. The complications of logging contracting, sub-contracting, and sub-sub-contracting divide and obscure responsibility. In such a situation no one feels responsible for the preservation of water values. A complete discussion of these considerations is somewhat beyond the scope of this article. In almost all cases, however, the economic problems resolve themselves into one of possible increased initial capital investment versus much higher maintenance costs. Experience has clearly indicated that a properly regulated and operated logging job, utmost importance in connection with municipal and industrial watershed management.

Summary
For the most part, the difficulties of
while it may require higher initial outlay of capital, results in lower maintenance cost in the final analysis and a more efficient and profitable operation. In addition, the properly operated job which abides by known and demonstrated principles of watershed management maintains the water resource of the watershed. This is of harvesting wood products from areas of high watershed values center around the general problem of transporting the forest products out of the watershed onto main roads. The general problem may be broken down into three sub-problems connected with:

1. Location and design of access road and skid trails.
2. Use of road building and logging equipment.
3. Road maintenance.

Common-sense remedies will reduce the turbidity associated with the typical uncontrolled logging operation, and will also improve the overall efficiency of the operation itself. In order to test this on a practical basis, plans are being made to log another Coweeta experimental watershed of some 300 acres, using the best existing knowledge. Quantitative measurements similar to those described will be taken on the area.