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FORESTRY ACTIVITIES AND WATER QUALITY IN ALABAMA: Effects, Recommended Practices, and an Erosion-Classification System

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Forestry Activities and Water Quality in Alabama: Effects, Recommended Practices, and an Erosion-Classification System

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INTRODUCTION

THIS REPORT has been prepared primarily as a source of information regarding the relationships between forestry practices and water quality. Its emphasis, orientation, and interpretations are directed most heavily toward practices and conditions currently found in the State of Alabama.

There is a large body of literature relating to forests, forestry, and water. Directly cited in this report are 162 scientific reports, reviews, texts, and essays on these subjects. The files gathered and referenced for this study include several hundred more papers. Obviously, the subject matter is broad and encompasses many scientific disciplines, including hydrology, ecology, silviculture, engineering, biology, economics, soil science, meteorology, geology, chemistry, and physics, among others. Volumes could be extracted from available sources and knowledge about most of the major topics of this report.

The attempt here was to extract that which seemed pertinent to the questions addressed for Alabama and to present it simply and fairly concisely. The statements have been interpreted and colored by the senior author's knowledge, observations, and experience, including 7 years of teaching a college course in forest watershed management, personal observations of forests and forestry in Alabama, and both teaching and research in the fields of silviculture and ecology.

In spite of all the material written, there are still many gaps in scientific knowledge about many of these issues. Forest ecosystems are complex, and a wide diversity of them occurs in Alabama. The

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forest resources of Alabama, which include high quality water, are of immense value. We must use all of the knowledge available, and work toward obtaining more, so that we can simultaneously wisely utilize and protect all of these resources.

This report proceeds first with a description of potential pollutants and possible pathways for their entering forest water bodies. The second major section is primarily a summary of information about major silvicultural and harvesting activities as they relate to water quality. The third major section provides a direct statement of recommendations of principles and practices designed to aid in watershed management and to minimize the probability of adverse water quality effects from forestry practices in Alabama woodlands. These were developed from scientific reports, recommendations by other scientists, and personal knowledge and experience of the authors. They should largely be taken as suggestions and some are not appropriate for all possible circumstances.

The last major section is an attempt to provide a relatively simple framework for making assessment of erosion hazard in Alabama's forest lands easier for knowledgeable practitioners. The land type classification and descriptions were intended to serve as a starting point for planning and for identification of most likely important factors to be considered in on-site assessment.

TYPES AND SOURCES OF STREAM POLLUTANTS IN FORESTED WATERSHEDS

Sediment

Sediment can be defined as solid material, both mineral and organic, which has been eroded from its original location by wind, water, ice, gravity, or some other agent and is being transported or has come to rest on the earth's surface *(135)*. Suspended sediment is that most directly affecting stream or water quality. It is particulate matter light enough so that it is suspended in moving water *(18, 73)*.

Sediment is generally the most widespread and important pollutant in streams from forested watersheds *(133)*. It affects the uses to which water can be put, particularly for domestic water supply, fish production, or recreation. Public health standards restrict the amount of suspended sediment allowed in municipal water supplies, so increased sediment increases water treatment costs. Although sediment seldom reaches levels that are directly lethal to fish, it can interfere with spawning, cover, and food, and adversely affect the aquatic food chain by blocking light *(8, 18)*. Aesthetically, sediment-laden water is usually objectionable and is often avoided for some recreation uses, such as swimming.

Sediment also produces problems when deposited in stream channels and reservoirs. It reduces the capacity of the stream to carry water and of reservoirs to hold water. This in turn can cause increased flooding, decreased water supplies, decreased water power potential, and increased costs of maintaining navigability of waterways *(8)*.

Sediment also serves as a carrier for nutrients and chemicals, such as fertilizers and pesticides. These can become adsorbed and attached to the clay and silt-sized particles, which are the most easily transported as suspended sediment *(14, 133)*.

Suspended sediment in water decreases light penetration, a characteristic termed "turbidity." Turbid water tends to have a higher temperature than clear water due to heat absorption. It also typically has a lower dissolved oxygen content. This lower dissolved oxygen occurs both because warmer water holds less oxygen and also because the organic component of the sediment increases biochemical oxygen demand *(133)*.

Suspended sediment concentrations are highly variable, even in a given stream *(18)*. Concentrations are generally highest during periods of peak flow. This makes quantitative assessment of sediment levels complex. The questions of when and how sediment concentrations should be measured, and how to assess effects of sediment at varied levels, are important but difficult ones.

"Bed load" is sediment which spends much of the time on the stream bottom. It is primarily sediment which is too heavy to be continuously suspended in flowing water. Much of it is rolled or bounced along the bottom, but some of it may become suspended temporarily during periods of peak flow when water velocity is sufficient to carry it *(18)*. Bed load poses a special problem in studies attempting to determine a cause and effect relationship between watershed treatments and stream sediment concentrations. Material that is already in the stream channel as bed load before the treatment or activity can become suspended sediment during high stream flow levels. This makes it difficult to separate the treatment effects from effects of sediment that was produced earlier and usually upstream.

Erosion is the process whereby most sediment is produced. It is the first phase of the process which includes sedimentation. Erosion refers to the removal of material and sedimentation to its deposition

(73, 133). Sediment can be produced directly as decomposing organic debris, but that of most concern and greatest amounts is from erosion.

The erosion process involves detachment, transport, and deposition of soil or other particles. Detachment occurs when a soil particle is dislodged from the soil surface or from a soil aggregate. Falling raindrops and drip constitute the greatest sources of detachment energy for soil erosion in forests *(133)*. This can occur, however, only when the surface is exposed. Detachment can also result from flowing water. The detachment energy of a given amount of water is much greater as raindrop splash than as surface flow, however *(73)*.

Usually, greater force is required to detach soil particles than is necessary to transport them. The bonding forces between soil particles can be strong in well-aggregated soils. Individual soil particles are much more easily carried. Transport of soil particles is also possible by raindrop splash, but usually only for short distances. Most water transport of sediment is by water flowing along the soil surface in rills, gullies, or stream channels.

Deposition of sediment occurs when the forces available for transport of soil particles are no longer sufficient to offset gravitational pull. The major factor influencing this is velocity of flow. Thus, flowing water tends to deposit sediment wherever it slows. Of course, the heavier particles are deposited first, the lighter ones last.

This means that the finer, smaller, clay and silt particles reach a stream more quickly from erosional processes upslope than do the heavier sand particles. Such was found to be the case by Hewlett *(72)* in the Georgia Piedmont and Beasley *(9)* in the Coastal Plain of northern Mississippi. It also means that anything slowing the movement of sediment-carrying surface water before it reaches a stream will cause some deposition of sediment at that point and thus reduce the total amount which reaches the stream.

There are three basic types of erosion: surface erosion, mass movement, and channel cutting. Surface erosion by water is the movement of individual soil particles from the soil surface. In Alabama, the usual agents are falling rain, flowing water, or the chemical activity of water. It involves splash, sheet, rill, and gully erosion. In forested situations, all of these normally require exposed or disturbed soil surface. Chemical solution may occur even without exposed soil, but is greatly speeded by exposure.

Mass movement of soil occurs under the influence of gravity as landslides, slumps, or soil creep, mainly on steep slopes. This type of erosion is most important in mountainous terrain. However, it can be important on a small scale level on any steep road cut or fill.

Channel cutting is a natural process normally occurring in most streams. The natural process is most rapid where the stream has a low base level. Cutting may be vertical and/or lateral. As streams meander, banks are undercut and slump into the channel, thus increasing sediment load. Cutting is accelerated by increased water flow, which may result from some management activities.

Natural erosion is a geologic process which occurs even without any influence of man. Thus, sediment will be produced at some level without any human intervention *(18)*. Man-induced increases and erosion rates are typically referred to as "accelerated erosion." Both natural and accelerated erosion occur at highly variable rates and are commonly not easy to separate *(18)*.

Suspended sediment in streams from managed forest lands cannot automatically be attributed to forest management. Channel cutting, particularly during peak flows, and other forms of natural erosion do occur, although, as documented later, they are usually small in total quantity from undisturbed forests. A more important confusing factor in some southern forest streams is the legacy of sediment left from previous poor agricultural practices. Hewlett *(71)* indicated that a tremendous amount of sediment load in Georgia's forested Piedmont streams and rivers was originally deposited there during the time the land was farmed and is still slowly being flushed downstream. Ursic and Duffy *(151)* found that most of the sediment produced from pine-covered watersheds they studied in northern Mississippi actually was produced from ephemeral channels which had been created during prior agricultural use.

In looking at surface erosion as a source of stream sediment from Alabama's forest lands, it is important to note that erosion does not necessarily produce stream sediment. Many, and probably most, soil particles detached and moved on forest lands are deposited before they reach a stream channel. Some accelerated erosion will always occur whenever the natural forest soil surface of litter, organic matter, and debris is disturbed and the soil exposed. However, on forest lands this eroded material may be stopped quickly by an irregular surface, litter, debris, rock, or man-made diversions between the source and the stream. Thus, where erosion occurs, stream sedimentation does not necessarily follow.

This is not to downplay, however, the potential of accelerated surface erosion for causing degradation of forested stream quality. It is clear that it has tremendous potential for such degradation.

Nutrients

Mineral nutrients are natural components of water bodies and are necessary to maintain aquatic ecosystems. Concentrations of dissolved minerals in water from undisturbed watersheds are generally low *(18, 133)*. Mineral and organic nutrients enter streams naturally by: atmospheric input (from dust, rainfall, and fixation by organisms); weathering and decomposition of rock; natural erosional processes which move particulate matter and organic materials directly into the stream; and leaching of nutrients from the soil. Since these input sources vary, natural nutrient levels vary widely and fluctuate, even for a given stream *(18, 53, 90, 148)*.

Nutrients in high concentrations can cause water quality problems. Drinking water standards specify maximum amounts of dissolved ions *(49)*. Waters exceeding such levels require treatment for their removal. As with most pollutants, the intended use will define high levels and determine if they are a problem.

Another potential problem resulting from drastic increases in nutrients in water bodies is that of destabilization of the aquatic ecosystems involved. Enrichment of a water body with nutrients which are naturally in short supply, such as phosphorus or nitrogen, will usually result in a rapid increase in algal populations which were formerly limited by lack of these nutrients. Such an algal "bloom" may cause rapid and undesirable changes. Formation of a mat of algae or "scum" at the water surface can block light penetration and reduce the aesthetic qualities of the water. Decomposition of the greatly increased biomass as it dies will increase biochemical oxygen demand, leading to a reduction in dissolved oxygen. This, in turn, may lead to death of fishes and other normally occurring aquatic fauna. This process, termed "eutrophication," has commonly occurred in water bodies receiving some domestic sewage rich in phosphates.

In forestry situations it is possible to get some nutrient enrichment from recreational areas, particularly at developed campgrounds. Leaching from outdoor toilets, discharge of sewage from facilities, and dishwashing directly in the stream are the most likely possibilities.

Drastic alteration of nutrient cycling patterns in the forest ecosystem is another potential avenue of elevated nutrient input to streams. Sudden complete removal of large amounts of vegetation which normally take up nutrients from decomposing matter can interrupt the cycling process and result in increased leaching of nutrients from the soil system through ground water, subsurface, or surface flow to a stream. The potential for this was most dramatically demonstrated by an experiment at the Hubbard Brook Experiment Forest in New Hampshire *(90)*. However, as discussed later in this report, the conditions and rather drastic treatments involved there make their findings completely inappropriate for extrapolation to normal forestry practice or to Alabama conditions. There are other studies which bear directly on timber harvesting.

Human application of fertilizers to increase forest growth is a significant potential pathway for nutrient enrichment of water bodies from forestry practices. This can get to the stream most readily from aerial applications in the stream area. From these and ground applications, it is possible for nutrients from fertilizers to move to a stream in surface flow, subsurface storm flow, or by leaching into ground water.

Pesticides

The use of pesticides in silvicultural activities should be examined in two separate categories: those for controlling undesirable plants (herbicides); and those for controlling undesirable fauna (insecticides and rodenticides). Chemicals in these two categories generally differ markedly in their nature, application, and toxicity. Also, their levels of use are vastly different in Alabama.

Silvicultural herbicides are used for concentrating productivity on selected species. This is accomplished by reducing the number of unwanted plants which may compete with the desired species for limited resources of space, light, water, and nutrients.

Herbicides are particularly useful for silviculture in the Southern United States. Southern pines are the most widely managed and economically the most important tree species in Alabama. Southern pines are intolerant of shade and occupy an intermediate position in ecological succession. This means that the pine forest manager must continually work against the natural successional tendencies which are toward hardwood dominance. The three major approaches to this, which are used alone or in combinations, are mechanical treatment, burning, and herbicide application. Where feasible, the latter two are usually cheaper and pose less threat to site productivity than mechanical treatment, particularly in site preparation for regeneration.

Herbicides are widely used for silvicultural purposes in Alabama. Their most widespread use currently is for site preparation, that is, for reducing competing hardwood species and vines in the establishment of pine seedlings. The trend seems toward increasing this use. Herbicides are also widely used for pine release, although this is not as great as before 2,4,5-T was restricted to certain non-forestry uses. The methods used will be discussed more fully in a later section of this report.

Insecticides are rarely if ever used in wide scale application to forests in Alabama at present. Some limited use in Christmas tree plantations is likely. These are generally applied by hand or with small equipment such as farm tractors. In some other areas, particularly the Northeastern and Northwestern United States, some insecticides are applied over broad areas to combat widespread infestations, particularly of gypsy moth and tussock moth. It is possible that such large scale infestations of one or more forest insects, such as the gypsy moth, could occur in Alabama in the future.

Insecticidal use on forest lands has been tightly regulated in recent years. The materials now registered as insecticides for aerial application, with the exception of endosulfan, are short-lived organophosphates and carbamates. Endosulfan is used principally on local insect outbreaks, in Christmas trees and ornamentals *(110)*. Generally, most of the presently registered insecticides are relatively immobile and short lived. Chlorinated hydrocarbons (DDT being the best known), however, are quite toxic, persistent, and subject to biomagnification in aquatic systems. These pesticides are no longer used except in rare instances, and then only after specific government approval *(14)*.

Rodenticides, specifically endrin, are used only to a limited degree in Alabama as a repellent on pine seed. The total quantities employed in a particular area are small and their total effects on water quality are not likely to be detectable *(110)*. The amounts in a particular basin would be miniscule in comparison to common agricultural use of insecticides.

Herbicides are chemicals produced to kill or defoliate green plants. They employ various modes of operation. Forestry herbicides are toxic to animals and to man but generally only at high levels and in varying manners *(18,110)*.

Toxicity is a complicated concept. Toxicity may be acute (after short exposure time) or chronic (after long exposure time). Most toxic effects are not lethal. Any chemical-induced change which adversely affects an organism is a toxic effect. These effects can include reduced growth, reduced reproduction, cancer, and organ malfunction or failure. The nature of a toxic effect is a function of the characteristics of the chemical, characteristics of the organism, the size of the dose, the frequency of the dose, and the duration of the dose *(18)*. A large number of commonly used substances, such as aspirin, salt, and sugar, can be toxic under certain circumstances.

The important questions regarding the potential of forestry chemicals (herbicides, other pesticides, and fertilizers) as toxic materials in water bodies revolve around the possibilities of these chemicals reaching high enough concentrations for sufficient periods to produce toxic effects on aquatic organisms or upon water users. Knowledge of the behavior of forestry chemicals in the forest under likely conditions of use and information about acute and chronic toxicity characteristics should be used together to assess the potential hazard.

Brown *(18)* has presented data on toxicity of common herbicides, insecticides, and rodenticides. Norris *(111)* also presents such data. These data illustrate that the toxicity of commonly used forestry herbicides (such as the phenoxys and picloram) are mostly 1,000 to 10,000 times less toxic to aquatic insects, crustaceans, and fish than are some of the more toxic insecticides, such as DDT, dieldrin, and aldrin (which are now essentially not used in forestry). Registration of any pesticide by EPA follows only after rigorous evaluation of its safety and usefulness under specified conditions of use. Additionally, the registration of a particular pesticide may be withdrawn by EPA anytime a potential hazard to public health or the environment is suspected *(18)*.

The herbicides currently most widely used and which are likely to continue to be used in Alabama for silviculture are 2,4-D, picloram (Tordon), silvex, 2,4-DP, hexazinone (Velpar), and triclopyr (Garlon). Other herbicides are used and some more are now being tested for possible registration and use. Forestry herbicides are applied in four basic ways: to foliage, to the soil, to basal portions of stems, or to cuts made through bark. The latter two approaches involve low probability of the herbicides ever reaching a water body—almost none for cut surface application.

Foliar application involves the greatest potential for the chemical to reach a stream. Much of the foliar application is aerial by helicopters or airplanes. A lesser amount is applied from the ground, typically by a tractor-mounted or backpack mist blower or sprayer. The greatest hazard is through direct application and entry of the herbicide to a water surface. This can occur by simply including the stream in the area covered by the spray or by the material drifting from the intended target area through the air to the water.

Soil application of some herbicides has recently become more widespread with the registration of picloram (Tordon) and hexazinone (Velpar) for forestry use, although others are also soil-active. These formulations are moved into the soil by rainfall and taken up into the root systems of plants. Application of soil-active herbicides is accomplished both at ground level and from the air. Pelleted hexazinone and picloram are frequently applied aerially. Such aerial application poses the greatest hazard, for avoidance of stream channels is not quite as simple as when applied from the ground.

The major modes of transport for forestry herbicides to a water body are three: directly through the air (direct aerial application or by drift); in surface water runoff; or through leaching processes in soil water or ground water. The third of these poses the lowest degree of hazard. Leaching or subsurface flow of most pesticides is considered a relatively slow process which is capable of moving only small amounts for relatively short distances *(111)*. Many pesticides are quickly adsorbed by soil particles or organic matter or taken up by plant roots *(18)*. Picloram, hexazinone, and amine formulations of 2,4-D are the most water soluble herbicides used commonly in Alabama forests and would have the highest probability of reaching streams through leaching.

A greater hazard is that of movement in surface runoff. Again, water solubility increases chances that compounds adsorbed on particulate matter can be moved with these particles. However, as will be discussed more thoroughly later, surface water flow in well-developed forests is usually low or nonexistent, except where the soil surface has been severely disturbed.

Obviously, the highest degree of hazard is that of direct application of the material to a water body. Here, by definition, the material reaches the stream. Care in application is the major safeguard.

Organic Material

Excessive or badly placed forest organic debris in streams can have adverse effects on water quality. This includes whole trees, logs, slash, litter, and soil organic matter. The adverse effects are primarily of three types: effects on the aquatic ecosystem through increased biochemical oxygen demand, effects on the flow of the stream, and effects on aesthetics. It is also possible on some streams for debris to pose a hazard to navigation or recreation. Drastic increases in organic matter in streams can alter the stability of the aquatic ecosystem. As this material is broken down both by decomposer organisms and chemical action, the processes absorb dissolved oxygen in the water. If serious reductions of oxygen result, many aquatic organisms will either leave or die. This effect is most likely to be significant in sluggish, slow moving streams with low total water flow. Most rapidly flowing and large streams are not as likely to be noticeably affected in this manner by potential amounts of debris from forestry activities.

Streamflow itself may be affected. Debris dams can form, especially during periods of high stormflow. These can cause increased flooding and in some cases temporary rerouting of the stream. Less drastically, debris can cause redirection of flow in the channel, thus increasing bank cutting and the resulting sediment production *(44, 91)*. The potential aesthetic effects are obvious, though the significance of this will depend upon the location. Placement of organic materials and debris in streams by forestry activities is most likely from road construction, direct tree felling, skidding through or in streams, mechanical site preparation, using debris or log piles for makeshift stream crossings, and placement of loading decks close by streams. These are avoidable under most circumstances by reasonable care.

Temperature

Temperature is a principal regulator of biological activity in aquatic ecosystems. Since the capacity of a liquid to hold a gas in solution is inversely proportional to its temperature, the temperature of a water body determines to a large degree how much oxygen it can hold. Adequate oxygen is necessary for survival of fish, aquatic insects, and crustaceans.

Most aquatic organisms, including fish, are cold blooded. This means their bodies assume the temperature of the water in which they live. Thus, water temperature strongly affects their metabolic activities. For specific organisms, these metabolic activities can operate in a particular limited range of temperatures. Above or below this range the organism cannot survive, and an even narrower range of temperature normally defines the optimum for activity and development of particular organisms. Thus, temperature affects and may determine the composition of an aquatic community by influencing the species which can survive and those which can dominate *(16, 18)*.

The primary source of heat for small forest streams is solar radiation directly striking the stream surface. Little heat comes directly from the air by conduction or convection *(18)*. This has important ramifications for stream temperature control. It is exposure to direct sunlight, not exposure to warm air, which will have the most significant effect on stream water temperatures *(18)*. For small streams, this means that shading from riparian or streamside vegetation has a strong influence on the water temperature regime.

Therefore, removal of vegetation which shades a stream can have a marked effect on the stream's temperature regime due to the increased solar energy input. The height of any streamside vegetation and its orientation relative to the stream are obviously important. Tall overhanging trees are most effective in shading. However, on various small streams even shrubs or brush can provide significant shade. Vegetation south and west of the stream is generally more important than that on the north and east sides, since the sun angle is more direct and the intensity greater from these directions during the midday and afternoon.

There are also stream characteristics which affect the temperature response of a stream to direct sunlight. These include amount of flow, amount of surface area, nature of the stream bed, and water clarity. The temperature change produced by a specific amount of heat is inversely proportional to the volume of the water heated *(18)*. Thus, small streams with low discharge rates should heat up faster than larger streams with higher discharge. Also, under otherwise similar conditions, a given stream will be likely to reach higher temperatures during a period of low flow compared to a period of high flow.

Magnitude of temperature rise also varies directly with the amount of water surface exposed to the sun *(18)*. Thus, for the same flow, a wide shallow stream will get hotter than a narrow, deeper one.

If the stream is fairly shallow and clear, the nature of the stream bed may affect its temperature regime. Dark-colored stream beds and rock stream beds absorb more heat than light colored and silt bottoms. High heat absorption by the stream bed tends to lower the stream's peak temperature and broaden the peak periods *(18)*. The bed reradiates absorbed heat after the sun goes down.

Thus, small streams, particularly those which have rocky or wide channels, are the most sensitive to changes affecting direct sunlight *(18, 142)*. Large creeks and rivers should be less affected.

The specific consequences of water-temperature rises in Alabama streams are not clear. Temperature rises above lethal limits have been documented for trout streams in other states, including North Carolina *(141, 142)*. It is not clear that any suitable trout streams exist within Alabama. For trout, stream temperature should not exceed 70°F, and should preferably stay below 68°F. If any Alabama streams have a regime where summer temperatures do not exceed 70°F, they probably at least approach this temperature, and thus would most likely exceed it if shading vegetation were cut.

Waste and Litter

For the sake of completeness, waste and litter should be included as potential pollutants of forested water bodies. Wherever human activity occurs there is a definite potential for the production of trash and litter. The presence of these in streams is detrimental primarily from an aesthetic standpoint. However, large amounts of organic garbage can have the same effect in lowering dissolved oxygen as that mentioned earlier for organic debris. Large trash, such as old refrigerators, tires, and washing machines, can also restrict or divert water flow.

Some kinds of waste can be directly highly detrimental to stream quality. Motor oil, hydraulic fluid, anti-freeze, and other petroleum products are toxic to many aquatic organisms and also affect water use. Leftover or residue pesticides from containers or application equipment are also another type of serious potential pollutant.

Any facility or structure which will attract or concentrate human activity near a stream poses a potential hazard for waste and litter pollution of streams. Chief among these are roads. Loading docks, parking lots, picnic tables, and camping spots are also obvious examples.

FOREST MANAGEMENT ACTIVITIES AND WATER QUALITY

Road Construction and Use

Among studies documenting the production of stream sediment from forestry operations, most have concluded that roads are the greatest single source *(43, 72, 115, 117, 118, 119, 127, 150)*. More than 90 percent of sediment production from forestry operations has been attributed to roads—primarily logging roads *(72, 117, 119)*. The effects of construction, use, and maintenance of roads are difficult to separate from the effects of timber harvesting operations, since the two are so inextricably linked. Roads are essential for harvest and management, and heaviest use of forest roads usually occurs in conjunction with harvesting operations. Most of the studies cited in this section made some attempt to separate the effects of roads from other logging effects. Many studies have not done so. Those studies not separating roads from other logging effects are not cited here but in the later section on timber harvesting.

Access is essential for the use, management, and harvesting of forest resources. At a minimum, a skeletal network of good permanent roads is required in managed or utilized forest lands. They serve as main haul roads during harvesting and for general access at other times. Minor roads constructed specifically for harvesting operations are commonly considered temporary but frequently become permanent or semi-permanent—being used for recreation and management access for years after the logging job. Thus, their level of planning may frequently be inadequate for their actual use, resulting in their being located with grades too steep or without adequate erosion protection.

The movement of heavy machinery, the mass movement of soil and rock, and the permanent baring of a significant amount of soil surface area all contribute to the high potential of roads for producing sediment. Mass wastage from road fills or poor road placement may also directly slow or alter stream flow.

Taken in context of their potential for deleterious water quality effects, their tendency to become permanent whether intended or not, and their importance to efficient forest land use, careful planning in road layout design and maintenance is one of the most effective ways to avoid water quality deterioration from forestry operations *(26, 84, 115, 127)*. Several studies have shown that logging roads can be designed and constructed such that sediment levels in streams are not seriously affected *(43, 72, 85, 115, 126, 136)*.

The very nature of roads, particularly unpaved ones, makes them areas having high potential as contributors to the production of sediment. During construction, the road right-of-way is a scene of purposeful and intense soil disturbance. Repetitive passage of heavy machinery, movement and piling of large masses of loose soil and rock, and, commonly, the establishment of steep areas of bare unvegetated soil materials in cuts and fills all make road construction near stream channels a great potential hazard to stream quality. Additionally, in both use and maintenance, unpaved roads receive continued disturbance by passage of heavy trucks or equipment. They are generally maintained in a highly compacted state, thus producing surface water flow which can erode adjoining unprotected sensitive areas.

Fortunately, in spite of the high detrimental potential of forest roads, a number of scientific investigations have established that the detrimental effects of such roads need not be severe or long lasting. Study after study has concluded that careful planning, resulting in proper road layout and design, can keep erosion and stream sedimentation originating from forest roads to quite minimal levels.

Several studies from the Fernow Experimental Forest in West Virginia *(126, 136)* found that carefully planned skid roads and logging practices resulted in only minor temporary increases in stream turbidity. On gentle, stable topography on the Bull Run Experimental Watershed in Oregon *(127)*, no increase in sedimentation was detected from well-designed logging roads except for a brief period during construction. A study watershed at the Coweeta Hydrologic Laboratory in North Carolina where roads were carefully planned and constructed exhibited only slight increases in turbidity following logging road construction and use *(43)*.

In forested land where the adjacent soil surface layers are not denuded, sediment leaving a road or road cuts usually does not travel great distances and thus may never reach a stream channel unless the road is located close to it. In the White Mountains of New Hampshire, Trimble and Sartz *(145)* observed surface sediment flows over undisturbed slopes with heavy forest litter below open top culverts. Though the slopes ranged from 10 to 46 percent, 80 percent of the surface sediment flows were less than 85 feet long and none exceeded 130 feet. On steeply sloping granitic soils in Idaho, Haupt *(65)* found most surface sediment flows below roads to be less than 120 feet long. In these and other studies reported *(66, 116)*, sediment flows varied largely with slope gradient, the spacing and kind of obstructions, the cross drain spacing on roads, and the vegetative cover. Unfortunately, none of these studies examined the effects of varied types and degrees of forest litter cover. This is likely of great importance in Southeastern forests.

Another interesting and encouraging finding from some reported studies is that where logging roads do have significant adverse water quality impacts, the effects usually decrease with time *(11, 72)*.

Timber Harvesting

As noted in the previous section, the effects of timber harvesting cannot readily be separated from those of roads. Much of the available documentation does not attempt to separate their effects.

Cutting of trees, in itself, typically has no direct effect on sediment production. For example, a study on the Hubbard Brook Experimental Watershed in the White Mountains of New Hampshire *(90)* and two in the Appalachians *(41, 88)* found no increase in turbidity after complete felling of all trees, where the trees were not removed but were left where they were felled. Clearcutting an Oregon forest using a high-lead system produced no measurable increase in stream sediment *(20)*. Indirectly, the possible resulting increase in streamflow due to decreased evapotranspiration after cutting may lead to greater stream bank and stream bed cutting, producing more suspended sediment. Rapid oxidation of the forest floor after removal of the canopy can reduce protection of the soil surface and lead to increased soil movement on slopes. However, rapid invasion by herbaceous vegetation in the humid South normally quickly compensates for much of the loss of forest floor *(29, 148)*.

Access, movement of vehicles and machinery, and the skidding and loading of trees or logs account for most of the potential detrimental effects of timber harvest. Of course, just the presence of active humans can result in production of waste materials, such as cans, bottles, paper, or fecal matter, in streams.

The degree of hazard to water quality from timber harvesting depends upon a number of factors including type of cover, soil type, and slope steepness, but the one generally most important is the care and planning involved in the logging operation itself *(1, 3, 4, 161)*. Most detrimental effects result from soil disturbance, soil compaction, or direct disturbance of stream channels (including ephemeral ones or gullies). Specific activities with the severest potential are construction and use of haul roads, skid trails or roads, and loading decks. Careful logging may disturb as little as 8 percent of the soil surface, in contrast to 40 percent being disturbed by careless logging *(1)*. Poor or careless skid trail layout has been indicated as causing severe impacts, often increasing stream sediment manyfold *(41)*.

Use of skid roads placed perpendicular to the contour in the Appalachians resulted in first year sediment yields of 40 tons per acre of skid road surface *(82)*. During a 4-year period following logging in the North Carolina mountains, 8,500 tons of soil eroded from a 2.3-mile road system in a 212-acre watershed *(81)*. Much of this sediment did not, however, reach a stream channel.

Several studies have documented erosion and compaction damage from logging operations in the Southern United States. Tree-length skidding with rubber tired skidders in the Coastal Plain of northern Mississippi significantly increased soil compaction *(30)*. Bulk densities were increased 20 percent in skid trails, reducing soil macropore space to one-third that of undisturbed soils. Higher bulk densities and lower macropore spaces tend to reduce soil infiltration capacities, thus increasing surface runoff.

Hatchell et al. *(63)*, in the Lower Coastal Plain of South Carolina and Virginia, found that infiltration rates were reduced to 10 percent of those of undisturbed soils on log decks, to 11 percent in primary skid trails, and to 22 percent in secondary skid trails. They found that these areas tended to recover naturally over time. However, they estimated that natural recovery to undisturbed bulk density levels on the log decks would take 18 years. Fortunately, only 1.5 percent of the logged area was occupied in loading decks, 12.4 percent in primary skid trails, and 19.9 percent in secondary skid trails.

Another study in northern Mississippi *(28)* looked at soil disturbances in sawtimber and pulpwood harvesting operations on tracts of 40 to 700 acres. Sawtimber logging disturbed an average of 15 percent of the soil surface (21 percent in a clearcut area), whereas the pulpwood logging disturbed 12 percent. Combined, most of the disturbed area was in roads (5 percent of the area) and skid trails (7 percent). One year after the operations, 1 percent of the pulpwood-harvested areas and 3 percent of the sawtimber-logged areas showed signs of accelerated erosion. This illustrates to some degree the rapidity of revegetation in southern forest lands after disturbance. In another study of skid trails from tree-length skidding in northern Mississippi, Dickerson *(29)* concluded that sediment movement increases of 0.85 ton per acre of trail were "minor." They also declined rapidly due to rapid reinvasion by herbaceous growth. These studies apply only to soil baring, reduction in infiltration, and local sediment movement. They have given an indication of the potential for stream sediment impact under unfavorable conditions, but do not represent levels of sediment actually reaching a stream.

There are few studies which have documented direct sediment production in streams resulting from harvesting operations. In Coastal Plain catchments with highly erodible soils in western

Tennessee, Ursic *(148)* found that clearcut logging which avoided the stream channels produced stream sediment concentrations about three times that of undisturbed pine watersheds. However, these levels were similar to those he found in eroded watersheds occupied only by low quality hardwoods.

Small catchments harvested in the Ouachita Mountains of central Arkansas resulted in sediment production 11 times that of preharvest levels *(129)*. However, these still amounted to less than 0.1 ton per acre per year. Sediment in streamflow returned to the preharvest levels within 3 years *(148)*.

Clearcut logging in the southern Appalachians of North Carolina using "poor" logging techniques and road selection resulted in sediment during storms reaching levels 10 to 20 times greater than in a nearby undisturbed watershed *(43)*. the maximum reached was 5,700 p.p.m. They compared this to a watershed that was "logged properly from well-designed roads" and found that sediment increased "only slightly."

A study in the upper Bear Creek watershed of Alabama *(12)* looked at water changes in two small catchments after harvesting operations. One was commercially clearcut using normal Forest Service practices, then residual trees were treated with herbicides and the area was burned and planted. The other was selectively logged, then damaged by a tornado. This necessitated clearcutting 30 percent of the area and selectively salvaging timber on the remainder. Buffer strips were left along the streams. No obvious changes in sediment concentrations occurred on the partially cut watershed, except during road construction. On the clearcut and burned watershed, the treatment "did not have a noticeable impact on sediment concentrations." These results were attributed to good planning.

The sediment and erosion levels produced by logging can be put into better perspective. It has been estimated that the average annual erosion loss from all Southeastern lands is almost 1.3 tons per acre *(1)*. Levels of erosional soil loss considered "tolerable" by the SCS *(153)* for soils in Alabama range from 1 to 5 tons per acre per year. In contrast, the measured erosion losses from skid trails in northern Mississippi of 0.85 ton per acre per year *(29)* and the estimated averages of Dissmeyer and Stump *(36)* for logged areas of physiographic regions found in Alabama of 0.19 to 0.88 ton per acre per year are lower than these. Again, these are *erosion* levels. Sediment entry into streams should be much less.

A study conducted on the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire *(90)* raised concern over the effects of clearcutting on water quality. However, the treatment used was designed to determine the effects of the complete elimination of mineral cycling of forest vegetation within an ecosystem. They felled and left all the trees, killed understory vegetation, then repeatedly treated the area with herbicide to prevent any regrowth. Such a large amount of nutrient leaching to the stream occurred that drinking water standards were exceeded.

This study in no way compares to conventional clearcut harvesting, particularly in the South where climate and soils are different. Conventional logging removes the felled trees, whereas their decomposition on-site in the experiment contributed largely to the leached nutrients. Reestablishment of vegetation normally occurs rapidly, especially in the South. This is usually sufficient to maintain mineral cycles. Subsequent studies in North Carolina *(43)* and West Virginia *(4)* have shown only small and short-term increases in stream nutrient levels and sediment after clearcutting by good logging practices. These studies demonstrated clearly that reasonable precautions in logging, such as careful road layout, avoidance of wet-weather logging on sensitive soils, and maintenance of a streamside zone where vehicles were restricted, could result in only minor and temporary adverse effects on streams.

Removal of all streamside vegetation has been shown to increase stream water temperatures significantly. Maximum daily summer temperature increases reported have ranged from 4°F to 14°F, mostly in the West *(18)*. In the southern Appalachians, maximum summer stream temperatures were increased by 12°F *(142)*. A summer maximum stream temperature increase of 11°F was reported for the Georgia Piedmont *(72)*. Effects are most drastic on smaller streams. The effectiveness of a streamside buffer strip for avoiding drastic stream temperature rises has been demonstrated in several studies *(16, 19, 141, 142)*.

Regeneration Practices

Purposeful regeneration of harvested forest lands to desired species composition and stocking levels is a cornerstone of forestry practice. The basic forest regeneration techniques are clearcutting, seed-tree, shelterwood, and selection. The first three are even-aged approaches, whereas the selection method results in uneven-aged stands *(134)*. These methods are inextricably tied to the harvesting system employed.

From an economic standpoint, the forest tree species in Alabama which are generally most important are the southern pines—principally loblolly, longleaf, slash, and shortleaf. All of these fast-growing species are intolerant of shade. Their seedlings will not survive and grow in shaded conditions. Thus, good pine regeneration methods primarily are even-aged approaches. Most of the commercially valuable hardwood species are also at least moderately intolerant and do not grow well in shaded conditions. Consequently, even-aged regeneration techniques are generally recommended and frequently used for hardwoods as well as pines.

Clearcutting followed by planting seedlings is the simplest and surest of the even-aged methods and is extensively used for pine regeneration in Alabama and most of the Southern United States. Besides its simplicity, it has further advantages of not being dependent on an existing desirable seed source, allowing use of genetically improved or selected planting stock, and gaining a year's growth over stands originating from seed. However, for successful establishment of well stocked seedling stands, some degree of site preparation is usually needed. Site preparation and its effects are described in another section.

Commerical forest tree seedlings planted in Alabama are usually 1-year-old nursery stock, although cuttings are used for some hardwood species, such as sycamore and cottonwood. Seedlings may be planted by machine or by hand, but the former is typically preferred due to its being faster and having more consistent results. Machine planting is fairly dependent upon the planting site being relatively clear of standing trees, brush, logs, and other large debris. This results in a strong dependence upon mechanical site preparation on most cutover sites. Planting by direct application of seed is another approach which can be used successfully after clearcutting for many species in Alabama. It is most widely used with pines after clearcutting or on some extreme sites, such as minespoils. Seeds are normally treated with insect, bird, and rodent repellents to reduce predation. Aerial application by helicopters or planes is most widely used, although seeds may be distributed by hand or with a hand-operated seeder. They also have been applied by a row-seeding machine pulled by a tractor or other machinery.

Site preparation by burning and/or herbicide use is commonly used with direct seeding since competition control and a suitable seedbed are the major requirements. A debris-free site is not required. Disking may also be used but in this case it is usually applied in strips rather than over the entire area. Seedbed requirements are discussed below.

The seed-tree method involves a harvest which removes much of the overstory but leaves an adequate number of well-distributed seed-producing trees to provide rapid seeding of the harvested area. This generally involves leaving 2 to 12 trees per acre. Ideally, everything else is harvested. If the trees are valuable, they can be removed later after sufficient regeneration is established.

As applied to southern pines, the basic shelterwood method differs from the seed-tree approach largely in the number of trees remaining after the regeneration (seed) cut. Generally a basal area guideline is applied, with 25 to 40 square feet per acre commonly left as a shelterwood. Depending upon size, this means roughly 30 to 50 trees per acre remain. These trees provide seed and their shading retards development of competing species. These are then removed in a final cutting after sufficient seedlings are established, usually in 3 to 5 years.

Desirable seedbed conditions are necessary for adequate seed germination and seedling establishment for both of these methods. For the light-seeded species normally involved (especially pines), any approach relying on seed requires that mineral soil be exposed in sufficient quantity and distribution to allow adequate seedling establishment. This does not mean that the entire soil surface need be bare. This is, in fact, an undesirable condition from the standpoint of increasing soil erosion. Bare soil interspersed and mixed with a litter or duff provides ideal conditions for seed germination. Well distributed patches or strips of bare soil with litter in between provide the exposed soil needed and also provide some protection from soil erosion and seed loss by washing, help to hide the seed from predators, and provide a more favorable microclimate for the seedling.

The harvesting operation itself, particularly where skidders are used, may provide sufficient exposed soil to provide an adequate seedbed. Frequently this, along with a controlled burn to reduce slash and litter cover and remove some of the competing vegetation, will produce excellent seedbed conditions for a seed-tree, shelterwood, or even direct seeding after clearcutting. More drastic site preparation for competition control may be necessary where a heavy understory has developed prior to the regeneration cut.

The selection method is not widely recommended or used for commercial timber species in Alabama. It involves selective removal of individual trees or small groups of trees as they mature. This results in stands being composed of a mixture of age classes. It is best suited to tree species which are highly tolerant of shade. It has been, however, successfully used for loblolly pine at the Crossett Experimental Forest in Arkansas.

Site Preparation

Site preparation is widely used in conjunction with clearcut-and-plant regeneration in Alabama. The usual major objectives are to facilitate the planting process (particularly if it is by machine) and to control established competing vegetation. Mechanical site preparation by large tractors which shear, disk, drum-chop, or root-rake the site is quite common, particularly on land managed by forest industries. Controlled burning and herbicides are also widely used for site preparation either alone or in combination. Because mechanical site preparation results in considerable disturbance of the surface soil over large areas, it has high potential for damaging stream quality. Dissmeyer *(33)* found that data from river basin reports in the Southeast indicated that site preparation contributed from 30 to 80 percent of sediment produced by forest management in the areas studied.

Removal of vegetation and litter cover, soil compaction resulting in increased surface flow and erosion, direct soil disturbance, direct channel disturbance, and increased stormflow due to decreased evapotranspiration are possible treatment effects which can increase stream sediment.

Beasley *(9)* instrumented four small watersheds in the hilly northern Mississippi Coastal Plain. Soils on parts of these watersheds are of series common in the hilly Coastal Plain of Alabama (Ruston and Smithdale series). Slopes were steep, mostly 30 percent or greater. Three of the watersheds were logged and mechanically site prepared—one by single drum-chopping followed by burning, one by shearing and windrowing into the stream channel (windrows were burned), and the other by shearing, windrowing, and bedding on contour. The fourth watershed was left uncut as a control. Immediately after treatment, bare soil surfaces were 37 percent, 53 percent, and 69 percent on the chopped, windrowed, and bedded watersheds, respectively. Bedding literally turns under surface residues and results in the beds having a largely bare soil surface. The three site preparation treatments tested all resulted in similar increases in annual sediment production for the first year, 5.4 (chopped) to 6.3 (bedded) tons per acre (2,471 to 2,808 milligrams per liter in stream flow). The high sediment production on the bedded watershed was due partly to the formation of a gully through the beds near the stream channel. The three site preparation treatments also resulted in greatly increased total stormflow compared to the uncut control. This was due to decreased evapotranspiration. Sediment production on the control watershed was less than 0.3 ton per acre. However, the streamflow sediment concentration was quite high—2,127 milligrams per liter. This occurred because of the much smaller stormflow production on the control compared to the treated watersheds—1.2 inches versus 18.0 to 20.3 inches. Thus, the smaller total sediment was nonetheless concentrated in a much smaller amount of water. A single heavy rainstorm accounted for 90 percent of the sediment production on the control watershed.

A temporary cover crop of subterranean clover was planted on the site-prepared watershed but did not produce a substantial ground cover until the second year. However, during the second year both the clover and other vegetation covered about 85 to 95 percent of the soil surface. This resulted in considerable decreases in sediment production during the second year—down to 1.0 (windrowed) and 2.5 (bedded) tons per acre.

Beasley concluded that: (1) all three site preparation treatments increased annual sediment production similarly; (2) the amounts of sediment production decreased after the first year; (3) proper bedding on contour is difficult to accomplish on steep, stump-covered areas; and (4) stream channel scouring resulting from increased stormflow can be a major source of stream sediment where stream banks or channels are erodible.

Another study has been reported from the Georgia Piedmont *(72)* where the site was drum-chopped twice (April and October), then machine-planted. Peak sediment production was in the year following machine planting—about 2.1 tons per acre. This followed the rather severe practice of using a 6-foot wide V-blade on the front of the planting tractor and scalping the soil to a depth of 4 to 6 inches. No information is available regarding any stream protection involved. Although the planting was generally on contour, this practice resulted in baring about half of the soil surface. However, these wide trenches may have served to stop much of the overland flow from reaching the stream. Movement of this much topsoil away from the planted seedlings doubtless also reduced site productivity significantly.

Dissmeyer and Stump *(36)* compiled data on erosion from forest management activities in the Southeast. The resulting rates were derived from the Erosion Data Bank of the U.S. Forest Service, comprised of erosion observations from throughout the Southeast. The rates reported from mechanical site preparation activities in several physiographic regions existing in Alabama are given in table 1.

These erosion rates do not represent sediment actually reaching a stream. They are for soil movement to the bottom of a slope. They represent the maximum amount of material that could reach a stream if it was located immediately below the affected slope with no intervening strip of vegetation or litter to stop sediment movement. Factors other than the erosion rate itself have a profound effect upon the probability of this material reaching the stream. These factors are discussed elsewhere in this report. Thus, these figures represent only the potential for stream sedimentation, showing the magnitude which may be involved under the worst conditions.

Several observations are noteworthy regarding the data in table 1. The erosion rates are the tons per acre per year average for the recovery periods indicated. The "average" value given is for "average" application of a treatment. The "high" and "low" values rep-

TABLE 1. PREDICTED EROSION RATES FROM MECHANICAL SITE PREPARATION FOR PHYSIOGRAPHIC REGIONS IN THE SOUTHEASTERN UNITED STATES WHICH OCCUR IN ALABAMA; TAKEN FROM DISSMEYER AND STUMP *(36)*; RATES ARE AVERAGES FOR THE RECOVERY PERIOD

Physiographic region	Site preparation type	Erosion rates (tons/acre/year)			Recovery period, years
		Average	Low	High	
Ridge & Valley	Bulldozing	13.7	0.19	66.0	3
Sand Mountain	KG-Blade	4.0	.05	11.5	4
Southern Piedmont	Chopping	.22	.002	10.4	3
	Chop & burn	.38	.002	17.6	4
	KG-Blade	1.8	.02	44.5	4
	Disking	4.1	.06	100+	4
	Bulldozing	1.9	.04	41.6	4
Southern Coastal Plain	Chopping	.24	.004	35.5	3
	Chop & burn	.41	.01	84.7	3
	KG-Blade	.65	.03	45.3	4
	Disking	2.46	.16	100+	4
	Bedding	.66	.04	100+	4
	Bulldozing	.89	.04	54.8	4
Blackland Prairies, Alabama and Mississippi	KG-Blade	1.2	.09	33.6	4
	Disking	3.3	.25	100+	4

resent the heaviest impact under poor treatment and the expected lightest impact under excellent conditions, respectively.

The average rates for site preparation range from 0.22 ton per acre per year for chopping on the Piedmont to 13.7 tons per acre per year for bulldozing in the Ridge and Valley area. The maximum rates predicted are enormous—more than 100 tons per acre per year for bedding on the Coastal Plain, as well as for disking on both the Coastal Plain and Piedmont. These values reflect a tremendous potential for erosion from some such drastic treatments under the worst conditions and with the poorest application. However, the "low" values are encouraging. None are greater than 0.25 ton per acre per year and most are less than 0.06 ton per acre per year. They represent the potential result when careful planning and execution are involved.

The recovery periods listed are the times in years generally required for the erosion effects to heal, i.e., almost complete soil cover to be reestablished. Those time periods are all either 3 or 4 years. This, too, can vary. The highest values for erosion result from site damage which may last much longer than 3 or 4 years, whereas in low value situations the site may be completely recovered in less time.

The interaction between the site preparation technique, the care in application, and the site conditions cannot be overemphasized. There is no "standard" effect from a particular treatment. As the data just cited indicated, a particular machine application on steep erodible soils with no intervening filter strip can result in sediment production with more than 100 tons per acre per year, with most of it reaching a stream, but on gentle, coarse, and stable soils this same machine application may produce sediment of less than 0.1 ton per acre per year, with considerably less of this reaching the stream.

Prescribed Burning

The effects of fire on forest ecosystems have been studied extensively, primarily in the West and South. However, most studies have examined effects on vegetation, soil, and wildlife. Few have quantified direct effects on streams. Nonetheless, much of that relating to soil exposure and soil movement in erosion has obvious potential implications for water quality.

The studies available justify several generalizations, chief among these being that controlled burns in most southern forests are not likely to produce large increases in erosion loss or sediments and nutrients in streams *(58, 83, 99, 107, 122, 128)*. Fires that are more likely to produce adverse effects are those which burn intensely on steep slopes close to streams and remove most of the forest floor and litter down to mineral soil. Thus, wildfires, which tend to occur under conditions favoring intense fires, present a much greater danger than prescribed fires *(104, 122)*. Prescribed fire seldom consumes more than 50 percent of the total surface layers, and the surface soil (A1) is not generally affected by light burns *(122)*. A steep moisture gradient between the forest floor and mineral soil surface tends to restrict combustion of the litter layer so that most prescribed fires consume less than one-third of the total forest floor mass *(128)*.

The amount of erosion following a fire depends upon: (1) the inherent erodibility of the soil; (2) steepness of slope; (3) time, amount, and intensity of rainfall; (4) severity of the fire; (5) cover remaining on the soil; and (6) rapidity of revegetation. For sandy soils on flat terrain land types of the Coastal Plain, there seems to be extremely low probability of any significant soil movement, even after hot fires *(99, 107, 122, 123, 137)*. However, some soil movement and consequently stream sedimentation may occur after hot fires on steep terrain of hilly Coastal Plain, Piedmont, and Mountain land types. Amounts are still likely to be less than that produced by normal agriculture, by roads and skids trails, or by site preparation treatments which scarify the soil.

Burning, where most of the vegetation is killed, may increase stream flow, particularly during intense storms *(146)*. This can have some impact by increasing channel cutting and flooding.

A study examining both winter and summer controlled burns in the Georgia Piedmont on 10-20 percent slopes found little adverse impact *(17)*. Surface soil movement was negligible, even after 7 inches of rain fell in August. The low impact was due to almost all of the decomposed litter and O soil horizon remaining after the fires. They found that such small forest floor reduction resulted where the fuel moisture (litter layer) was 10-40 percent and the relative humidity of the air was 20-60 percent.

Another study reported on examinations of old gullies after controlled fires in the South Carolina Piedmont *(25)*. It found no increased movement in gullies after both spring and summer burns. A set of paired watershed studies in the Coastal Plain of South Carolina examined streams before and after fires *(25)*. A 20-yard-wide buffer strip was left unburned. No change in the chemical constituents attributable to the fires was detected. Apparently, particulate matter and ash were filtered by the unburned litter, soil, and the buffer strip.

In a study of both summer and winter burns on steep slopes of the hilly Coastal Plain of Alabama, some limited surface soil movement was observed on areas where all duff was consumed (mainly after summer burns) *(23)*. However, there was no reason to expect that any of the soil reached a stream. In contrast, no soil movement was detected after single or repeated spring or summer burns in upper Piedmont pine hardwood stands of South Carolina *(58)*. Nine consecutive annual burns on flat loess soils (which have highly erodible surface textures) in Arkansas had little effect on the surface 4 inches of soil *(107)*.

A study examining the hydrologic effects of burning on low quality hardwood stands on hilly northern Mississippi sites *(146)* found increased overland flow, sediment, and storm flow in streams following winter burning, hardwood injection, and hand planting. Increased sediment yield of the first year averaged 428 pounds per acre (about 0.21 ton). Sediment increases from the sandy watershed were lower and ceased after 1 year; that from the loess (silty) watershed was higher and persisted for 3 years.

Some studies of fires in the West have found significant soil movement and adverse soil effects due to burning *(27, 46, 144)*. These have typically been hot fires on steep terrain in ecosystems where vegetation cover is much less and revegetation occurs much more slowly than in southern forests. However, one study of burning in ponderosa pine stands on steep slopes in California *(13)* found no increased surface flow or erosion that could be attributed to fire. Remaining duff and debris protected the site.

Application of Forestry Chemicals

The use of chemicals for silvicultural objectives on forest lands has become more widespread and important as the intensity of forest management has increased. This certainly applies to Alabama. The term "chemical" commonly has a negative connotation in the mind of the lay public, particularly in context of the forest. However, development and use of effective chemicals for increasing productivity, reducing competition, and controlling destructive agents allowed modern agriculture to reach phenomenal levels of productivity compared to a short time ago. Use of chemicals is becoming similarly widespread, although generally at much lower application rates, for modern intensive forestry.

As described earlier, the chemicals with widespread silvicultural uses are fertilizers and pesticides. After an extensive review of scientific study reports and reviews concerning these chemicals relative to silvicultural use, it seems justified to conclude that: due to the usual pattern of application, the nature of the chemicals currently registered for use, the infrequency of application, the low concentrations reaching streams, and the nature of the natural systems treated, current normal silvicultural treatment of forest lands poses little or no significant threat to water quality. Other reviewers have reached essentially the same conclusion *(14, 18, 110, 113)*.

Newton and Norgren *(110)* conducted an extensive review of silvicultural chemical uses and effects and an inquiry of water quality scientists from several state and federal agencies in the Northwest, Southeast, and Washington, D.C. They stated that "no recognized reports of injury to stream life have come to the attention of the writers relative to properly applied herbicides or fertilizers in forestry." They did find some reports of injury to fish from applications of insecticides in large projects, but these were principally restricted to cases where chlorinated hydrocarbons were used (these are now restricted from general use). These cases occurred where large streams were not adequately avoided, and fish kills were generally locally restricted to short stretches of water. Improved general application practices, EPA restrictions on uses of toxic forestry insecticides, and the infrequent need for large-area application of forestry insecticides in Alabama seem to make the possibilities of any significant problem low in this State.

Pesticides

Quite a lot of the research on forestry herbicides and water quality has been conducted in the Pacific Northwest. Most of these findings should be applicable to the South, at least in terms of the specific herbicides studied and the amounts reaching streams.

Norris and his coworkers have systematically monitored forest watersheds in Oregon, where operational herbicide treatments have been carried out over a period of years *(54, 112, 113)*. They consistently found herbicide residues in all streams which flowed in or near treated areas. However, peak concentrations seldom exceeded 0.1 p.p.m. in areas without buffer strips and seldom above 0.01 p.p.m. in streams not actually in the spray units. Peak concentrations normally occurred shortly after treatment and persisted for short periods. They have not found any long-term contamination of forest streams by herbicides *(54, 112, 113)*. After 8 years of monitoring operational studies, they had found no instance of detectable herbicides in forest streams more than 1 month after application *(54)*.

They also found that the magnitude of short-term contamination was not a function of the herbicide or of the geographic area, but rather it was closely related to the manner in which the treatment area was laid out with respect to live streams *(113)*. Where spraying directly over streams was avoided, herbicide levels were extremely low.

Most of these studies involved picloram, 2,4-D, 2,4,5-T, or amitrole. The first two of these are widely used in Alabama. Reviewing their work, Norris concluded, "based on an evaluation of the toxicity and the behavior of 2,4-D, 2,4,5-T, picloram, and amitrole, I conclude the proper use of these herbicides in the forest normally will not result in either an acute or chronic hazard to the inhabitants of the forest environment" *(113)*.

The studies just cited involved aerial foliar application of herbicides. Application of soil-active herbicides (those taken up through roots) is frequently by pellets or granules. These may be applied by hand spreader from the ground or over large areas more conveniently by aircraft. Sensible hand application poses little or no threat to water quality where the herbicide is not likely to be washed directly over a bare soil surface or through gullies to streams. This should usually be true of spreader applications also. The simple safeguard of not throwing it directly into a stream should ensure this. Application by aircraft allows less control relative to streams, especially small ones.

Miller and Bace *(102)* conducted a study on the Alabama Piedmont where pelletized hexazinone (Velpar Gridball) was applied from a helicopter in February at a rate of 16 pounds of pellets per acre (1.6 pounds per acre of hexazinone). A small stream averaging about 1.5 feet in width was in the middle of the study area and no attempt was made to avoid it. They found a peak hexazinone concentration of 2.4 p.p.m. in the stream water 30 minutes after the application. This declined rapidly to less than 0.5 p.p.m. within 2 hours. No contamination was detected after 5 days.

The researchers concluded that essentially all of the herbicide in the stream water came from pellets falling directly into the stream, with none moving from the surrounding area. The pellets used were not materially intercepted by any foliage, since it was winter. After exploring the circumstances and comparing the toxic levels produced, they concluded for the herbicide treatment studied that "downstream water users and fish are probably safe from toxic exposure if treatment areas have only small streams (less than 20 inches average channel width) and if label rates are not exceeded." Appreciably larger streams are much more easily avoided, so less problem would be anticipated.

Application of herbicides through cut surfaces by injection or frilling is another useful silvicultural approach, used primarily on larger trees. Release of established seedlings is the most common purpose for these treatments. Due to the nature of the treatment and the nature of the chemicals involved, there is no reason to expect any substantial amount of chemical to reach the stream from such application. No study indicating such was found.

Ground-applied insecticides and rodenticides are used in such small quantities in forests that their total effects on water quality are not likely to be detectable *(110)*. They are usually applied to small areas and/or isolated from water.

Aerial applications of insecticides (primarily in other parts of the country) are usually applied over large areas, often encompassing many watersheds. Similar considerations hold as for aerial applications of herbicides, but there is more likelihood that large insecticide operations may lead to low level contamination of streams. Little data are available regarding concentrations of organophosphates and carbamates in water. Most of the research into forestry insecticides and water were focused on the now defunct DDT. Many instances of fish kills have been reported from use of chlorinated hydrocarbons *(110)*. The worst offenders in this respect, DDT, aldrin, dieldrin, and heptachlor, are not now registered for silvicultural use. The chemicals replacing them, carbamates (carbaryl) and organophosphates (malathion, fenitrothion, phoshamidon, and trichlorfos) have short biologically active lives and low toxicity to mammals and many fish. They do present hazards, however, to aquatic insects and to certain fish, so concentrations must be kept at low levels. Strict maintenance of a buffer strip will normally accomplish this *(110)*.

Fertilizers

The practice of fertilization in forestry is relatively new compared to its use in agriculture. Unlike agriculture, however, this new practice presents much less of a threat to water quality *(10)*, perhaps no threat at all, given the silvicultural limitations on the use of fertilizer. Consideration of some of the differences in agricultural and silvicultural practices indicates the nature of these limitations. It would be a mistake to extrapolate from the effects of agricultural fertilization on water quality to the effects of silvicultural fertilization. The pertinent differences are *(10)*:

1. **Frequency of application.** Agricultural crops are annuals; thus, crop rotation and fertilization occur at least yearly. The rotation for pine plantations is every 20 to 35 years, with probably only one application of fertilizer during the rotation—usually when the trees first begin to completely dominate the site (approach of crown closure at 10-15 years). Applications earlier or later are generally ineffective. Earlier, the additional nutrients would be taken up mostly by competing herbaceous growth, and later, the trees' growth rate would have slowed to the point where they would not respond significantly to treatment *(132)*.

2. **Nature of the site at time of fertilizer application.** The bare soil of agricultural fields is subject to considerable erosion—erosion which is prevented by an intact litter layer of the forest floor. Erosion and runoff are the main channels for movement of phosphorous into streams, since it is quickly and strongly fixed to colloidal particles in the soil and not easily leached *(110)*. The litter also provides a temporary "sink" for nitrogen compounds, since they are quickly utilized by the microbial organisms feeding on the litter. Furthermore, the tilling of agricultural fields, as opposed to the undisturbed soil (for at least 10-15 years) of the forest floor, aerates the soil, permitting nitrification to occur at greater depth. This, plus the practice of irrigation and weed eradication, would accelerate the rate of leaching of nitrate nitrogen. Forest sites also have a greater water retention capacity due to higher transpiration rates per unit area of forest cover.

3. **Nature of the crop.** Agricultural crops need nutrients quickly, so fertilizer must be highly soluble, thus increasing the risk of loss by runoff or leaching during periods of heavy rainfall. Since trees grow over a much longer time, less soluble fertilizers can be used which release nutrients more slowly. Sulfur-coated urea shows promise here *(10)*. The deeper roots of trees further safeguard against nutrient leaching.

The only factors in silviculture which would increase the risk of water pollution from fertilizers are the necessity of using aerial application on large tracts (thus making it difficult to avoid the stream surface) and the tendency of forest sites to have shallower soils and steeper terrain than agricultural soils *(10)*. Recent studies, however, have shown that forested watersheds are low risk in terms of water pollution from fertilization.

Several studies in the West *(54)*, including one in the South Umpqua Experiment Forest in Oregon *(108)*, and one in the East at Fernow Experimental Forest in West Virginia *(5)*, have yielded similar results from aerial application of forest-grade urea at 200 pounds of N per acre and 230 pounds of N per acre, respectively. At both Umpqua and Fernow, the streams draining the treatment watersheds were small, so the fertilizer was applied without attempting to avoid them. In neither case, except for a brief period at Fernow, did levels of N in any form come close to the 10 p.p.m. limit set by the Public Health Service *(5, 10, 108)*. At Fernow, an extremely high peak of 19.8 p.p.m. was reached during a September storm which dropped 4.5 inches of rain in 48 hours after a prolonged dry period in which streamflow ceased. This peak lasted for only a few hours, dropping to less than 10 p.p.m. in a few days. Out of a 13-month sampling period at Fernow, NO_3-N levels rose higher than 10 p.p.m. for a cumulative period of about 1 month.

To generalize from this and other experiments *(10)*, certain patterns become clear. Without avoiding streams the urea-N level rises first, but not enough to be considered polluting, and the urea is completely flushed out within a month. NH_4-N, presumably from the breakdown in urea falling on or near stream banks, is quickly flushed into the streams and out within 2 months. Avoiding streams during application would reduce this insubstantial rise in concentrations *(108)*, though the rise might not be so insubstantial if the surface area of the stream were larger. NO_3-N levels are directly associated with rainfall, usually reaching a peak in the winter (the rainy and dormant season), and "usually returning to background concentrations within 3 to 6 weeks" *(54)*.

Though conducted on a much smaller scale, a study by Duke University on the Piedmont of North Carolina also yielded encouraging results *(132)*. Fertilization was applied by hand at rates of 100, 20, 40, and 11 pounds per acre of N, P, K, and S, respectively, on a 10.6-acre, 34-year-old loblolly plantation. This area is not a self-contained watershed, but is bounded on both sides by perennial streams with sampling done at a weir 328 yards downstream as well as at various points bordering the plantation. After one year of sampling there was "no statistical difference (< = .05) between pre- and post-treatment nutrient concentration" in streams for any of the nutrients applied.

Except for the short periods at Fernow, all studies found have yielded nitrogen concentrations well below the maximum acceptable level of 10 p.p.m. Since "levels of fertility necessary to cause eutrophication are not fixed" *(110)*, it is difficult to determine whether the small increases in stream nutrients due to fertilization of forested watersheds are enough to cause eutrophication. However, it is evident that increases in nutrient levels over time are not sustained but occur as "pulses." Since "major increases in aquatic plant biomass require sustained increases in nutrient levels" *(110)*, we can conclude that the use of fertilizers in forestry generally presents no significant threat to water quality.

Disposal of Waste

Harvesting, site preparation, and some silvicultural operations unavoidably bring both people and machinery into forested watersheds. Naturally,this presents a potential for many types of waste material to be placed into streams or to be placed where they can be washed into streams. No studies documenting such waste as a problem were found, probably because it is an obvious potential problem but one that is almost totally dependent upon human carelessness.

All the trash and litter which commonly accompany human activity can potentially get into streams. The most serious threats would be from dumping of waste petroleum-based products, such as used oil, hydraulic fluid, or antifreeze. These might originate from servicing or repair of machinery or vehicles near streams. Dumping of containers is another possible avenue which might also include pesticide cans or barrels.

Other Forestry Effects on Water

Another major silvicultural activity which has significant hydrologic effects should be mentioned here: the conversion of hardwood forest types to pine. This, of course, is being undertaken on a wide scale on managed forest lands in Alabama, largely for economic reasons. The two major expected hydrologic effects of this identified in the research literature are a decrease in total annual streamflow and the increased protection of previously abused watersheds. The initial effect of any drastic cutting or deadening of forest stands is an increase in streamflow. This has been well documented in the South *(9, 43, 72, 75, 146, 149)* and in other areas of the United States *(42, 78, 131)*. First-year increases in streamflow in the South after clearcutting hardwoods should range from 8-18 inches *(43)*. However, after a pine plantation is established and occupies the site, water yields are greatly reduced, ultimately to levels below that of the original hardwood cover. When hardwood watersheds were converted to white pine in North Carolina, measured annual streamflows were reduced an average of almost 8 inches by plantation age 15 *(138)*.

When interception losses in loblolly pine stands in the Piedmont of South Carolina were compared to those of a mature hardwood-pine forest, the pine stands lost about 4 inches more per year *(139)*. Greater loss by pines is attributed primarily to its maintenance of foliage during the dormant period.

Measured streamflows from catchments converted to pine in northern Mississippi decreased 2-4 inches per year by age 15 *(149)*. The decreases were less on sandy loam soils than on silt loams.

The slow decomposition of pine litter results in its rapid accumulation to greater depths than that of hardwood leaves, most of which decompose fairly rapidly. This results in the forest floor of well-stocked pine stands having generally better infiltration and raindrop-protective characteristics. For this reason, plus its rapid growth, loblolly pine is considered one of the best plants for long-term erosion control on eroded lands in the South *(92)*.

The reduction of streamflow has both beneficial and negative aspects. In areas where total water quantity is important, such as in a municipal watershed, water yield reductions of this magnitude may be quite serious. From a sediment production standpoint, the comparison is positive because of the streamflow differences as well as watershed stabilization differences. Lower total flow and storm flow peaks will reduce channel cutting and movement of bed load sediment, thus contributing to better water quality. Ursic *(149)* has documented that replacing hardwood stands with pine in the hilly Coastal Plain of Mississippi has reduced streamflow sediment concentration levels by an average of 75 percent.

RECOMMENDED PRACTICES TO MINIMIZE POTENTIAL WATER QUALITY DEGRADATION

Basic Principles

In pursuing the concepts and application of best management practices for water quality protection, several basic concepts are crucial to success. The most fundamental of these is the need for preliminary planning to ensure that scheduled forestry practices do not unnecessarily degrade water quality in the watersheds involved. As has been detailed earlier, in many situations there is a definite potential for negative water quality impacts. Therefore, conscious action is needed. The first step is an awareness of the need for conscious attention.

This basic awareness should then lead to assessment of the specific potentials of the activities planned and deliberate planning to reduce those potentials for damage. Planning with protection of water quality in mind is one of the most important aspects of applying best management practices *(14, 18, 41, 48, 98)*.

Using all available resources for planning is important. These will include topographic maps, aerial photos, stand maps, and soil surveys *(14, 48, 155)* where available. These should be supplemented with field reconnaissance to confirm the present conditions, particularly in planning roads *(48)*.

The planning process should include the identification of high hazard areas or locations in particular *(95, 140)*. The hazard is, of course, relative to the planned activity, whether it be road construction, timber harvest, pesticide application, fertilizer application, fire control, or other activity.

Because of their high potential for sediment production, the careful planning of road layout is among the most crucial needs. Also, due to their critical nature and their potential to reduce the amount of sediment generated upslope which reaches a stream, streamside buffer strips or streamside management zones should be planned as to their nature, extent, and width.

Finally, a post-activity inspection should be included in planning. This is to assess the need for corrective or rehabilitative action. Sometimes quite simple or low cost actions taken early will prevent the need for difficult or expensive ones later.

Suspended sediment is the most important and widespread pollutant from forest management activities *(39, 47)*. Sediment is normally produced by erosional processes. Then, except for that produced by erosion of the stream channel itself, it must move to the stream channel to become a stream pollutant. This suggests that the two fundamental strategies to reduce production of stream sediments are: (1) to prevent or reduce the detachment of soil particles, thus reducing the supply of potential sediments, and (2) to reduce or prevent the movement of detached material from their source to the stream channel *(86)*. Where possible, the first of these strategies is preferable since other negative effects, such as reduced site productivity, result from movement of soil and erosion. However, a combination is usually necessary and most effective.

As an adjunct to better planning of forestry operations for sediment control, it is also recommended that the landowner, a forester, or other interested party take specific responsibility to see that the plans are implemented as well as is practical *(66)*. This can be accomplished by specifying the important aspects in a contract *(72)* then following through with periodic onsite visits while the operation is progressing.

In terms of reduction of erosion and sediment movement to streams, minimizing removal of forest litter (leaves, pine needles, slash) and the soil surface organic layer is one of the most important endeavors *(124)*. There are studies supporting the conclusion that the major soil factor in preventing soil erosion in forests is the presence of surface litter and organic matter in the soil, rather than the presence of a forest canopy *(15, 31, 98, 124, 152)*. Forest litter increases the absorption of water by the soil, reduces raindrop impact, and adds greatly to ground storage of rainfall. The surface litter and organic matter can also function effectively to minimize the potential impact of forest chemicals *(54)*. Such chemicals are often tied up in organic matter. Also, their most direct route to the streams is by overland flow and a healthy organic layer will reduce or stop overland flow.

Any erosion control measure deemed necessary, such as seeding fill slopes, installing cross drains, or stabilizing gulleys, should be initiated as soon as possible after the need is identified *(66, 97)*. This immediacy is warranted for two major reasons: (1) much of the erosion that occurs after forestry activities such as road construction, logging, or site preparation has the greatest effect during the first months or year; and (2) frequently, erosional forces increase as rills or gullies form, thus control must be exerted early to reduce the maximum degree of erosion encountered.

Stated briefly, in terms of both planning and application, the major basic actions to reduce adverse water quality impact from forestry practices are: (1) minimize soil disturbances which leave large areas of soil exposed for long periods; (2) reduce active erosion rates; (3) avoid disturbance of stream channels; (4) maintain filter strips along stream channels to protect them and intercept sediment from upslope disturbances; and (5) avoid direct application of chemicals and fertilizer into stream channels *(14, 32)*. These are detailed and discussed further relative to planning and specific practices in the sections which follow.

Classification of Sensitive Areas

The identification of areas or locations which present a high potential for adverse interaction with forestry activities can be a valuable tool in planning best management practices *(86)*. Since unnecessary care may cost money or time and inadequate care or improper practices may lead to drastic increases in stream sedimentation or lost productivity, the time involved in assessing exactly where special care is and is not needed is time well spent.

Once sensitive (high hazard) areas or spots are identified, activities which bare significant areas of the soil surface should be avoided there if possible. Thus, roads, skid trails, log decks, and root raking, disking, or bedding site preparation treatments should be planned to exclude these sensitive areas.

Stream banks and channels are, by definition, sensitive areas. Soil-disruptive activities there will produce stream sediment immediately. The location of all stream channels should be one of the primary planning objectives. This is not always simple, however. Some large gullies may be ephemeral stream channels carrying storm flow during heavy rains. Channels of intermittent streams will be dry part of the year. Direct field inspection for evidence of water movement is the best approach for determining which channels are active during storms. Channels exhibiting such evidence should usually be considered sensitive areas.

However, even non-active channels such as old stabilized gullies should usually be considered sensitive areas. Such areas are easily destabilized and may then deliver sediment-laden runoff directly to a stream channel.

Streamside Management Zones

Strips on both sides of all perennial and intermittent streams should be managed so that vehicular traffic, skidders, mechanical site preparation, and fire are excluded and so that the forest floor is left essentially intact. Maintaining an adequate "streamside management zone" or SMZ can be a key element in preventing stream sedimentation *(66)*.

"Buffer strips," "filter strips," or "streamside management zones" are widely recommended in the watershed management literature *(77, 130, 147)*. In the present context, the term "streamside management zone" is most useful. It implies that this is an especially sensitive and important area which requires special management but not necessarily no management. In fact, timber harvesting is not generally excluded. Providing a zone of no, or at least minimal, activity near all active streams can reduce adverse water quality impacts on Alabama streams in two major ways. Simple physical separation of potentially detrimental activities from the stream reduces the probability of adverse effects. Certainly stream banks and channels are less likely to be disturbed (directly producing sediment), but also substances such as pesticides and fertilizers are less likely to get to the stream if their use is restricted within a certain distance. In addition, the maintenance of a relatively undisturbed zone (the forest floor in particular) between the stream and disturbances potentially producing surface sediment flow should result in the trapping or filtering of some potential pollutants before they reach the stream. Thus, relative to the basic processes of sedimentation, SMZ's can serve to reduce or avoid *detachment* of particulate matter in or near the stream and reduce the *transport* of sediment (and other pollutants) from areas outside the zone to the stream.

Another effect which may be important is that of avoiding higher stream water temperatures. This is especially important for small streams, where solar energy impact is relatively great. Removal of all trees next to streams has generally resulted in an increase in stream temperature *(43, 85)*. Simply leaving trees or other vegetation to shade the stream is sufficient to remedy this and is recommended *(141)* where increases in stream temperature might be considered detrimental. The effect will be greatest on south-facing watersheds *(85)*.

Although there seems to be general agreement that SMZ's are useful or even crucial to maintaining water quality, the question of SMZ width and nature have not been subjected to rigorous study. Since activities are greatly restricted in SMZ's, logging costs increase and forest management options decrease as these zones are made wider. Thus, in areas managed intensively for timber production, it is important that SMZ's be no wider than necessary to achieve water protection objectives. But how wide is this?

A set width for SMZ's is not desirable or valid hydrologically. The minimum width needed for an SMZ to accomplish its purposes will vary with several factors which are related primarily to the nature of the area around the stream. The major ones influencing the needed width are: the nature and degree of ground cover, the erodibility of the soil, the degree of slope, the shape of the streamside area, and the presence of gullies or ephemeral stream channels in the potential SMZ.

In addition, the effectiveness of an SMZ is influenced by characteristics other than those of the zone itself. These include the amount of runoff and sediment coming from the slope above, which is a function of rainfall intensity, slope, amount of bare soil, infiltration characteristics, and slope configuration, among others. In most of Alabama, the topography is irregular enough that there are opportunities for surface runoff to concentrate in swales, depressions, and old gully systems. Once runoff is concentrated, it will cut through most SMZ's. This will be especially true for intensive site preparation, such as by windrowing, disking, bulldozing, and chopping plus a hot fire.

However, for the SMZ itself, the litter and organic matter at the soil surface, along with any low vegetative cover, are the most important parts of an SMZ affecting its ability to serve as a filter strip. An intact forest floor is generally recognized as the key to the undisturbed forest's ability to infiltrate any amount of rainfall normally occurring *(15, 31, 45, 98, 124, 152)*. If surface water infiltrates, it can then be expected to deposit any suspended sediment.

An undisturbed forest floor helps maintain high infiltration rates in at least four ways: (1) the litter intercepts falling raindrops, releasing the water slowly to the soil surface thus improving infiltration; (2) it prevents the kinetic energy of the falling drops from detaching soil and puddling the soil surface, which would slow or stop infiltration; (3) both the litter and organic matter slow any moving water, making it more easily infiltrated; and (4) the organic matter is highly absorbent and maintains high porosity at the surface, both directly and by encouraging activity of soil organisms.

Interestingly, the presence of a forest *canopy* alone does not reduce the erosive force of raindrops and may even intensify it *(38)*. The value of forest cover for erosion control comes mainly from its production of litter and maintenance of the organic layer. Low brush or other vegetation near the ground surface can reduce erosive raindrop impact by reducing the effective fall height of the water *(34, 159).*

The nature of the litter and organic matter affects any SMZ's ability to affect surface water flow and sediment infiltration. Pine litter is excellent for these purposes *(92).* Litter of most hardwoods is less effective than that of pines. It usually decomposes more rapidly. It may mat down, forming a partial barrier to water, or it may wash off easily, depending on circumstances. Thus, having pine litter or pine litter mixed with hardwood litter is usually more effective than hardwood litter alone. A dense root mat in the organic layer also helps produce a highly favorable condition for erosion prevention.

The degree of litter or ground cover is quite important. It is one of the factors of the universal soil loss equation *(159).* Dissmeyer and Foster *(34)* have assessed its importance such that they consider a complete litter layer at the surface to completely stop all surface erosion (cover factor of 0.0). Obviously, the more cover the less surface flow and erosion. With less than complete cover, the interspersion of the litter layer becomes important. As long as intact forest floor surrounds small bare or disturbed patches, most sediment movement will be kept to short distances. Thus, as long as disturbances are dispersed and small in total area, most of the forest floor's ability to prevent erosion and sediment movement will be maintained, so felling of trees and winching them out of an SMZ is unlikely to seriously reduce the benefits of the forest floor.

Erodibility of the soil involved also affects the effectiveness of an SMZ. The more easily eroded the soil, the wider the protected zone needs to be just to reduce the amount of sediment which needs to be filtered.

Resistance of soils to erosion is a complex subject and is dependent on a number of specific characteristics. Most of them are related to a soil's permeability and its resistance to detachment *(45).* The simplest overall characteristics are soil texture and organic matter content. In general, a soil becomes more erodible as the proportion of silt (0.002-0.05 mm diameter) and very fine sand (0.05-0.10 mm) increases, due to the susceptibility of these soil particle sizes to detachment. Soils become less erodible as the organic matter content increases. The presence of a layer of low permeability will also increase the erodibility of a particular soil by reducing its ability to infiltrate water, thus increasing surface runoff. Clay is the least permeable textural class, with sand the most permeable. Thus, a soil with a silty or very fine sandy surface layer with low organic matter and a shallow clayey subsoil would be extremely erodible.

The universal soil loss equation (USLE) identifies a soil erodibility factor, K, which is used to quantify erodibility of soils under severe cropping situations *(159)*. The Soil Conservation Service has developed K factors for soil series and surface textures found in the South *(153)*. Recent county soil surveys of the SCS also list K factors for soils of the surveyed county. Although the absolute value of the K factor has meaning only in the USLE, it provides a means of both categorizing and comparing soils as to their erodibility under exposed conditions. K factors for soil series of major soil associations of Alabama *(61)* are given in table 2. Variations in interpretation are possible, but one reasonable classification by K factors is: low erodibility, less than 0.21; moderate, 0.21 to 0.27; high, greater than 0.27 *(60)*. This can provide a means for predicting the sensitivity of a particular soil to erosion under disturbed or exposed conditions. It can aid in judging a reasonable SMZ width, as well as in making other decisions affected by erosion hazard.

The tendency for rainfall or surface water to run off increases as slope increases. Of course, this tendency is modified strongly by interaction with other factors, primarily soil properties and surface conditions. All other factors constant, an SMZ should be wider where slopes are steeper. This gives a greater distance for surface flow to be stopped by the surface layers of the SMZ, allowing infiltration of water and deposition of sediment.

The use of slope as a guide is relatively simple where the slope is uniform from the stream bank out to a point beyond that being considered for an SMZ. However, most streamside areas are not shaped that way. Most perennial and some intermittent streams have flood plains of varying width which, although with a lot of irregularities, are close to level (figure 1-A). The surrounding uplands may approach the flood plain or terrace at any positive angle. Also, many stream valleys are not truly symmetrical, such as illustrated in figure 1-C to E. The result is a tremendous variety of stream basin shapes, figure 1. Shape has pronounced effects upon the functions of an SMZ as a filter strip. Whenever a sudden change from steep to gentle gradient occurs (as at the foot of a slope as it enters a flood plain), the velocity of any surface water flow drops sharply and its ability to carry sediment declines even more rapidly *(73)*. Some suspended sediment will then be dropped. Also, since the velocity of flow has decreased, the probability for infiltration increases.

TABLE 2. VALUES OF K FACTORS FOR SOIL SERIES OF MAJOR SOIL ASSOCIATIONS OF ALABAMA *(61)*; TAKEN FROM THE SCS *(153)*

Series	Surface texture[1]	K	Series	Surface texture	K
Alaga	LS, LFS, FS	0.17	Flomaton	GR-LS, GR-S	0.15
Albertville	SIL, L	.37	Flomaton	GRV-LS, GRV-S	.10
Albertville	SL, FSL	.32	Fullerton	CR-SICL	.20
Allen	L, FSL, SL	.28	Fuquay	LS, LFS	.15
Allen	GR-L, GR-FSL, GR-SL	.15	Fuquay	S, FS	.10
Allen	CL, SCL	.20	Grover	SL, FSL, COSL	.24
Appling	FSL, SL, LS	.24	Grover	SCL	.28
Appling	GR-SL, GR-COSL	.15	Gwinnett	SL, SCL	.28
Appling	SCL	.20	Gwinnett	GR-SL, GR-SCL	.17
Bama	FSL, SL, L	.24	Hartsells	FSL, L	.28
Barfield	SICL, SIC, C	.24	Hector	GRV-FSL, GRV-L	.10
Barfield			Hector	GR-FSL, GR-L	.17
(stony)	ST-SICL, ST-SIC, ST-C	.17	Hector	FSL, L	.24
Benndale	FSL, SL, L	.20	Hector		
Benndale	LS	.17	(stony)	STV-FSL, STV-L	.10
Bodine	CR-SIL, CR-L, CR-SL	.28	Hector		
Bodine	ST-SIL, ST-L, STV-SIL	.28	(stony)	ST-FSL, ST-L	.17
Boswell	FSL, SL	.28	Hiwassee	SL-FSL	.28
Boswell	SIL, L	.43	Hiwassee	CL, SCL, L	.28
Cahaba	SL, FSL	.24	Holston	L, FSL, SL	.28
Cahaba	LS, LFS	.15	Iredell	GR-L, ST-L	.24
Cecil	SL, FSL	.28	Iredell	FSL, SL	.28
Cecil	GR-SL	.15	Iredell	L, SIL, CL	.32
Cecil	SCL, CL	.28	Johnston	MK-L	.17
Cheaha	ST-L, ST-SIL	.24	Johnston	L, SL, FSL	.20
Cheaha	ST-FSL, ST-SL	.20	Lee	CR-SIL, GR-L	.28
Chewacla	FSL, SL	.24	Leeper	SICL, SIC, C	.32
Chewacla	SIL, L	.28	Leesburg	GR-SL, GR-FSL, GR-L	.15
Colbert	SIL, SICL	.43	Leesburg	CB-SL, CB-FSL, CB-L	.15
Conasauga	SIL, L	.43	Linker	FSL, L	.28
Conasauga	SICL, CL	.37	Linker	GR-FSL, GR-L	.24
Davidson	L, CL, SCL	.28	Linker	ST-FSL, ST-L	.20
Decatur	L, SIL, SICL, SIC, C	.32	Lobelville	CR-SIL, CR-L, GR-SIL	.28
Demopolis	L, CL, SICL	.37	Louisa	GR-L, GR-SL, GR-FSL	.17
Demopolis	GR-L, GR-CL, GR-SICL	.20	Louisa	L, SL, FSL	.28
Dewey	SIL, L	.32	Lucedale	SL, L, FSL	.24
Dewey	SICL, SIC, C	.24	Lucy	LS, S, LFS	.15
Dickson	SIL	.43	Luverne	SL, FSL	.24
Dorovan	MPT	-	Luverne	LS, LFS	.20
Dothan	LFS, LS	.15	Madison	FSL, SL	.24
Dothan	FSL, SL	.24	Madison	GR-FSL, GR-SL	.15
Enders	GR-FSL, GR-L, GR-SIL	.32	Madison	CL, SCL	.28
Enders	FSL, L, SIL	.37	Malbis	FSL, L	.24
Escambia	FSL, VFSL, SL	.24	Mayhew	SICL, SIL, L	.37
Escambia	L, SIL	.32	McLaurin	LS, LFS	.17
Esto	LS, LFS	.17	McLaurin	SL, FSL	.20
Esto	FSL, SL, L	.28	McQueen	SIL, L	.37
Eutaw	SIC, SICL, C	.32	McQueen	FSL, SL	.28
Firestone	SIL, L	.37	Mecklenburg	L, FSL, SL	.24
Firestone	GR-SIL, GR-L	.32	Mecklenburg	GR-L	.17
Mecklenburg	CL, SCL	.28	Savannah	FSL, SL	.24
Minvale	CR-SIL, CR-L, CR-SICL	.28	Smithdale	LS	.17
Minvale	SIL, L, SICL	.37	Smithdale	SL, FSL	.28
Montevallo	SH-SIL, SH-L	.28	Smithton	FSL, SL, L	.32
Montevallo	SHV-SIL, SHV-L	.20	Stough	L	.28
Musella			Stough	FSL, L	.37
(stony)	ST-CL, ST-SCL	.20	Sumter	SICL, SIC, C	.37
Musella			Susquehanna	FSC, SL	.28
(gravelly)	GR-CL, GR-SCL	.20	Susquehanna	SIL, L	.37
Musella			Susquehanna	LS	.17
(gravelly)	CL, SCL	.32	Talbott	SIL	.37
Myatt	FSL, SL, L	.28	Talbott	SICL, C	.32
Myatt	SIL	.32	Tallapoosa	L, SIL	.32

Continued

TABLE 2 (*CONTINUED*). VALUES OF K FACTORS FOR SOIL SERIES OF MAJOR SOIL ASSOCIATIONS OF ALABAMA *(61)*; TAKEN FROM THE SCS *(153)*

Series	Surface texture[1]	K	Series	Surface texture	K
Oktibbeha	FSL, SL, L, SIL	.37	Tallapoosa	FSL, SL	.28
Oktibbeha	CL, SICL	.32	Tatum	SIL, L, VFSL	.37
Orangeburg	LS, LFS, S	.10	Tatum	SICL, GR-SICL	.37
Orangeburg	SL, FSL	.20	Tatum		
Osier	S, LS, FS	.10	(gravelly)	GR-SIL, GR-L, GR-VFSL	.37
Osier	FSL, LFS	.25	Townley	L, SIL	.37
Pansey	FSL, SL	.20	Townley	SICL, CL	.32
Pansey	LFS, LS	.17	Townley	FSL, SL	.28
Plummer	S, FS, LS	.10	Townley		
Poarch	FSL, SL, L	.20	(gravelly)	GR-FSL, GR-L, GR-SIL	.32
Quitman	FSL, L, SIL	.28	Troup	FS, LFS	.17
Quitman	LFS	.17	Troup	LS, S	.15
Red Bay	SL, FSL, SCL	.20	Wagram	LS, LFS	.15
Red Bay	LS, LFS	.10	Wagram	FS, S	.10
Ruston	GR-FSL, GR-SL, GR-L	.15	Wilcox	SICL, SIC, SIL	.37
Ruston	FSL, SL, LFS	.28	Wynnville	FSL, L	.24
Savannah	L, SIL	.37	Wynnville	SIL	.28

[1]Abbreviations: C = clay, CB = cobbly, CO = coarse, F = fine, GR = gravelly, GRV = very gravelly, L = loam or loamy, MD = muck, MPT = muck peat, S = sand or sandy, SH = shaley, SHV = very shaley, SI = silt or silty, ST = stoney, STV = very stoney.

Compounding this, the soils usually change, often drastically, at the interface between sloping upland and flood plain or terrace. Consequently, the erodibility of the soil may change from very high on a slope to very low on the terrace or flood plain, or vice-versa.

Another factor which can influence the efficacy of an SMZ is the presence of gullies or other ephemeral channels which extend part or all of the way through it. During storm periods, such channels will frequently become an extension of the main stream channel system *(76)*. If, for example, a gully extends from a perennial stream channel through a carefully maintained SMZ into a landscape which has been root raked, windrowed, and bedded, sediment may move during heavy rainfall directly from the exposed surface soil into the gully and thence directly to the main stream channel. Thus, the effectiveness of the SMZ as a filter strip will have been short-circuited.

All of the contingencies just discussed make the establishment of simple guidelines for SMZ widths a rather dubious approach in terms of hydrologic validity. Nonetheless, some adjacent Southern States are pursuing a simple prescriptive approach. Georgia's BMP guidelines *(56)* specify exact SMZ widths based on just a regional physiographic breakdown into three classes. Florida *(51, 52, 60)* specifies widths based on the erodibility class of soil series (using the K factor value) and on slope classes. This is an improvement over a simple set width, but the system makes no allowances for varied zone shapes, slope changes (no instructions are provided regarding how to handle the typical slope break at the upland-flood plain

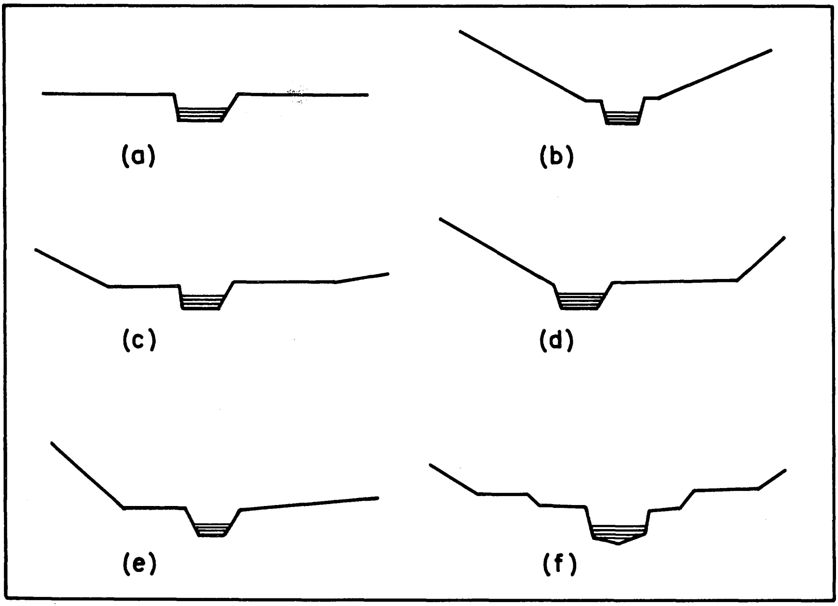

FIG. 1. Some possible streamside shapes in cross-section.

interface), soil changes, or presence of gullies. Most of Florida has simpler topography than most of Alabama, so this system may work better there than it could across the tremendous variability found in Alabama.

No research-derived recommendations for SMZ widths between site-prepared areas and streams are available at this time. Some recommendations for distances between roads and streams were found. For buffer strips between roads and streams in the Appalachians, Trimble and Sartz *(145)* recommended a 25-foot strip on level terrain, with the width increasing 2 feet for each 1 percent increase in slope. Within municipal watersheds, they recommended that these widths be doubled. These recommendations were apparently based on their observations of surface sediment flows from mountain roads.

If such simplistic SMZ width requirements are to be specified for Alabama at this time, this action must be justified on grounds other than hydrologic. Any reasonably valid (hydrologically) specification of SMZ width should include consideration of all the factors discussed earlier and also should have further study and validation than is now available.

From the standpoint of balancing the water quality benefits of an SMZ with the need for efficient and economical use of forest lands for timber production, the best present course seems to that of educated, informed, site specific decisions based on careful onsite inspection. This approach requires subjectivity and its success is dependent on the knowledge, attitude, and intent of the persons making the decisions. However, considering the complexities involved there is no other scientifically valid approach available at this time.

It is worth emphasizing that establishment of SMZ's of any width should not be taken as the answer to all forestry-related sediment problems. With poor land management above the SMZ, concentrated surface flow can cut gullies through any SMZ's that are established. There must be concentrated effort to reduce surface flow at the source. This is crucial also for maintaining site productivity that is lost when topsoil is eroded away.

Roads

As noted earlier, construction, use, and maintenance of roads in the forest have the greatest potential for water quality degradation of any forestry activity, except possibly for certain types of mechanical site preparation. However, several studies have demonstrated that careful planning and proper maintenance of logging roads systems can keep any increases in stream sediment to minor levels *(4)*.

In this report, a "road" is considered any surface purposely prepared for vehicular traffic where the mineral soil has been exposed by removal of the organic surface layer *(120)*. Important aspects are: that a road involves the direct exposure of mineral soil to erosional forces, its construction involves soil disturbances, and with use it usually becomes quite compacted internally but may be loose and disturbed at the surface.

One of the most important practices to reduce adverse road impacts on stream quality is to carefully plan roads before they are constructed *(2, 40, 66, 72, 74, 84, 87, 103, 126, 127, 156)*. Both road layout and design should be suited to the field conditions. This has benefits both in reducing sedimentation problems and usually reduces costs in the long run *(74)*. Carefully planned road systems usually have fewer miles of road per unit area than those established haphazardly. Careful planning may reduce the number of stream crossings necessary, thus reducing costs of culverts or bridges as well as reducing stream impact. Determining road design consistent with the conditions in order to avoid drainage problems will reduce long term costs and problems due to maintenance and lost time.

To provide adequate drainage on any roads constructed at a given location *(6)*, keeping moving water to a minimum on road surfaces is the most effective way to minimize sediment produced from roads *(77)* and thus minimize road deterioration and resulting maintenance requirements. Proper drainage can be accomplished by use of cross drains, culverts, broad based dips, or water bars.

Roads should, as much as practical, be located away from streams *(21, 48, 64, 84, 121, 130)*. This avoids damage directly to the stream channel during construction and also decreases the probability that sediment from the road will reach the stream. Routes through steep narrow canyons, over slide areas, through marshes, or through natural drainage channels should be avoided *(48, 130)*.

If it is necessary for roads to cross streams, they should cross at right angles *(67, 84, 88, 121)*. This minimizes the amount of road near the stream and also avoids having the stream move along part of the road surface during high water. Open-top culverts, water bars, or broad based dips should be placed in the road on either side of a stream crossing *(84)*. They should divert water into a sediment trap of some kind (grassy sod, heavy litter, rocks) to prevent its reaching the stream.

Roads should cross streams on bridges or culverts *(121, 130)*. Under stable circumstances, streams with hard and relatively level banks and beds on rock, coarse gravel, or packed sand may be temporarily crossed with fords *(77)*. Movement of vehicles or machinery across unprotected stream channels generally contributes significantly to suspended sediment.

Whenever the stream drains a watershed of 200 acres or less, a properly sized culvert will usually suffice if properly installed *(77)*. Table 3 shows recommended culvert sizes for physiographic regions found in Alabama.

TABLE 3. RECOMMENDED DIAMETERS FOR CORRUGATED METAL CULVERTS 15 FEET LONG; TAKEN FROM HEWLETT ET AL. *(77)*

Drainage area, acres	Coastal Plain	Piedmont or Mountains	Flat-woods	Ridge and Valley
	In.	*In.*	*In.*	*In.*
10	12	12	12	18
50	18	30	30	36
100	30	42	48	48
200	42	54	60	2(48)

Fill slopes next to stream crossings should be seeded and mulched immediately following construction *(77, 130)*. Due to their proximity, sediment movement will be directly into the stream. Time of complete soil exposure to rainfall should therefore be kept to the minimum possible.

Roads should be laid out and designed to minimize cuts and fills *(48)*. These are sites of instability and exposure of soil to rainfall.

Roads should normally follow contours and be kept to grades less than 10 percent, except where impractical *(64, 84, 114, 121, 130)*, and then they should not exceed 15-20 percent. On particularly slippery soils, such as in the Piedmont and Clay Hills, 8 percent is a better maximum grade *(77)*. Steeper grades increase the velocity and thus erosive force of water draining along the surface. Slippage of vehicles moving up the grade is also more likely, leading to formation of ruts and destruction of the road surface.

Road construction should be limited to dry weather *(52)*. Construction during rainy periods will result in increased movement of soil, production of rills and gullies, and compaction of soils.

For best results, roads should be located on the sides of ridges rather than directly on top. A side hill location allows easier drainage, whereas a flat hilltop location often is difficult to drain and may result in gradual entrenchment of the road bed under traffic *(67, 77, 84)*. For these reasons also, completely flat areas should be avoided whenever possible. A minimum road grade of about 3 percent is desirable to provide adequate drainage *(67, 84)*. With completely flat roads, water collects on the road surface.

On dirt haul roads on slippery soils, do not in-slope or out-slope the general road surface *(77)*. Use broad based or rolling dips, open top culverts, or gentle water bars to provide adequate drainage. In-sloping would require side ditches and expensive cross drains. Out-sloping can create dangerous conditions where road surfaces are slippery. For some locations, including rocky or gravelly roads, out-sloping of 3 percent has been recommended *(67)*.

The broad based or rolling dip is highly recommended for achieving drainage on dirt woods roads. It has been specifically recommended and used in the Southern Appalachians *(74, 84)* and Southern Piedmont *(24)*. This structure is basically a short stretch of road which is given a 15- to 20-foot reverse grade of 2-3 percent and out-sloped about 3 percent in the bottom of the dip created, figure 2. To achieve the reverse grade, the road slope descending into the drop is steepened to 1.2 times the basic grade of the road. The

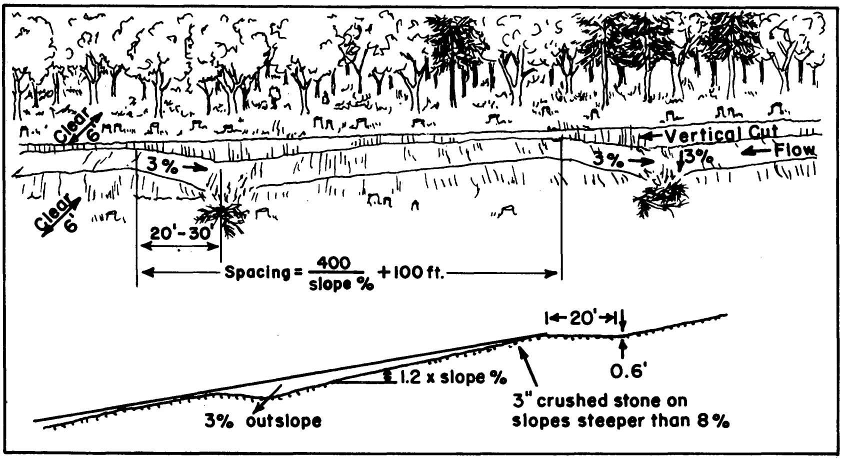

FIG. 2. Specifications for broad-based dips on wood roads. Taken from Hewlett et al. (77).

material scraped from the long side of the dip is used to make the back slope or hump, which should be rounded. The dip bottom should also be skewed down slope 10-20 degrees to reduce sediment buildup *(24)*. Dips should be spaced as: spacing (feet) = 400/percent slope + 100 feet, where the slope is the basic road grade *(74)*.

Besides providing needed drainage, other benefits are claimed for broad based dips: they usually require little or no maintenance (often for years); they are safe for transit of loaded trucks, although some slowing is necessary; and they remove the need for water bars. They usually preserve the road bed in usable condition for future use and harvest *(74)*.

Some type of dispersion system or sediment trap should be placed below the outlet of any dips, culverts, or dispersion drains *(62, 130)*. This will encourage the settling of sediment before it can reach a stream and also will prevent the formation of gullies. Stone rip-rap, grass sod, heavy litter cover, brush, logs, or anything else can be used which will reduce water velocity and spread the force of water as it exits the drainage structure *(145)*.

Any roads which are not in constant use but are actively eroding or are highly susceptible to erosion should be seeded to grasses or covered with forest litter or mulch. Roads which are not needed after logging should be blocked off, water bars should be installed, and all exposed areas stabilized with vegetation or mulch *(130)*. This should be accomplished immediately to avoid development of rills and gullies. Water breaks should be installed at a 30-degree angle down grade. Recommended water bar spacing is shown below *(62)*:

Road grade, pct.	*Distance between water bars, ft.*
1	400
2	245
5	125
10	78
15	58
20	47
25	40
30	35

Harvesting Operations

Logging practices which protect water quality and soil productivity values usually are beneficial in other ways, such as reducing total mileage of roads and skid trails, lowering equipment maintenance costs, and providing better protection of roads and lower maintenance costs for future use *(82)*. This results in some of the possible short-term increased costs of better practices being balanced by cost reductions in other ways.

Trees should not be felled into streams unless there is no safe alternative. When a tree is felled into a stream, however, removing it before limbing or bucking reduces disturbance and reduces debris in the stream *(14)*. Any debris placed in the stream channel should be removed during the logging operation.

Skidding in stream channels and across streams is undesirable *(120, 121, 130)*. Operating skidders in and across channels directly produces stream sediment and can result in the collapse of stream banks and gouging of both channel beds and stream banks.

Log landings or loading decks should not be located near streams *(120)*. Generally, maintaining an adequate SMZ will avoid improper placement of landings near streams. It is highly desirable to keep them well away from SMZ's also since they normally become quite compacted and puddled, and until revegetated are usually a source of rapid surface runoff. For this reason also, it is desirable that landings not be located in high erosion hazard areas or close to gullies.

Downhill skidding is undesirable, especially on steep slopes, because it concentrates water into main skid trails and directly onto landings *(154)*.

It is highly desirable that main skid trails not climb directly up steep slopes. Grades in skid trails should normally be kept below 20 percent and below 10 percent wherever practical. Where it is necessary to use steep major skid trails, the grade can be regularly broken with short gentle stretches to allow surface water to move off the trail and avoid a large buildup on the trail surface. On steeper skid trails (greater than 10 percent) where the soil's surface is completely bare, it is desirable to install water bars when the skid trail is no longer needed, preferably seeded and/or mulched with logging debris *(14, 156)*. Steep bare skid trails have a high potential of moving soil down slope and forming large rills or even gullies. Logging and vehicular movement should be avoided whenever possible if soils are wet, due to the tremendous increase in compactability. Compaction reduces the infiltration capacity of the soil, increasing surface runoff which may reach a stream with its attendant sediment. This also lowers site productivity and makes seedling establishment more difficult *(63, 106)*.

Movement of heavy equipment over wet soils also may lead to puddling. This occurs when soils have been subjected to enough compressive and shearing forces to compact them and cause clay particles to become oriented parallel to each other *(7)*. Also, fine soil particles become clogged in the resulting smaller pore spaces. Puddled soils are often impervious to water, thus resulting in surface runoff.

Where it is necessary to continue logging operations under wet conditions, there are steps which can reduce the detrimental effects. These include scheduling of operations during wet periods on the best drained areas (ridges and areas with sandy soils). Also when logging moist soils, particularly those of medium texture (such as loams, silt loams, and fine sandy loams), total compaction damage will be reduced if the number of skid trails is kept to a minimum *(63)*. Under moist conditions, medium-textured to medium-fine-textured soils are the most readily compacted and puddled *(143)*. A minimum number of major skid trails should be used under these conditions. Considerable damage is done by one pass, so it is better to keep the skid trail area to a minimum.

When logging dry soils, particularly very porous ones (such as sands, loamy sands, coarse sandy loams), it is better from a soil compaction standpoint to disperse skid trails as much as possible. Avoiding travelling over the same exact trail more than once or twice is desirable because only minor compaction occurs the first trip but becomes critical as trips increase *(63)*.

Any harvesting operation in a particular area should be completed as quickly as possible. Any sediment produced by logging and use of logging roads is usually greatest during the operation itself *(82)*.

An approach which can reduce the amount of soil impacted by skid trails and damage to residual trees (in selective harvests) is that of planning and designating skid trails before the harvest. Results of a study involving thinning of a young growth Douglas-fir stand in sloping terrain in Oregon *(55)* illustrate the effects of such an approach. The size of the trees removed (8-12 inches dbh), terrain, and presence of understory brush made conditions similar to those in parts of Alabama. Skid trails were designated before logging, laid out to involve only about 10 percent of the area (compared to a typical 20-40 percent), and cleared of brush in a single dozer pass before tree felling began. Trees were directionally felled to facilitate their being winched to the closest skid trail. The skid trails were laid out basically parallel to contour. Overall productivity in logs per hour was similar to a conventional non-designated skid trail operation to which it was compared. Time lost in extra winching was mostly made up by faster and easier skidding on the designated trails.

Such an approach could have particular applicability when used with SMZ's if a skid trail is designated and cleared at the edge of the SMZ in a manner to facilitate winching and skidding. The job of felling and winching harvested trees within the zone should be simpler, easier, and more effective than if the sawyer and skidder have to determine such details as they go.

Regeneration Practices

Planting seedlings with machines which involve a scalping blade, coulter, or plow should follow slope contours and never be oriented downhill. Downhill orientation will serve to produce erosion rills, moving surface water and sediment, and also will frequently wash away seedlings.

Planting with soil-baring machinery should be excluded from SMZ's. Hand planting, direct seeding, or natural seeding can be used in these areas to avoid baring of mineral soil.

Natural regeneration or direct seeding has advantages on steep slopes with erodible soils. Mechanical disturbances of such sites should be avoided if possible.

The time to plan for regeneration is *before* a timber stand is harvested. This will usually leave more options open for regeneration. Many regeneration methods must be closely integrated with the timber harvest. Thinning to increase seed production and timing of seedbed preparation to take advantage of good seed years are steps that are often necessary for successful natural regeneration. Prior reduction of competition by burning or herbicides can be valuable in any regeneration approach. Such activities sometimes need to be planned years ahead of harvest.

Site Preparation

For both stream quality and site protection, one major objective in all forms of site preparation should be, within the limits of the system and site conditions, to leave as much of the forest litter and topsoil (soil O and A1 horizons) in place as possible *(59, 94)*. This is the key to ensuring that detrimental effects do not occur or are minimal. If soil is not detached, it cannot be transported downslope to a stream. Documentation is abundant that an unbroken litter layer, with or without any trees or living vegetation, will essentially stop raindrop detachment, maintain good infiltration (thus preventing overland flow), and will also serve to slow or stop flow which may encounter it *(92, 94)*.

On steep, highly erodible slopes, the use of mechanical site preparation treatments which bare most of the soil surface, such as root raking, bulldozing, and disking, are undesirable. Alternative, less disruptive treatments are better, if available *(94)*. These include drum chopping, herbicide application, and properly controlled burning. If an adequate, desirable seed source is present, natural regeneration or direct seeding are alternatives which may reduce the need for intensive site preparation on such sites. If intensive soil-baring treatments are used on erodible slopes (an undesirable practice which should be avoided), leave an SMZ below which has very high capability for trapping sediment. Make sure that no gully channels extend beyond the SMZ into the site-prepped area. The SMZ may need to be wider than usual and should have a heavy intact forest litter layer. A windrow along the outer edge of the SMZ will be helpful in slowing surface sediment movement. Even so, the SMZ may not be adequate under such circumstances.

Use of a non-toothed bulldozer blade for windrowing debris is a damaging practice. Avoiding removal of most of the soil organic matter and significant quantities of topsoil is almost impossible with such equipment, particularly on slopes. The results are undesirable in terms of stream sediment movement and also site productivity reduction *(57)*. On some sites in Alabama, removal of just 1 inch of topsoil can reduce pine site index by 11 feet or more and may easily reduce the present net worth of the resulting plantation by $120 per acre *(59)*. Drastic losses of site quality between windrows have also been shown on deep sandy soils where scarce organic matter was moved away *(22)*.

Mechanical site preparation should also be avoided on wet soils *(106, 143)*. Increased compaction and puddling may result on many soils, particularly on those of medium to medium-fine texture (loams, silt loams, silts, very fine sandy loams). This will increase surface runoff, increasing the possibility of stream sedimentation.

Bedding on sloping terrain should always be applied carefully on contour *(147)*. Where breaks through the beds do not occur, such beds can provide retention storage for surface water and serve as sediment traps to stop a significant portion of soil material before it reaches the foot of the slope *(9)*. However, if breaks in the beds occur on slopes, they can produce significant amounts of sediment *(9)* and should be stabilized. Putting beds on steep slopes is unsatisfactory where frequent large stumps have been left. Following the contour is essentially impossible under these circumstances, and this will lead to breaks in the beds, producing gullies *(9)*.

For similar purposes, disking should also be on contour wherever possible. The furrows will tend to resist surface water movement this way. Orienting them perpendicular to contour on sloping terrain will cause rill and gully formation.

Where possible, it is more desirable to run tree crushers or drum choppers perpendicular to slopes, thus orienting the resulting soil indentations along the slope. This orientation is more effective at trapping surface flow and sediment *(147)*. There is no concrete evidence, however, that chopper or tree crusher marks oriented perpendicular to slopes will increase erosion. They are short and normally discontinuous and tend to increase infiltration even in this orientation.

Windrows should be placed on contour wherever possible. This way they may serve to temporarily stop any surface water movement down slope, thus allowing it to drop much of its suspended sediment. An exception is in actively eroding gullies where windrowing some debris into the gullies will encourage their stabilization and the deposition of suspended sediment before it reaches a stream. However, this does not apply to active stream channels!

Use of properly timed, controlled fires at periodic intervals throughout the rotation represents good management of southern pines. This will avoid buildup of competing woody vegetation and allow regeneration after harvesting which will not require drastic soil baring treatment for competition control *(123)*. The section on burning contains recommendations for properly prescribed fires to avoid sediment problems.

Prescribed Burning and Fire Control

Since intense uncontrolled wildfires often cause lowered stream quality as well as other negative effects *(33, 123, 125)*, management to prevent wildfires is one important practice for water quality protection. In southern pine stands it is highly desirable to maintain a regular hazard reduction burning program. This avoids fuel buildup to dangerous levels. Thus, any wildfires should cause no more than minor damage.

For this purpose, pine stands should be burned on a 2- to 4-year schedule beginning when the trees are tall enough to withstand the fire, although longleaf pine may be burned when in the "grass stage." A carefully controlled backfire in winter, with low ambient air temperatures, a steady breeze, and a moist lower duff layer is preferable if a significant amount of fuel is present. A strip head fire may be used since it is faster for repeat burns where fuel is limited if environmental conditions are cool and steady *(33, 50)*.

Such a regular burning program through the rotation in pine plantations will have other benefits as well. These include increased wildlife foods *(14)*, control of understory hardwoods *(17, 93)*, and improved accessibility. For pine management, the control of understory hardwoods can result in having regeneration options at harvest which avoid any drastic disturbances of the site, thus further protecting water quality.

Careful advanced planning by knowledgeable persons is an important aspect of good controlled burning practice. Such well-planned burns seldom have significant adverse effects *(105)*.

In controlled burning, existing roads and openings are used as fire lines wherever practical *(105)*. However, some plowed fire breaks are usually necessary for most controlled burns and typically are required to suppress wildfires.

Wherever practical, fire lines should be located on gentle slopes along the contour *(25)*. Where they must be placed downhill on steep slopes, water bars and leadoff ditches at regular intervals are needed *(77, 105)*. Having a water bar and turnout is particularly important as any fire break approaches a stream or SMZ. These water bars and turnouts are preferably installed when the fire breaks are plowed, unless they are to be used for access of vehicles. If not earlier, they should be installed as soon as possible after the burn is completed.

Plowing fire breaks directly to or across stream channels and gullies is damaging since this will funnel sediment directly into the stream.

On steep slopes it is highly desirable that the exposed soil of fire breaks be fertilized and seeded after the fire is out *(105)*. This will usually serve to stabilize them before gullies may be formed.

SMZ's around all perennial streams can be protected by establishing fire breaks carefully at the edge of SMZ's and using water bars and turnouts on fire breaks which must approach from uphill. Fire breaks along the edges of SMZ's can also serve as sediment traps below site prepped or intensively burned areas, especially when fertilized and seeded.

Since soil movement can occur when all the surface organic matter is consumed in a fire, applying controlled burns on slopes is best when the lower layer of duff is moist *(23)*. This normally is sufficient to ensure that an organic layer will remain to maintain good infiltration and protect soil against raindrop splash. This maintenance of organic matter is critically important in the hilly and mountainous areas of the Piedmont, Clay Hills, Ridge and Valley, and Plateau regions of Alabama.

Use of Forestry Chemicals

In the context of this report, forestry chemicals are herbicides, insecticides, and fertilizers. Broadcast use of herbicides, and to a lesser degree fertilizers, is common in Alabama. Broadcast use of forestry insecticides appears to be quite rare other than at tree nurseries at this time, although spot and individual tree applications are occasionally used. Herbicides are also applied as spot and individual tree treatments.

The practices to avoid contamination by forestry chemicals are relatively simple. They involve avoiding direct applications to water surfaces, taking precautions to prevent accidental movement by wind to water surfaces *(54)*, and maintaining conditions which will prevent surface water movement from treated areas to streams during storms.

All three of these principles can be effected to some degree by maintenance of well protected SMZ's. No aerial or soil-applied chemicals should be used in an SMZ or applied directly to water surfaces *(26, 111, 122)*. Avoiding flood-prone areas, particularly with soil-active herbicides, will prevent the direct application of chemicals to the water and will reduce the probability of their moving to the stream by aerial drift or surface water flow. Leaving vegetation and organic cover of SMZ's also serves to absorb and break down or tie up many chemicals *(10)* before they reach a stream.

Aerial applications of forestry chemicals can be safely used only when the wind is quite low or absent and the danger of drift is minimal *(14)*. This frequently requires that such application be early or late in the day when the wind is usually lowest. For aircraft applications particularly, drift control spray nozzles and spray adjuvants are necessary for reducing volatilization and drift *(110)*.

Good erosion control practices are required on all areas where aerial or soil chemical treatments are applied. Keeping herbicides away from large areas of bare soil is suggested to minimize surface water flow and possible washing of the chemicals to streams.

Herbicides may be injected directly in the trees even within an SMZ. There appears to be little danger of such treatment adversely affecting streams *(93)*. However, cleaning storage tanks or application equipment in or near streams or other water bodies, or disposing of any materials or containers in streams is a dangerous practice.

With all labelled forestry chemicals, it is essential to follow the label directions carefully as they relate to the conditions at hand. Pesticide labels specify desirable application methods, rates, and precautions.

Stabilization of High Erosion-Hazard Areas

Stabilization of active gullies is of high priority in reducing sedimentation. The greatest benefit will be in stabilizing active gullies which are not yet connected with a system that directly reaches a stream but is approaching such conditions *(69)*.

Stabilization of deteriorated watersheds begins at both the mouth and gully heads. Damming gullies at the mouths will tend to raise the local base level of the streams and gully systems, making stabilization easier *(70)*. Active gullies should immediately be stabilized at their upper ends to prevent further cutting upslope.

Establishing vegetation, where possible, is the best form of rehabilitation of disturbed areas. It offers more permanent control than most artificial structures *(70, 100)*. However, frequently a combination of structures and vegetation establishment is required. If the vegetation is perennial and can perpetuate itself, it will not require later maintenance as would artificial structures *(68)*.

For erosion control, the most effective plant cover is dense, with deep dense root systems and low total heights *(68)*. However, loblolly pine is one of the best long-term erosion control plants for planting in the South *(92)*, since a continuous, interlaced mat of pine litter ½ inch or more thick will halt most surface soil movement. When compared to other species planted on eroded sites, loblolly pine survives well, grows fast, and casts more litter.

Vegetative mulches, such as hay, straw, leaves, and wood chips, are also quite effective for erosion control *(101)*. Both established vegetation and vegetative mulches serve to dissipate much of the energy of falling raindrops, slow runoff velocity of surface water, and serve to maintain a higher capacity for water storage in the soil *(100)*.

In areas with active gullies, brush dams constructed by loosely overlapping brush across the gully and anchoring it with material from the gully bottom can be useful in stabilization. It is usually desirable to push organic debris (logs, tops, stumps) into active erosion gullies. This is particularly relevant to site preparation operations, but is helpful at any time equipment is near an identified active gully. This debris can serve as a dam, slowing water movement and allowing deposition of sediment before it gets to a stream.

AN EROSION-SEDIMENTATION HAZARD CLASSIFICATION SYSTEM FOR ALABAMA'S FOREST LANDS

Introduction

To effectively plan and implement forestry best management practices for protecting water quality, it is crucial that lands under management be evaluated as to their sensitivity to erosion from forestry activities. This need was discussed earlier in this report.

This section is an attempt to provide a framework and some specific information regarding the widely diverse forest sites found in Alabama relative to their erodibility under forestry practices. Herein is presented a physiographic classification scheme with some descriptions and basic information to aid in the process of erosion-hazard (thus sediment production) evaluation. It is aimed at a level which should be usable by the trained professional forester and many others who have some knowledge of soils and geology. The level is such that it can be easily learned by most persons who diligently make the effort.

The concept and the basic classification framework are the same as those presented in the bulletin "Forest Habitat Regions and Types on a Photomorphic-Physiographic Basis: A Guide to Forest Site Classification in Alabama-Mississippi" *(80)*. A hierarchical classification scheme is employed. That is, one beginning with broad categories and progressing to successively more specific ones. This allows the system to be used at any desired level for planning or informational purposes.

Factors Affecting Erodibility of a Particular Site

Once a site is classified as to its land type, the range and general pattern of topography and soil characteristics which affect sensitivity to disturbance and erosion should be relatively narrowly defined. In some cases, such as the Sand Hills and Plains land type, the type and nature of the usual vegetative cover will also be defined.

The erodibility and therefore the erosion hazard of a particular site is dependent on a number of factors. These factors have been studied and applied most thoroughly through the development of the so-called "universal soil loss equation" (USLE). Its development has progressed through a number of stages *(109, 157, 158, 159, 162)*. The USLE predicts long-term average soil losses to sheet and rill erosion for specific areas under specific cropping and management systems *(159)*. It predicts, however, soil movement only to the bottom of the effective slope, and is not directly equivalent to soil reaching a stream. Originally developed and most widely used on agricultural crop land, it is being increasingly refined and adapted for other land uses, including forestry *(35, 86)*.

The USLE is defined as $A = RKLSCP$, where A is the predicted average annual soil loss in tons per acre; R the rainfall factor; K the soil erodibility factor; L the slope length factor; S the slope steepness factor; C the cover factor; and P a support practice factor. The factors most affecting forestry situations are discussed below.

The ULSE was developed and is most used for agricultural lands under continuous cropping. Forest lands and forestry practice conditions are vastly different in degree of vegetation, debris and rock cover, length of effective slope, land surface irregularities, length of time the soil remains bare, and frequency of mechanical disturbance, among others. It has been recommended, with good reason, that the USLE as described for agricultural use *(159)* not be used for forestry purposes without modification *(73)*. Modifications for forestry use, however, are still in the development stage *(21, 34, 35)*.

Rainfall

Rainfall affects erodibility for a particular location, since it provides energy for detachment and transport where the soil surface is exposed. Both the total amount of rainfall during the year and the peak rainfall intensities usually encountered influence the effects on erosion. These aspects of rainfall vary widely across the United States and vary considerably within Alabama. The USLE *(159)* develops a rainfall erosion index based on 22-year rainfall records. This index is used as the "R" factor in the soil loss equation. In Alabama, the index increases from slightly less than 300 in the northeast corner of the State, to more than 550 in southern Baldwin and Mobile counties *(159)*. These latter values are among the highest in the United States.

This indicates that the erosive force generated by rainfall is 50-100 percent greater in the southernmost parts of the State than in the far northern portions. Fortunately, the slopes are gentler and soils frequently less erodible in these southernmost areas, so there is some balancing of effect. However, it does indicate that erosional forces increase as one moves southward in the State.

Soil

There are characteristics of the soil itself which greatly affect its resistance or lack of resistance to erosive forces. For the USLE the soil erodibility factor (K) has been developed experimentally for many soils but can be estimated from nomographs *(159, 160)* which employ data on soil texture, organic matter, structure, and permeability. K factors of many of the major soil series found in Alabama are given in table 2.

In field observation, texture of the surface is the simplest indicator of soil erodibility. Simply put, the erodibility of a given soil tends to increase as the proportion of fine particles (silt and very fine sand, 0.002-0.1 mm diameter) increases. These particle sizes are small enough to be easily detached and transported, yet not so small as to have significant aggregation properties (as, for instance, does clay).

Organic matter content and soil structure can be more difficult to judge. Resistance to erosion increases with increasing organic matter (up to 4 percent). It also increases slightly as the structure varies from very fine granular to blocky, platy, or massive—in other words, as degree of aggregation increases.

Permeability may also be difficult to assess in the field. However, the most obvious indicator is the texture of the surface soil and the possible presence of a dense, fine textured, compacted, or otherwise impervious layer near the soil surface. The nearer such a layer is to the surface, the stronger its influence and the lower the total soil permeability. Thus, a soil having a surface with good erosion resistance and infiltration properties (e.g., a coarse sand) may still be moderately to highly erodibile if a dense clay layer is only a few inches under the surface.

The surface texture influences infiltration, with fine textures reducing it and also easily becoming clogged. Obviously, if all surface water infiltrates, there can be no erosion by moving surface water flow. Conversely, the lower the infiltration, the higher the amount of available erosive force of moving water at the surface.

Slope

Slope characteristics have a strong influence on erosion. Both slope steepness and slope length are important and are typically combined for the USLE as the topographic factor, LS. The slope length affects erosion because the amount of runoff accumulates, leading to an increase in the velocity of surface flow over distance, and velocity is the key factor influencing erosive force of flowing water *(73)*. The *effective* slope length (for increasing erosive force of overland flow) is broken whenever the slope flattens enough to cause deposition or any obstruction stops or concentrates surface flow significantly *(159)*. In forest situations under most conditions, effective slope lengths are broken frequently by slope irregularities, debris, or windrows. Effective slope lengths in forest situations usually average 100-120 feet and will seldom exceed 400 feet *(34, 36)*. Intensive site preparation, such as windrowing or disking, can generally have the longest effective slopes, but even these should seldom exceed 200-300 feet if windrows form a barrier to surface movement and are on contour.

Effective slope length is one consideration where forestry differs markedly from agricultural cropping in use of the USLE (cover is another). It is crucial that *effective* rather than total slope length be used if the USLE is applied in forestry situations. Otherwise, large overpredictions of future soil loss will result.

Slope steepness strongly affects the erodibility of a specific site by increasing the effects of gravity on surface water flow and also other types of soil movement, such as saltation and soil creep *(8)*. Steep slopes are encountered in forestry activities, but their influences are commonly counterbalanced to some degree by short effective slope lengths and by cover. Nonetheless, slope steepness is the most easily assessed and one of the most important aspects to be considered in judging forest land susceptibility to sediment production. It should be carefully considered in assessing erosion sensitivity to forestry operations. In addition to the direct erosion-affecting attributes of slope, slippage of vehicle tires or tracks will occur on steep slopes, causing direct soil damage and sediment production.

Cover

The nature and degree of cover which can reduce raindrop impact and/or slow surface movement is a factor which in forests can override the potential effects of the other factors. This is verified by observations of complete absence of overland flow in many undisturbed forests *(15, 31, 45, 98, 124, 152)*. It is in evaluating this factor for predicting erosion that the standard version of the USLE *(159)* most severely falls short for use on forest lands. Dissmeyer and Foster *(34, 35)* present an approach which provides a better approximation of conditions encountered in forestry practices. It reflects somewhat the complexities involved.

In assessing site sensitivity, both the nature and the amount of existing cover and the anticipated degree of cover loss under the planned use should be taken into account. If present cover is already sparse, the site is more sensitive to further loss of cover than would be the same site with an existing heavy cover on the soil surface.

In this context, effective cover is practically anything that is on or close to the ground surface. Short vegetation is more effective than tall vegetation, and material on the soil surface is most effective of all. Rock, logs, slash, and leaves are included as cover along with living or dead rooted plants. Rock is particularly important in some of the land types described later.

The Classification Scheme

The classification presented here is physiographic in nature. Thus, the basis is in physical attributes of the land. Geologic makeup, landform, and general nature of the soils are the principal factors, although climatic influences are included in an indirect manner.

The broadest unit is the *province*. Provinces reflect differing major broad scale patterns of landform and geologic material. For the most part, the provinces recognized are conventional southeastern physiographic provinces with a slightly changed nomenclature. For the Coastal Plain, the terms "hilly," "middle," and "flatlands" are used for the three provinces recognized, instead of "upper," "middle," and "lower." The former terms are more descriptive and the latter seem to have some confusion associated with them.

Forest habitat regions and *subregions* are classes representing a broad uniformity of general landform and/or geologic material at a more localized level than that of the province. They define and encompass a particular range and pattern of local habitat types. Subregions are defined and mapped only where two or more large scale topographic patterns are recognizable within a region.

Land types are basically uniform in geomorphology. This means uniformity with respect to type of topography, dominant geologic material, and the general soil profile associated with this material. These classes are the most useful as a framework for erosion classification and sensitivity assessment.

Within a land type, the specific attributes directly affecting erosion sensitivity, such as slope steepness, slope length, soil erodibility, and in some cases cover, will normally fall within reasonably small ranges. Thus, one can focus on those factors which are locally most critical.

The land type is the functional unit most useful for providing a framework for local planning. When a person becomes familiar with a particular land type through the descriptions, and more importantly through field observation and experience, he should be able to readily apply a knowledge of erosion factors and processes along with that of forestry practices to identify high hazard locations relative to planned activities.

To determine which land type classification fits a specific site, the following procedure is recommended: from figure 3, determine which forest habitat region or subregion contains the site in ques-

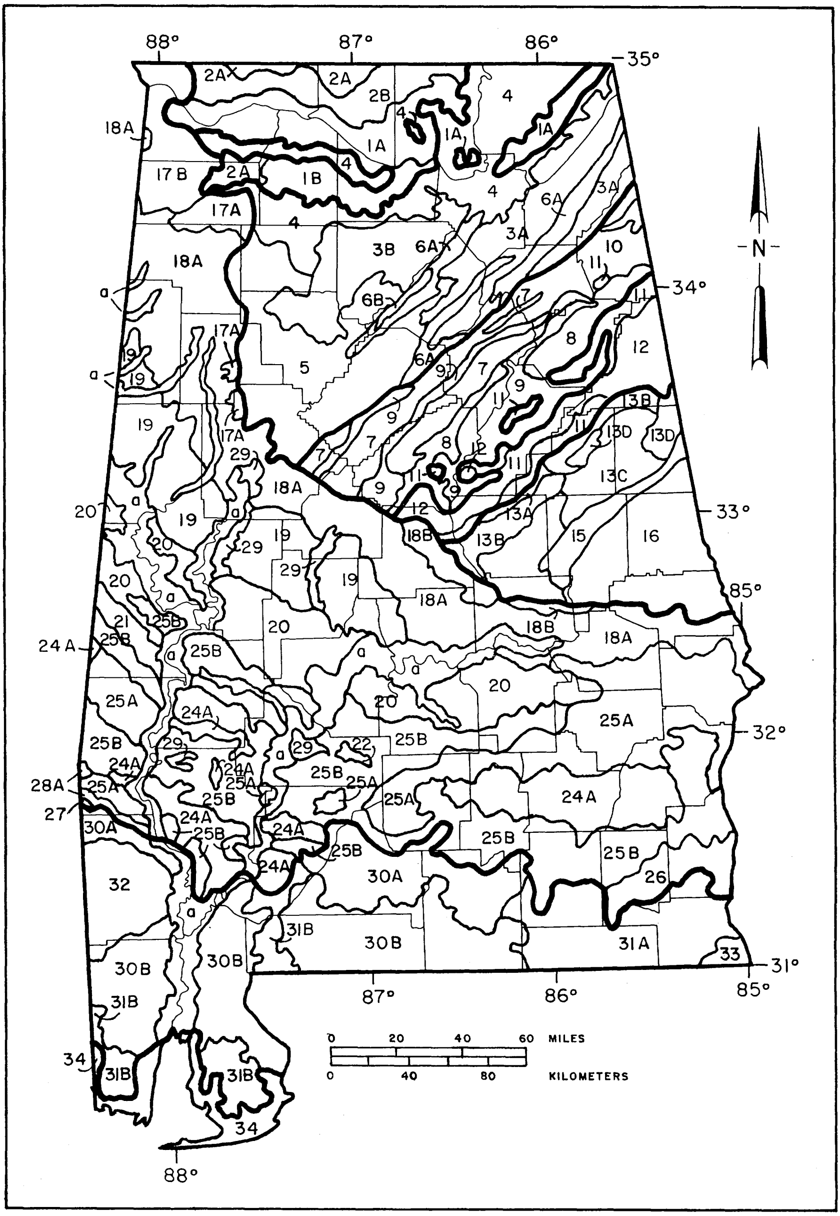

FIG. 3. Forest habitat regions and subregions of Alabama. The numbers refer to the units of tables 4 and 5. Taken from Hodgkins et al. *(79)*.

TABLE 4. LAND TYPES OF THE REGIONS AND SUBREGIONS OF THE CONSOLIDATED ROCK PROVINCES OF ALABAMA; AN X INDICATES THAT THE LAND TYPE IS FREQUENT; A - INDICATES THAT IT OCCURS OCCASIONALLY

Region/ subregion	Land types													
	Lime- stone	Lime- stone rockland	Chert hills	Sand- stone	Sand- stone rockland	Shale	Mixed sandstone- shale	Old alluvium	Mountain collu- vium	Quart- zite ridge	Slate- phyllite ridge	Schist hills	Granite- gneiss	Chlorite schist plains
1 Limestone Valley														
1A Tenn.-Gasper Valleys	X	X	-	-	-	-	-	-	-					
1B Moulton Valley	X	X	-	-			-		-					
2 Chert Hills														
2A Rugged Topo.			X						-					
2B Gentle Topo.	-	-	X											
3 Sandstone Plateau														
3A Table Plateaus	-	X		X	-		-							
3B Dissected Plateaus	-	X	X	X	-	-	-		-					
4 Sandstone Mountain	-	-		X	X	-	-		X					
5 Shale Hill & Mountain					-	X	X	X	X					
6 Cumberland Anti-clinal Valleys														
6A Typical Cumber-land Valleys	X	-	X	-	-	X	X	X	-					
6B Sequatchie Hills	X	-	X	-	-	-			-					
7 Sandstone Ridge		X		X	X	-	-		-					
8 Shale and Chert Ridge	X	X				X	-	X	-					

Continued

TABLE 4 (*CONTINUED*). LAND TYPES OF THE REGIONS AND SUBREGIONS OF THE CONSOLIDATED ROCK PROVINCES OF ALABAMA; AN X INDICATES THAT THE LAND TYPE IS FREQUENT; A - INDICATES THAT IT OCCURS OCCASIONALLY

Region/ subregion	Land types													
	Lime-stone	Lime-stone rockland	Chert hills	Sand-stone	Sand-stone rockland	Shale	Mixed sandstone-shale	Old alluvium	Mountain collu-vium	Quart-zite ridge	Slate-phyllite ridge	Schist hills	Granite-gneiss	Chlorite schist plains
9 Chert Valley	-	-	X					X	-					
10 Shaly Limestone Valley	X	-	X			-		X	-					
11 Quartzite Ridge				-	-	-			-	X				
12 Talladega Slate				-	-	-		-	-		X	-		
13 Schist														
13A Hillabee Depression														X
13B Upper Schist Hills											-	X		
13C Lower Schist Hills										-	-	X	-	-
13D Schist Plains												X	-	-
14 Granite Hills											-	X	X	
15 Piedmont Ridge										-	X	X	-	
16 Opelika Plateau												-	X	

TABLE 5. LAND TYPES OF THE REGIONS AND SUBREGIONS OF THE COASTAL PLAIN PROVINCES OF ALABAMA; AN X INDICATES THAT THE LAND TYPE IS FREQUENT, A - INDICATES THAT IT MAY BE FOUND OCCASIONALLY

Region/ subregion	Land types								
	Chalk	Clay plains	Clay hills	Loam hills and plains	Sand hills and plains	Wet depressions	Loam flats	Sand flats	Old sand dunes
17 Transition Loam Hills									
17A Gentle Topo.				X					
17B Rugged Topo.			X	X	-				
18 Upper Loam Hills									
18A Upper Loam Hills			X	X	-				
18B Loam Hill Border Terraces				X					
19 Upper Clay Hills			X	-					
20 Black Belt	X	-	-						
21 Interior Flatwoods		X		-					
22 Prairie Bluff	X			-					
24 Lower Loam Hills			-	X	-				
25 Lower Clay Hills									
25A Gentle Topo.			X	X	-				
25B Rugged Topo.			X	-					
26 Border Sandhills				-	X				
27 Jackson Hills				-	X				
28 Jackson Prairie									
28A Non-loessal Jackson Prairie		X							
29 Old Terrace				X					
30 Southern Loam Hills									
30A Rugged Topo.			-	X	X				
30B Gentle Topo.			-	X	X		-		
31 Plains									
31A Wiregrass Plains.				X	X	-			
31B Citronelle Plains		-		X	X	X	-	-	-
32 Southern Clay Hills			X	-					
33 Sand Plains				X	X	-			
34 Coastal Flatwoods				X		X	X	X	X

tion; table 4 or 5 indicates the land types normally found in that region or subregion. Study the descriptions (sections D and E) of the possible correct land types thus identified to determine which fits best. If a recent (within 20 years) county soil survey is available for the area (this will not be possible in a large part of the State) the soil series shown in the survey may aid in identifying the land type.

After the land type is identified, use information presented in the land type descriptions of sections C and D, and an understanding of the factors affecting erodibility (discussed in section B), along with knowledge of anticipated forestry practices to assess the erosion hazard. It should be relatively easy for informed persons to place most sites into simple broad categories, such as "low," "moderate," or "high." Refinement can come with experience and as the needs demand.

Land Types of the Consolidated-Rock Forest Habitat Regions of Alabama

Limestone Land Type

Gentle, level to undulating topography, often in wide valleys; moderate to deep soils formed over limestone; silt loam to loam topsoils most common, with clay to silty clay subsoils; mostly in agricultural uses.

Erodibility: Moderate to high; dependent mainly on slope and silt content of topsoil; highly erodible where slopes exceed about 10 percent.

Typical soil series: Decatur, Dewey, Colbert, Cumberland.

Limestone Rockland Land Type

Rounded low ridges, or slopes ranging from very steep to almost level; limestone rock outcrops common to dominant; loamy to clayey soil mostly in pockets and cracks.

Erodibility: Low to moderate; varies primarily with amount of rock and slope steepness.

Typical soil series: Barfield, Rockland.

Chert Hills Land Type

Rolling to very steep hills; chert (flint) rock abundant, loose and/or as outcrops; loamy topsoils (typically with chert fragments) and loamy to clayey subsoils.

Erodibility: Moderate to high; steepness of slope most important, with rock content moderating erosion hazard.

Typical soil series: Bodine, Dickson, Fullerton.

Sandstone Land Type

Nearly level or rolling (on plateaus) to steep mountain sides and ridges; typically sandy loam topsoils over sandy clay loam subsoils; soils usually 1-6 feet deep to rock.

Erodibility: Low to moderate; slope steepness and topsoil depth most influential; moderately high where shallow fine sandy loam topsoil on steep slopes.

Typical soil series: Hartsells, Mountainburg.

Sandstone Rockland Land Type

Mountainsides and ridges with sandstone outcrops or boulders common; soils usually shallow between rocks.

Erodibility: Low to moderate due to rock cover on surface; highest on slopes.

Typical soil series: Hector.

Shale Land Type

Rolling hills to steep-sided ridges with narrow hollows; brown to grey thin platy rock visible in road cuts; typically silty soils, loam to silt loam topsoils over silty clay to clay subsoils; soils typically 1-6 feet deep to decomposing shale.

Erodibility: High to very high; slope steepness and rock content most influential.

Typical soil series: Firestone, Townley, Montevallo, Conasauga.

Mixed Sandstone-Shale Land Type

Variable, gently rolling to moderately steep slopes; sandstone, shale, or both may be present; soils vary from sandy to silty in topsoil, depending on which material is most influential; subsoils clayey.

Erodibility: Moderate to high; slope is the most influential factor; soils tend to be highly erodible where slope exceeds 25 percent; the erodibility increases as the silt content increases.

Typical soil series: Enders, Muskingum, Leesburg.

Old Alluvium Land Type

Undulating to rolling hills within large valleys; often shallow, loamy topsoils, with clay loam to silty clay loam subsoils; rounded gravel frequently present; soils moderately deep to rock, 4-10 feet or more.

Erodibility: Moderate to high; influenced mainly by silt content of the surface soil and the length of the slopes.

Typical soil series: Anniston, Holston, Hiwassee.

Mountain Colluvium Land Type

Lower slopes, benches, and narrow coves of mountains or large ridges; abundant rock, even boulders in and on soil; soil usually loamy.

Erodibility: Low to moderate; slope steepness slightly influences erodibility; rock on surface retards erosion.

Typical soil series: Allen, Minvale.

Quartzite Ridge Land Type

Mountain ridges with steep slopes; frequent rock outcrops of quartzite; soils shallow, usually with rock fragments; sandy loam to loam topsoils.

Erodibility: Low to moderate; rock and silt content and slope steepness modify the erodibility; high permeability of these soils reduces the erosion potential.

Typical soil series: Clymer, Cheaha.

Slate-Phyllite Ridge Land Type

Narrow ridges with steep side slopes; slate or phyllite outcrops in road cuts; shallow soils (2-6 feet) with loam topsoils and clay loam subsoils typical; small platy pieces of slate or phyllite may be common in the profile.

Erodibility: Moderate to high; slope steepness is primary influence on erodibility.

Typical soil series: Talladega, Fruithurst.

Schist Hills Land Type

Elongated, rounded to sometimes narrow ridges of variable size, with gentle to steep slopes; schistose (very thin platy) rocks in road cuts and outcrops; soils shallow to sometimes moderately deep (1-10 feet); fine sandy loam to loam topsoils over clay loam to clay, or sometimes decomposing rock; mica flakes common in rocks and subsoils of many areas.

Erodibility: Moderate to high; moderate erodibility where slopes less than 20 percent; high erodibility where slopes exceed 20 percent.

Typical soil series: Madison, Louisa, Tallapoosa, Tatum.

Granite-Gneiss Land Type

Undulating to hilly, with broad ridges; depth quite variable, but usually quite deep; sometimes rock outcrops or road cuts showing granite or gneisses; sandy loam to loam topsoils, but thin or of clay loam where past erosion is severe; sandy clay loam to friable clay subsoil; moderate slopes often have old gullies from past farming.

Erodibility: Moderate to high; slope steepness and thickness of sandy surface layer are most influential; presence of old gullies indicates high hazard.

Typical soil series: Cecil, Appling, Gwinnett, Davidson, Pacolet.

Chlorite Schist Land Type

Almost level to undulating hills; thin loamy topsoils with sticky heavy subsoils that are commonly yellowish or greenish.

Erodibility: Moderate to high; dependent largely on slope steepness.

Typical soil series: Iredell, Mecklenburg.

Small Flood Plains Land Type

In these regions, usually quite narrow; level to irregular; soil textures diverse, but most commonly quite sandy; stream channels frequently incised.

Erodibility: Typically low due to low slope, but may be moderate where soil is silty.

Typical soil series: Lobelville, Mantachie, Augusta, Lee.

Large Flood Plains Land Type

Fairly limited in size in these regions; terrain level to irregular, some with terraces; soils quite diverse, but silty and clayey soils more common than in small bottoms; occasional swamps, but rare in most regions; drainage variable.

Erodibility: Low to moderate due to low slope angles; silty soils moderate.

Typical soil series: McQueen, Choccolocco, Chewacla.

Land Types of the Coastal Plain Forest Habitat Regions of Alabama

Chalk Land Type

Gentle to moderately rolling, with broad, relatively flat ridges, sometimes with short steep slopes into stream bottoms; commonly brown or darker loamy to clayey topsoils with light colored clay subsoils over light colored chalk or marl; most of these soils are alkaline and do not support pine stands; most of the gentle topography is in crops or pasture.

Erodibility: Moderate to high; low permeability produces high runoff, creating an erosion hazard.

Typical soil series: Sumpter, Demopolis, Oktibbeha.

Clay Plains Land Type

Flat to gently rolling, sometimes with short steep side slopes to stream bottoms; silt loam to loam surface soils usually with heavy clay subsoils; poor internal drainage is common, usually with some grey mottling in subsoil; poor surface drainage on many broad ridge areas.

Erodibility: High where slope exceeds about 5 percent.

Typical soil series: Mayhew, Wilcox, Eutaw.

Clay Hills Land Type

Landscape rolling to very hilly, with rounded ridges; topsoils commonly sandy (fine sandy loam to loamy sand) but sometimes silt loam or clay loam; subsoils sandy clay, silty clay, or clay (these will easily form a ribbon when moist and squeezed between thumb and forefinger).

Erodibility: Ranges widely; most are moderate to high erodibility, but slopes with deep (18 inches) coarse loamy sand topsoils are low in erodibility; slopes with shallow, silt loam or fine sandy topsoils are highly erodible.

Typical soil series: Boswell, Esto, Smithdale, Lucedale, Susquehanna, Luverne, Bama, Lucy.

Loam Hills and Plains Land Type

Includes wide range of topography, from almost level to steeply hilly; topsoils vary widely, but most typically are sandy loam to loamy sand, usually 12 to 24 inches deep, but sometimes to about 36 inches; key distinguishing feature is that the finest textured layer within 4 feet is sandy loam to clay loam, most typically sandy clay loam; many soils have fragipans, usually at 20 to 30 inches deep.

Erodibility: Varies widely; soils with shallow topsoils (< 6 inches) are usually highly erodible; fine sandy topsoils are usually moderately (less than 5 percent slope) to highly erodible (steeper than 10 percent slopes); silt loam topsoils are usually highly erodible and easily compacted; deep coarse loamy sand topsoils are low in erodibility, except on steep side slopes where they are highly susceptible to gully erosion.

Typical soil series: Orangeburg, Red Bay, Ruston, Bowie, Norfolk, McLaurin, Poarch, Stough, Smithton.

Sand Hills and Plains Land Type

Includes wide range of topography, from almost level to steeply hilly; key distinguishing feature is that soil is sand to loamy sand for 36 inches or more; natural forest vegetation is typically thin and scrubby; gentle areas are commonly under cultivation.

Erodibility: Low to moderate except where surface layer is very fine or very coarse sand and slopes are steep, then it is highly erodible.

Typical soil series: Lakeland, Pothan, Eustis, Troup, Fuquay.

Wet Depressions Land Type

Flats to shallow depressions; water frequently on surface, otherwise very shallow to water table; some organic soils; includes "ponds"; mottling shallow or at the surface.

Erodibility: Low, due to lack of slope and drainage.

Typical soil series: Grady, Pelham, Plummer.

Loam Flats Land Type

Broad flats or very gently sloping broad interstream ridges; usually sandy loam to loam surface soils with sandy loam to sandy clay loam subsoils; sometimes poorly drained, often shallow to grey mottling.

Erodibility: Low to moderate, due to lack of slope.

Typical soil series: Weston, Escambia, Atmore.

Sand Flats Land Type

Broad flats or very gently sloping broad ridges; sand to loamy sand to several feet; commonly poorly drained, with shallow water table and grey mottling; some soils have an organic hardpan.

Erodibility: Low to very low, due to lack of slope.

Typical soil series: Leon, Alaga.

Small Flood Plains Land Type

Level to irregular; soils quite variable, but frequently sandy; many are poorly drained with occasional standing water; shallow grey mottling when water table near the surface.

Erodibility: Low to moderate, due to lack of slope; silty soils may be moderate in erodibility if bared of cover.

Typical soil series: Leaf, Cahaba, Bibb, Catalpa, Myatt.

Large Flood Plains Land Type

Level to irregular; frequently with sloughs, flats, low ridges (only 1-5 feet), and terraces; complex soils ranging from mostly sand to mucks, silts, and silty clays; many flood for extended periods during the spring.

Erodibility: Low to moderate, due to lack of slope; some terraces with silty topsoils may be moderately high.

Typical soil series: Chewacla, Minter, Gaylesville.

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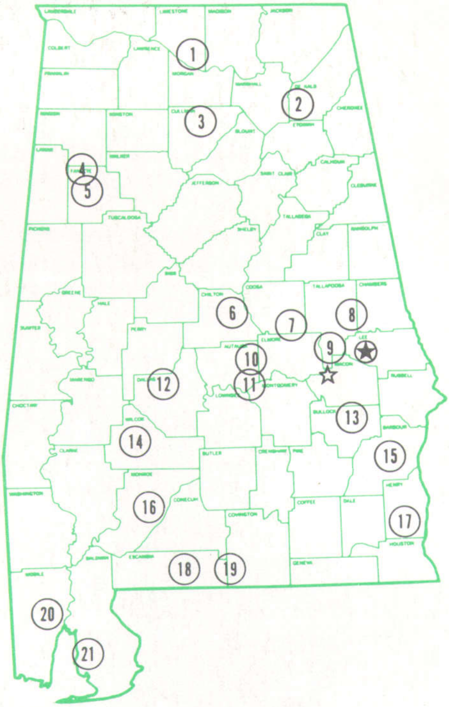
Alabama's Agricultural Experiment Station System
AUBURN UNIVERSITY

With an agricultural research unit in every major soil area, Auburn University serves the needs of field crop, livestock, forestry, and horticultural producers in each region in Alabama. Every citizen of the State has a stake in this research program, since any advantage from new and more economical ways of producing and handling farm products directly benefits the consuming public.



Research Unit Identification

★ Main Agricultural Experiment Station, Auburn.
☆ E. V. Smith Research Center, Shorter.

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
5. Forestry Unit, Fayette County.
6. Chilton Area Horticulture Substation, Clanton.
7. Forestry Unit, Coosa County.
8. Piedmont Substation, Camp Hill.
9. Plant Breeding Unit, Tallassee.
10. Forestry Unit, Autauga County.
11. Prattville Experiment Field, Prattville.
12. Black Belt Substation, Marion Junction.
13. The Turnipseed-Ikenberry Place, Union Springs.
14. Lower Coastal Plain Substation, Camden.
15. Forestry Unit, Barbour County.
16. Monroeville Experiment Field, Monroeville.
17. Wiregrass Substation, Headland.
18. Brewton Experiment Field, Brewton.
19. Solon Dixon Forestry Education Center, Covington and Escambia counties.
20. Ornamental Horticulture Field Station, Spring Hill.
21. Gulf Coast Substation, Fairhope.