Abstract—Soil and nutrient pollution of streams caused by woods roads, log skidding, mechanical site preparation, and prescribed burning are being studied in the Piedmont and Appalachian Mountains of the Carolinas. Stormflow from disturbed areas is measured by 1-foot H-flumes. Proportional samples for sediment and nutrient analysis are collected by 2-foot Coshocton wheels. Objectives of nonpoint-source pollution studies are to establish baseline levels of soil and nutrient loss, determine increases in losses due to certain forestry practices, and develop methods of estimating losses for other practices and other locations.

INTRODUCTION

Coweea Hydrologic Laboratory, near Franklin, North Carolina, was established by the United States Department of Agriculture, Forest Service, in 1933. Since establishment, the research goal has been to determine how man's use of the forest influences the quality, quantity, and timing of streamflow from small forested catchments in the Piedmont and southern Appalachian Mountains. For much of the past 44 years, water yield was emphasized, and both timing of flows and water quality received less attention. By 1970, research had demonstrated the changes in water yield that were possible with different cutting practices and vegetative types and relatively simple formulas were developed
to predict water yield after forest cutting. At that time, the research pro-
gram expanded to include nutrient budgets of undisturbed and manipulated
forests. Dr. Swank is reporting on this phase of the research.

The 1972 Federal Water Pollution Act Amendments set goals of "best practical
technology by 1977" and "best available technology by 1983," and focused
national attention on pollution and water quality. Nationwide, greater prob-
lems stem from nonpoint-source than point-source pollution (Pisano, 1976).
Furthermore, soil erosion is the major nonpoint pollution source. Prior
research has shown that erosion from stable forest lands in the East ranges
from only a few pounds to a maximum of 300 pounds per acre per year. Soil
lost from forest lands comes almost entirely from the stream channel, unless
disturbance has exposed mineral soil or changed natural drainage (Douglas,
1975; Patric, 1976). Because quantitative data on soil losses during site
disturbances is limited, research at Coweeta is being redirected to quantify
soil and nutrient losses from several types of forest disturbance.

Research at Coweeta focuses on the forest practices we expect to be typical
of future intensive management on both public and private land in the South-
east. No attempt is made to tie any of these practices to a particular silvi-
cultural system, such as clearcutting or selection harvesting. The rationale
behind this decision stems from knowledge that overland flow is an unusual
occurrence from a litter-covered forest soil in the East, even after the trees
are cut. Felling and bucking trees into logs have negligible impacts on soil
compaction, infiltration, surface runoff, or erosion. During timber sales,
erosion occurs primarily on sites where litter has been removed or destroyed
and soils have been compacted by skidding and decking logs or building roads.
Similarly, mechanical site preparation compacts soil, reduces infiltration,
and exposes large proportions of the prepared area to erosion. To a lesser
degree, fire removes some of the energy-absorbing litter and paves the way for
erosion and nutrient loss.

The current research program involves the USDA Forest Service, several
universities, and the North Carolina Forest Service. Our initial efforts are
concentrated on activities that produce the greatest disturbance and, there-
fore, are potentially important causes of nonpoint-source pollution from
forest land. Pollution from roads and logging are being studied in the sou-
tern Appalachian Mountains, and site preparation and fire are being studied
in the Piedmont.
METHODS

In general, the instrumentation and analyses used to determine soil and nutrient loss are the same for each study. Variations in methods are covered as each study is described.

Runoff from each sample plot is directed into a plywood trough that serves as an approach section for a 1-foot H-flume (Agricultural Research Service, 962). The trough is 27 inches wide, 19 inches deep, and varies from 5 to 10 feet long, depending on the steepness of the terrain (Figure 1). A 2-foot diameter Coshocton wheel (Parsons, 1954) mounted below each flume diverts approximately 0.5 percent of the flow into a plastic barrel. Where large flows are expected, a 10:1 splitter is placed in the drainline to reduce the routed sample to about 0.05 percent of the total flow (Figure 2).

Total flow is measured by two techniques. At some sites, stage height is measured by either a stripchart or a punchtape recorder at a stilling well connected to the H-flume (Figure 3). Flow volumes are calculated both daily

Figure 1. This typical sediment sampler, composed of an approach section, H-flume, and Coshocton wheel, was installed on a newly cleared watershed for a study of the effects of mechanical site preparation.
Figure 2. A 10:1 splitter is installed in the drainline between the Coshocton wheel and the sample storage barrel where necessary to reduce the sample volume to manageable size.

Figure 3. This is a typical recorder installation. The stilling well is a modified raingage can beneath the recorder shelter; it is connected to a 1-foot H-flume by tubing.
for storm events. For sites without recorders, the volume collected in sample barrel is multiplied by a sampling ratio to determine total flow in the sample interval. Before installation, the flume, wheel, and splitter each of these sites were calibrated together in the laboratory with trolleyed flows ranging from 0.5 to 80 percent of flume capacity. Operation of a recorder has the advantages of simplicity and economy. Disadvantages and potential problems are that: (1) total flow volume is the only parameter obtainable; (2) wheel and splitter operation is intermittent at very low flows (0.0007 cfs), but at these low rates, volume errors are small when compared to total runoff volume; (3) sample volumes are inaccurate in ice builds up on the wheel, in pipes, and in the splitter; and (4) reductions in velocity caused by sampling such a small fraction of total flow reduces carrying capacity of runoff and causes deposition of soil in the flume, possibly changing the splitting ratio when large volumes of soil are being transported. This last problem may be overcome by building a larger sediment trap in the approach section.

After each storm, the soil deposited in the approach section is measured and subsampled to determine total dry weight. Soil texture and nutrient contents are also determined. After the volume is measured, the sample in the barrel is thoroughly stirred, and two subsamples are collected. The sediment in one subsample is determined gravimetrically by filtration through fiberglass filters (0.42 μm pore size). The supernate of the other sample is analyzed by methods described by McSwain (1973) and McSwain et al. (1974) for NO₃-N, PO₄-P, NH₄-N, Cl⁻, SO₄²⁻, SiO₂, Na⁺, K⁺, Ca²⁺, and Mg²⁺. The total phosphate and total nitrogen contents of the centrifuged solids are determined by perchloric acid and Kjeldahl digestion procedures.

Total sediment loss per storm event is determined by multiplying total discharge for the sampling period by the sediment concentration of the sample and adding the weight of sediments deposited in the approach to the flume. Ion loss is the product of ion concentration multiplied by flow volume plus nutrients transported on soil. Ultimately, both soil and nutrient losses will be expressed in weight per unit source area, and soil loss will be correlated with rainfall and runoff amounts and rates.
STUDIES

Soil loss from roads

The Forest Service operates one of the largest road systems in the world (Forest Service, 1975). Approximately 84 percent of this system is classed as limited-use service or temporary roads, primarily constructed to provide access to timber sale areas. On private land, unpaved roads are built to similar, and often lower, standards by land developers, timber companies, and individual land owners.

At the Coweeta Hydrologic Laboratory, we are quantifying soil loss from roads built for a timber sale. Of the 4.6 miles of road built, 2.8 miles are outside the sale area, so the effects of road construction and use may be studied separate from the logging activity. Road location and design were specified, and construction was supervised by National Forest engineering personnel.

Some features of the roads include: backsloping cut banks and stabilization of cut and fill slopes with grass; road compaction by earth-moving equipment only; draining of the road surface by outspooling and by broad-based dips spaced about every 200 feet (Figure 4); culverts at all perennial and intermittent streams; 50-foot-radius curves; 8-percent maximum grade; and gravel surfacing of portions of the 10-foot travelway. The road traverses precipitous terrain, where some slopes exceed 100 percent. Debris barriers were constructed below all fill slopes using forest materials cut from the road right-of-way (Figure 5).

One objective of the road study is to measure actual soil loss during several traffic periods from portions of the road representing a range of construction practices. Sampling sites were chosen to contrast three soils, two design standards for cut-slope angle, and four types or degrees of roadbed surfacing. Study soils are a brown sandy loam laced with decomposed schist rock, a red clay, and a dark organic soil. Most cut-slope angles were selected by empirical rules based on steepness of terrain, but engineering soil tests were used to design one test section. Types of road surfacing are: a layer of crushed rock at a thickness specified from load-bearing tests on the soils in the road; a thinner layer of crushed rock, roughly one-half the
Figure 4. Drainage from a road built on moderately steep terrain is collected by a broad-based dip and channeled into a flow measurement and sampling installation.

Figure 5. Debris barriers at toe of road fill are constructed of slash from the cleared right-of-way. They are intended to trap soil material which may wash from the fill slope.
specified depth; a thick layer of washed 3-inch stone; and no gravel at all.
The study covers four use periods: stabilization immediately following
construction, limited use by the public, heavy use by logging trucks, and
limited use after logging ceases.

At each sampling site, overland flow from a test section of the roadbed is
collected in the drainage dip and directed by pipe or chute into the approach
section for measurement and sample collection (Figure 4). Because the roadbed
is outsloped and has no inside ditch, the measured flow from the roadbed at
six sites includes water and soil from both the cut bank and road surface.
Separate estimates of soil and water from the cut and fill slopes are based on
collections from 19 small troughs set into the slopes (Figure 6). These
troughs are 4 feet wide. The sides of plots, sampled by these troughs are
defined by short walls and the naturally developed drainage pattern above the
trough.

At two other sites, dikes have been constructed on the forest floor below
the debris barrier to direct any overland flow of water and sediment into
approach sections for measurement and sampling. Paired measurements above and

Figure 6. Soil and water from
road fill are collected by a
4-foot-wide trough sampler.
below the barrier at each of these two sites provide estimates of the effectiveness of the barrier. These measurements are extended by visual surveys of soil deposition patterns along the length of the road.

Two small perennial streams pass through measurement and sampling installations below the road. Flumes were installed on both streams shortly before construction began. Most of the sediment collected at these two sites came from gullying of the fills at the stream crossings plus failure of one debris barrier on an exceptionally steep slope above the stream.

The second objective of the study on roads is to test a process simulation model (Simons et al., 1975). The computer model, developed for the Rocky Mountain Forest and Range Experiment Station by members of the Colorado State University Engineering Research Center, simulates soil detachment and transport as functions of soil texture, infiltration rate, porosity and surface cover, precipitation intensity, and land slope. The model can route the estimated water and soil volumes along channels or across adjacent road or forest floor surfaces and then determine whether deposition or additional detachment occurs.

To test the model, separate measures of soil loss from the cut bank, fill slope, and road surface are required. At two sites, 50-foot troughs were inserted into the fill slopes to collect runoff and direct it to the measurement point. A berm along the top of the fill prevents water on the roadbed from reaching the fill. Soil and water from the cut banks are intercepted by 150-foot-long troughs and are separately measured. Runoff from the road surface is measured as before.

In total, instrumentation for the road study consists of 19 small troughs collecting total samples and 15 sites using the H-flumes with FW-1 chart recorders to measure flow plus Coshocton wheels to collect subsamples. Road construction began in March 1976. Data collection may continue for 3 years.

Soil and nutrient losses from cable logging

The Environmental Protection Agency (1973) believes that forests growing on slopes greater than 60 percent cannot be harvested with conventional equipment used in the East without causing unacceptably high rates of erosion. With cable systems that lift part or all of the log clear of the ground during skidding, these lands might be managed without unacceptable erosion.
The new roads at Coweeta provide access to a watershed that is being harvested by the highlead cable-logging method. One objective of this study is to quantify the soil loss that results after vegetation is clearcut and logs are removed by this method. We seek to obtain separate estimates of erosion from roads and from felling and skidding. The combined effect of logging and roads will be measured at a 90-degree V-notch weir. Proportionate and grab samples of streamflow are collected for particulate and nutrient analysis. Depositions in the ponding basin are measured quarterly, and samples of the sediments are analyzed. Similar measurements are being made at the weir of a nearby control watershed and will be used to estimate the change in soil loss from the treated watershed and to establish baseline values for undisturbed forest. Sediment losses will be determined before and after logging on three 10- to 15-acre subdrainages that are unaffected by roads. The effects of roads will be determined by differences. These measurements will span four periods: before road construction, after construction when only roads will constitute the disturbance, during logging when both roads and logging are potential contributors, and after logging is complete. Logging began in January 1977 and should be finished by fall.

soil and nutrient losses from mechanical site preparation

In order to increase production of pine in the South, forest owners often employ practices akin to those in agriculture. After harvest or salvage of existing stands, the remaining vegetation is cleared with heavy mechanical equipment and pines are planted. Soil disturbance is extensive (Figure 7).

In cooperation with the North Carolina Forest Service, soil and nutrient losses are being measured on areas mechanically prepared for planting pine. We wish to quantify the initial effects of site preparation on soil and nutrient loss, determine how these effects change as vegetation becomes established in the sites, and compare measured soil losses with those estimated using the Universal Soil Loss Equation (Wischmeier and Smith, 1965). Four treatments are replicated at four locations in the North Carolina Piedmont. A treatment set consists of a control area (hardwood or pine stand that has not been disturbed in the past 5 years) and three areas that have been logged and then cleared with a bulldozer and KG-blade. Debris was piled and burned in
Figure 7. After logging, the residual vegetation on commercial pineland is cleared and piled in windrows, and the site may be prepared for planting trees by disk ing with heavy equipment, as shown.

The three disturbances are: clearing only, clearing followed by disk ing, and clearing, disk ing, and planting a grass cover crop.

Soil and water yields are measured by methods similar to those used in other studies except that streamflow is not recorded continuously. The sample collected by each Coshocton wheel and 10:1 splitter is multiplied by the calibration ratio determined in the laboratory to get total discharge. The study is installed and measurements were begun in January 1976; it will continue for about 3 to 4 years.

Soil and nutrient losses from prescribed burning

On many sites, prescribed burning is a viable alternative to mechanical treatment for preparing sites for pine regeneration. Although burning reduces less disturbance, it exposes the soil surface to erosion and may increase nutrient losses.
In cooperation with Clemson University, the effects of prescribed burning as an alternative method of site preparation are being studied on eight small (1- to 5-acre) drainages. The study is in the South Carolina Piedmont on the Clemson University forest. The experimental design uses four pairs of treated and control watersheds. Forest cover is a 40-year-old loblolly pine stand that was planted on eroded old fields (Figure 8). Eight H-flumes with punch-tape recorders, Coshocton wheels, and 10:1 splitters are installed in ephemeral streams that are remnants of old gully systems. Measurements began in November 1975 before the forests were burned. The first prescribed burn is scheduled for this spring. A second burn will be made next fall, and will be followed by seed-tree cutting to regenerate the new pine forest.

Figure 8. The forest floor of this 40-year-old loblolly pine plantation will be prepared for natural reseeding using two prescribed fire treatments.
SUMMARY

During the past 6 years, emphasis in the research program at the Coweeta Hydrologic Laboratory has shifted from water yield to water quality. Studies in mineral cycling and erosional losses from undisturbed and manipulated forests have been started. Nonpoint-source pollution studies are disturbance-oriented, rather than directed toward specific silvicultural systems. Soil nutrient losses associated with highlead cable logging, forest roads, mechanical site preparation, and prescribed burning are being studied in the southern Appalachians and Piedmont. The three-phase goal of these investigations is to establish baseline levels of soil and nutrient export, to measure increases in export rates caused by several types of soil disturbance, and to develop methods of extending results from gaged to ungaged catchments.

REFERENCES


DISCUSSION

Holtan: I was pleased to note that you go entirely to type H flumes and broad crested weirs. In runoff that contains trash such as leaf litter and so forth, these will pass the litter whereas with your sharp crested weir there is a tendency for these things to cling to edges. Do you have problems with sediment settling out in the flumes?

Swift: We would have to produce a serpentine pattern or something of that sort to reduce the flow rate. I assume you are speaking of the sampler that is below the road bed. The flow that comes off the road is very flashy. It comes only during the rain period and then it really comes down. The soil that comes with it tends to slow it down pretty adequately. Our biggest problem is that we get a pretty good measurement of the head during the rising limb but then we get a deposit of soil in front of the holes into the well that connects up with the recorder and then we never know when the storm ended. We had to decide whether it would be more to our advantage to deposit the larger materials in the approach section or to try and flush them through. We put a false bed in one of the boxes with a grate, it wasn't quite that steep, I think it was about 6 percent and it didn't flush the material out so we went back to the flat bottom and felt it was better to deposit it where we could measure it rather than clog up the whole system from then on. We found that the larger material went into the Cohocton wheel then just blocked up the system underneath the wheel starting with the pan below the wheel then onto the plumbing and into the barrel.

Beyerlein: Have you done any cost analysis of the different types of logging practices?

Swift: That is part of the study, the economics group from the Southeastern Forest Experiment Station is observing the logger, determining how much longer it takes him to set up this fancy equipment. One of the purposes of this study is to show that this form of logging might be both beneficial as far as environmental protection but it might also be economically advantageous.