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1. Introduction and Site Description

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This volume is a collection of chapters describing results of a variety of research efforts with forested catchments as the common basis of ecosystem interpretation. The Coweeta Hydrologic Laboratory was established 50 years ago as a testing ground for certain theories in forest hydrology. That research required development of a firm data base describing the hydrologic cycle in watersheds (see Chapter 2). Later, in 1968, efforts began to establish an extensive data base on nutrient cycling phenomena in Coweeta watersheds with joint USDA Forest Service-National Science Foundation funding. This research was a logical extension of the research on watershed hydrology. Both types of research have been based on an ecosystem concept, explicitly for nutrient cycling studies and implicitly even for early studies in forest hydrology (see Chapter 30).

The research program at Coweeta represents a continuum of theory, experimentation, and application using watersheds as landscape units. Two underlying philosophies have guided the research approach at Coweeta as revealed by the contents of this volume; i.e. (1) that the quantity, timing, and quality of streamflow provide an integrated measure of the success or failure of land management practices, and (2) good resource management is synonymous with good ecosystem management. Response to disturbance has frequently been used as a research tool for interpreting ecosystem behavior. The use of perturbation or disturbance has allowed specific hypotheses to be tested with subsequent revision and development of theories and application of results when appropriate. We have continuously attempted to integrate individual research efforts into a holistic concept of watershed response.

Understanding hydrologic processes and responses of the various watersheds was an enormous advantage to research in nutrient cycling (see Chapters 22 and 25). Water is the vehicle by which nutrients are moved: inputs into ecosystems, movement through the soil, uptake by vegetation, and exit via streamflow are water mediated; their interpretation requires extensive knowledge of site-specific hydrology. Construction of the basic input-output budgets for nutrients in watersheds (Chapter 4) requires a very detailed knowledge of hydrology, as well as biotic transfer and storage.

The ecosystem concept was rescued from relative obscurity by E. P. Odum (1953). Ecology in the early 1950s was dominated by autecological approaches, but questions on the horizon could only be approached from an ecosystem basis, i.e., worldwide radioactive fallout, insecticides in the environment, and chemical pollution of waterways, etc. Initially, testing of ecosystem theory was largely confined to aquatic systems; particularly to ponds and lakes. A grasp of the forest watershed as exemplifying ecosystems, and the experimental analysis of forested ecosystems using nutrient

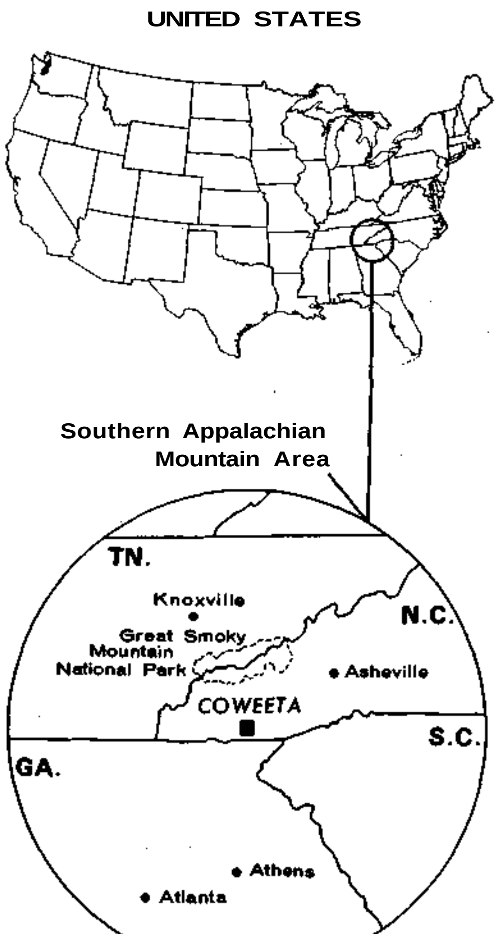


Figure 1.1. The Coweeta Hydrologic Laboratory is located in southwestern North Carolina, about a 2-hr drive north from the University of Georgia in Athens. The Laboratory is also in close proximity to other universities and centers of ecosystem research.

dynamics led to singular advances in the understanding of how natural ecosystems function (Bormann and Likens 1967; Franklin and colleagues, Chapter 30; others). Forested ecosystems are open, as are all units of the biosphere, but the amounts of many nutrients cycling internally within watersheds are much larger than the input-output flows. Observations about the responses of these cycles to disturbance have led to further theoretical development concerning ecosystem function (Odum 1969; Vitousek and Reiners 1975; Monk et al. 1977). Hypotheses concerning mechanisms of resistance to disturbance and resilience following disturbance, closing of nutrient cycles, important shifts in successional species accompanying changes in substrate quality, alterations of nitrogen cycles, shifts in herbivory, and changes in stream communities have all been tested experimentally. Results of studies with forested catchments have continued to make important contributions to understanding the nature of ecosystems.

Finally, we believe that the only level of ecological theory that will provide the necessary guidelines for proper resource management is the ecosystem level. The evaluation of landscape management practices, in the context of basic scientific inquiry into ecosystem structure and function, is one of the major benefits to be derived from cooperative work such as that described in this volume. Chapters 22 through 27 provide summaries of some of the management interpretations and implications of the research.

We begin the volume with a description of the Coweeta Basin and a historical account of the establishment and development of the program and facilities. The subsequent section focuses on climatology, geology and hydrology of the Laboratory. Then, five chapters address forest dynamics and nutrient cycling. Groups of chapters then describe herbivory, forest floor processes, and within-stream processes, followed by reviews of management implications of the research. The final section encompasses broader interpretations of the research program. It begins with a revision of an important component of the underlying theory which has guided the ecosystem approach at Coweeta, including illustrations of principles which utilize data from other chapters. The last two chapters consider the research within the context of national and international perspectives of forest hydrology and ecology programs.

Site Description

General Features

The Coweeta Hydrologic Laboratory is located in the Nantahala Mountain Range of western North Carolina within the Blue Ridge Physiographic Province, latitude 35°/03'N, longitude 83°25'W (Figure 1.1). The 2185 ha Laboratory is comprised of two adjacent, east-facing, bowl-shaped basins. Coweeta Basin encompasses 1626 ha (Figure 1.2) and has been the primary site for watershed experimentation, while the 559 ha Dryman Fork Basin has been held in reserve for future studies. Ball Creek and Shope Fork are fourth-order streams draining the Coweeta Basin and they join within the Laboratory boundary to form Coweeta Creek, a tributary that flows 7 km east to the Little Tennessee River. Elevations range from 675 m in the administrative area to 1592 m at Albert Mountain. The relief has a major influence on hydrologic, climatic, and vegetation characteristics (Chapters 3 and 10).

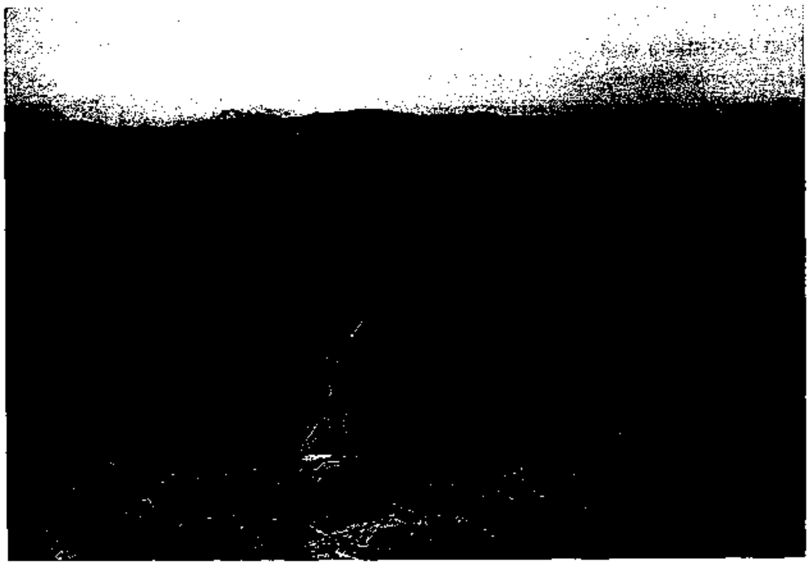


Figure 1.2. Aerial view of the Coweeta Basin taken looking west toward the main ridge of the Nantahala Mountains. The bowl-shaped physiography is typical of the region. The arrow in the photograph indicates the location of the Laboratory administrative facilities.

Access within the Laboratory is facilitated by two main graveled roads which are open throughout most of the year, and by service roads and trails which are closed to public vehicles. The Laboratory is open to the public, including hunting and fishing activities as regulated by state laws. No camping or fires are permitted in the area. Responsibility for fire protection, road maintenance, experimental timber harvest, and law enforcement is provided by and coordinated with appropriate National Forest System personnel. The administrative area currently consists of three office buildings totaling 600 m^2 of floor space, a complete analytical laboratory (370 m^2), residence 165 m^2), storage building (230 m^2), maintenance shop and instrument repair building (245 m^2), record storage vaults (100 m^2), and several house trailers. The remaining facilities such as weirs and instrument houses are located throughout the experimental area.

Watershed Description and Treatments

Since the establishment of Coweeta, 32 weirs have been installed on streams in the Laboratory. Locations of individual watersheds and other laboratory features are shown in Figure 1.3. Many weirs are no longer operational due to termination of studies or lack of resources for maintenance. Currently, 16 streams are gaged; a summary of physical characteristics for these watersheds, along with information for other catchments discussed in subsequent chapters, is given in Table 1.1. Watersheds range in size from 3 ha to 760 ha. Weir structures vary from the 90° V-notch type used on first order streams draining watersheds less than about 28 ha to the 3.7 m Cipolletti type

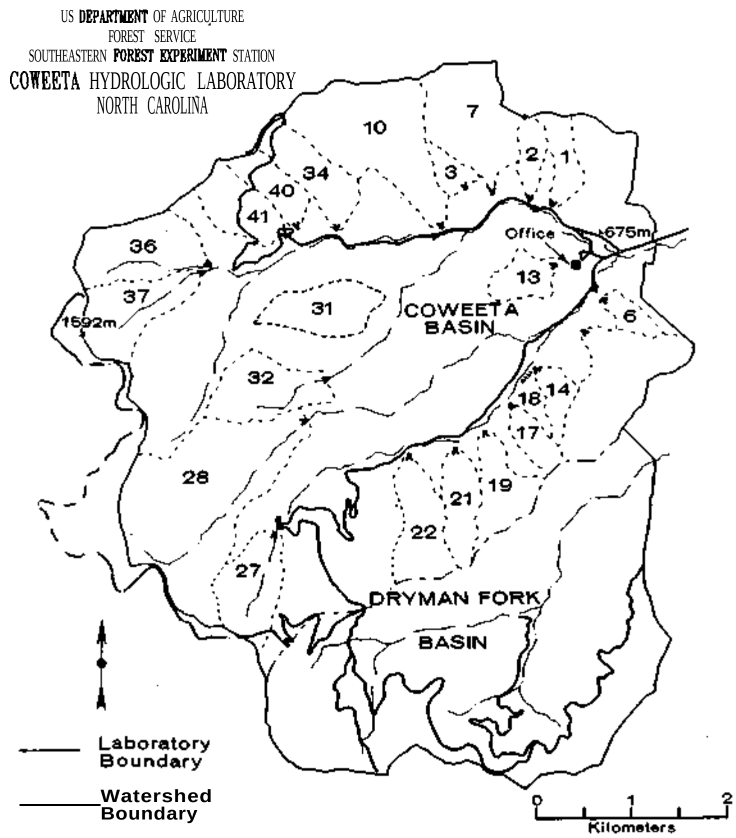


Figure 1.3. The 2185 ha Coweeta Hydrologic Laboratory is comprised of 2 main basins — Coweeta and Dryman Fork. Experimentation has focused on the Coweeta Basin and the numbers indicate individual watersheds referred to in this book.

used on fourth order streams. A 120° V-notch is typically used on intermediate sized streams. Stream gaging was initiated on most watersheds (Table 1.1) between 1934 and 1938. The most recent weir was constructed in 1981 on Watershed 31 (WS 31). Relief (from weir to top of the watershed) averages 300 m on small catchments and 550 m on large catchments. Side slopes average about 50% at low and mid elevations and increase to 60% or more on some high elevation watersheds. A variety of aspects are present in the Coweeta Basin, but most unit watersheds are predominately either north-or south-facing. For watersheds with long-term flow records, the maximum instantaneous discharge occurred either in May 1973 or May 1976, and both events were associated with intense orographic thunderstorms. Eight watersheds have remained relatively undisturbed since the establishment of the Laboratory and serve as controls in paired watershed experiments (Hewlett 1971). They range from 12 ha to 49 ha in size and are distributed throughout the Coweeta Basin. The experimental treatments at Coweeta

Table 1.1. Summary of Physical Characteristics of Watersheds at Coweeta Hydrologic Laboratory

Watershed Number	Name of Stream	Area (ha)	Date of First Record	Type of Notch	Elevation at Weir (m)	Maximum Elevation (m)	Maximum Discharge ($m^3sec^{-1}km^{-2}$)	Aspect
1	Copper Branch	16	6-13-34	90° V-notch	705	988	2.29	S
2	Shope Branch	12	6-22-34	90° V-notch	709	1004	2.41	SSE
3[a]	Little Hurricane	9	7-5-34	CIA deep notch	739	931	20.27	E
6	Sawmill Branch	9	7-10-34	90° V-notch	696	905	3.76	NW
7	Big Hurricane	59	7-31-34	90° V-notch	722	1077	2.18	S
8	Shope Fork No. 1	760	10-6-34	3.66 m Cipolletti	702	1600	1.68	–[b]
9	Ball Creek No. 1	724	10-12-34	3.66 m Cipolletti	687	1554	2.46	–[b]
10[a]	Camprock Creek	86	3-7-36	120° V-notch	742	1159	0.85	SSE
13	Carpenter Branch	16	3-12-36	120° V-notch	725	912	1.09	ENE
14	Hugh White Branch	61	5-26-36	120° V-notch	707	992	1.11	NW
16[a]	Shope Fork No. 2	382	6-4-36	1.83 m Rectangle	739	1600	1.88	–[b]
17	Hertzler Branch	13	6-6-36	90° V-notch	760	1021	1.06	NW
18	Grady Branch	13	7-3-36	120° V-notch	726	993	1.36	NW
19[a]	Snake Den Branch	28	5-16-41	120° V-notch	796	1119	1.28	NW
21[a]	Sheep Rock Branch	24	7-22-38	120° V-notch	823	1174	1.79	N
22[a]	Lick Branch	34	2-18-37	120° V-notch	847	1244	1.75	N
27	Hard Luck Creek	39	11-2-46	120° V-notch	1061	1454	5.65	NNE
28	Henson Creek No. 2	144	5-31-37	1.83 m Rectangle	964	1551	2.03	E
31	Mill Branch	34	10-1-81	120° V-notch	869	1146	NA	ENE
32	Cunningham Creek No. 2	41	10-25-41	120° V-notch	920	1236	1.35	ESE
34	Bee Branch	33	10-31-38	120° V-notch	866	1184	1.00	SE
36	Pinnacle Branch	49	4-29-43	120° V-notch	1021	1542	4.36	ESE
37	Albert Branch	44	4-15-42	120° V-notch	1033	1592	5.37	ENE
40[a]	Wolf Rock Branch	20	12-4-38	90° V-notch	872	1219	1.00	SSE
41[a]	Bates Branch	29	8-23-40	120° V-notch	893	1298	1.18	ESE
49[a]	Barker's Cove	3	3-14-38	90° V-notch	922	971	0.69	E

[a] Weirs are inactive or have been removed from service.
[b] Aspect not calculated for large watersheds.

Table 1.2. Summary Descriptions of Coweeta Watershed Treatments

Watershed No.	Treatment Description
1	Entire watershed prescribed burned in April, 1942. All trees and shrubs within the cove-hardwood type (areas adjacent to stream) deadened with chemicals in 1954. This treatment represented 25% of both land area and total watershed basal area. Retreated as necessary for three consecutive growing seasons. All trees and shrubs cut and burned in 1956-57, no products removed; white pine planted in 1957. In subsequent years, pine released from hardwood competition by cutting and chemicals as necessary.
3	All vegetation cut and burned or removed from the watershed in 1940. Unregulated agriculture (farming and grazing) on 6 ha for a 12-year period, followed by planting yellow poplar and white pine.
6	All woody vegetation cut and scattered in the zone 5 m vertically above the stream; reduced total watershed basal area 12%. Clearcut in 1958, products removed and remaining residue piled and burned. Surface soil scarified, watershed planted to grass, limed and fertilized in 1959; fertilized again in 1965. Grass herbicided in 1966 and 1967; watershed subsequently reverted to successional vegetation.
7	Lower portion of watershed grazed by an average of six cattle during a 5-month period each year from 1941 to 1952. Commercially clearcut and cable logged in 1977.
8, 9, 16	Combination watersheds containing both control and treated watersheds.
10	Exploitive selective logging during the period 1942-1956 with a 30% reduction in total watershed basal area.
13	All woody vegetation cut in 1939 and allowed to regrow until 1962 when the watershed was again clearcut; no products removed in either treatment.
17	All woody vegetation cut in 1940 and regrowth cut annually thereafter in most years until 1955; no products removed. White pine planted in 1956 and released from hardwood competition as required with cutting or chemicals.
19	Laurel and rhododendron understory cut in 1948-1949; comprised 22% of total watershed basal area.
22	All woody vegetation within alternate 10 m strips deadened by chemicals in 1955; reduced total watershed basal area 50%. Treatment repeated from 1956 to 1960 as required to maintain conditions.
28	Multiple use demonstration comprised of commercial harvest with clearcutting on 77 ha, thinning on 39 ha of the cove forest and no cutting on 28 ha; products removed.
37	All woody vegetation cut in 1963; no products removed.
40	Commercial selection cut with 22% of basal area removed in 1955.
41	Commercial selection cut with 35% of basal area removed in 1955.
2, 14, 18, 21, 32, 34	Controls with mixed hardwoods stands remaining undisturbed since 1927.
27	Control, but partially defoliated by fall cankerworm infestation from 1972 to 1979.
36	Control, but partially defoliated by fall cankerworm infestation from 1975 to 1979.

have produced a diverse array of ecosystems with respect to vegetation composition and structure. An abbreviated treatment history is provided in Table 1.2. More detailed descriptions can be found in previously published papers which focus on each watershed. The earlier mountain farming and exploitive logging demonstration studies on WS 3 and 10, respectively, have been among the most severe watershed disturbances (Figures 1.4 and 1.5). The main focus of these studies was to demonstrate the effects of land use on stream turbidity; experiments were terminated following fulfillment of objectives. The most re'cent severely disturbed ecosystem is WS 6, which was converted from hardwoods to grass (with applications of lime and fertilizer) and maintained in a grass cover for 5 years (Figure 1.6). The grass subsequently was herbicided for 2 consecutive years, and the watershed was then allowed to regrow with no additional manipulation (Figure 1.7). A variety of cutting prescriptions have been applied, including light selection cutting, clearcutting without roads and no products removed (Figure 1.8), commercial clearcutting (Figure 1.9), and a combination of thinning and clearcutting (Figure 1.10). Another manipulation included hardwood to white pine conversion on WS 1 and WS 17 (Figure 1.11). Vegetation on two control watersheds (27 and 36) was partially defoliated by insects each spring for several years. Watershed experiments were originally designed to test specific hypotheses or meet objectives related to assessing the effects of disturbances on the quantity, quality, or timing of streamflow. Subsequently, many of these ecosystems have provided a unique opportunity to examine ecological processes related to biogeochemical cycles.

Figure 1.4. One of the earlier land use demonstration experiments at Coweeta was conversion of WS 3 from a hardwood forest cover to mountain farming, a prevalent practice in the region until the late 1940s. This view shows 3 ha in pasture *(foreground)* 3 ha in corn *(center)*, and 3 ha of hardwood regrowth *(background).*

Figure 1.5. The effects of unregulated logging on water quality was demonstrated on WS 10. This 1952 view of a logging skid trail crossing a perennial stream is representative of practices in the region during this time period.

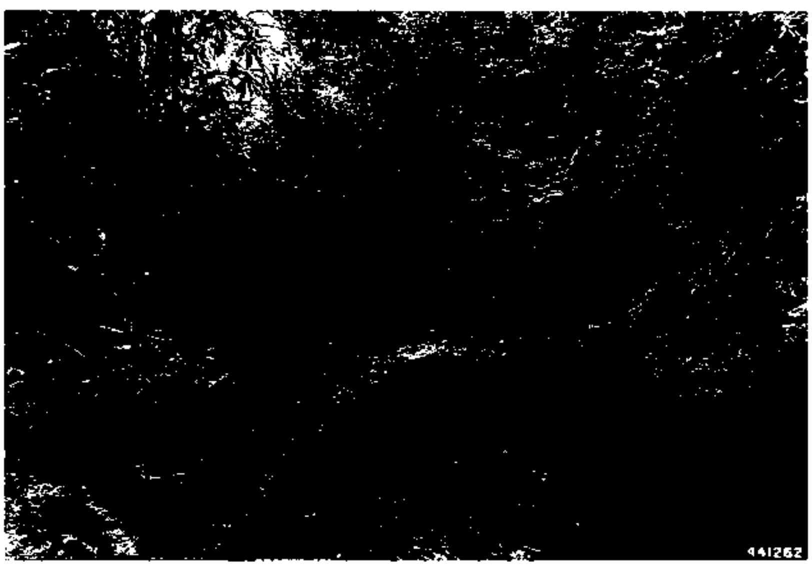


Figure 1.6. Conversion of hardwoods to grass on WS 6 (9 ha) was designed to examine changes in the quantity and timing of streamflow due to changing the vegetal cover.

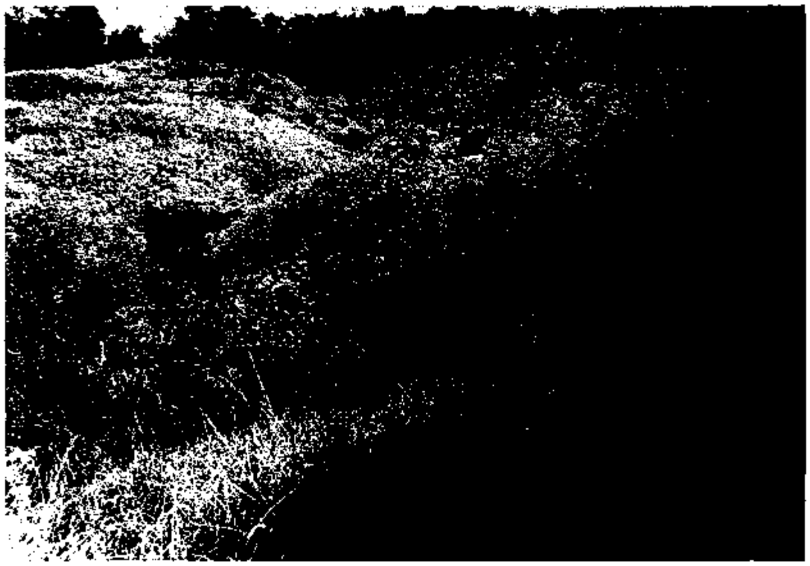


Figure 1.7. Luxuriant herbaceous vegetation covered WS 6 in the summer of 1968, two years after the grass cover was herbicided.

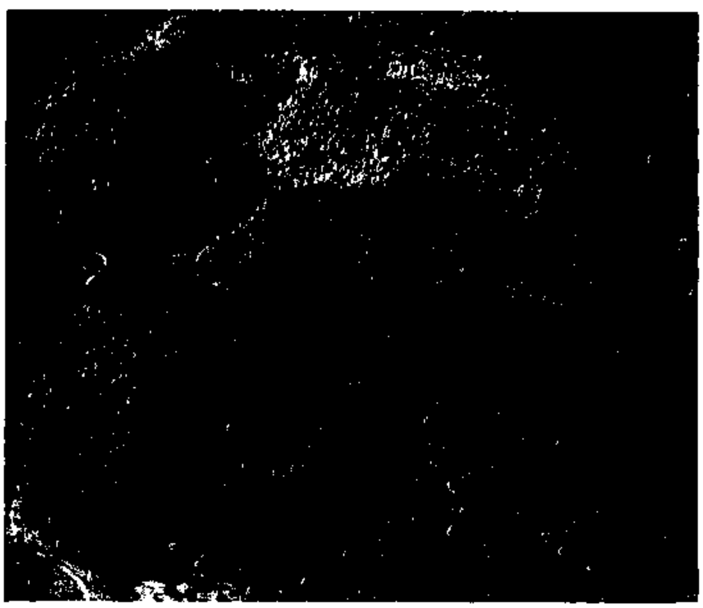


Figure 1.8. The first experiment conducted in the eastern United States to study the influence of forests on streamflow was initiated in 1939 on WS 13. All woody vegetation was clear-felled and no products removed; the treatment was repeated in 1962. This aerial view of the coppice regrowth was taken in 1967, five years after the second cut.

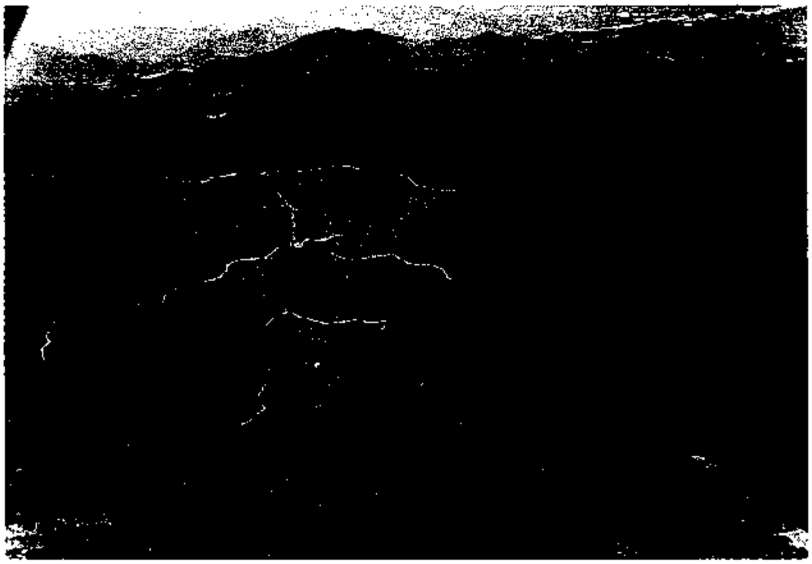
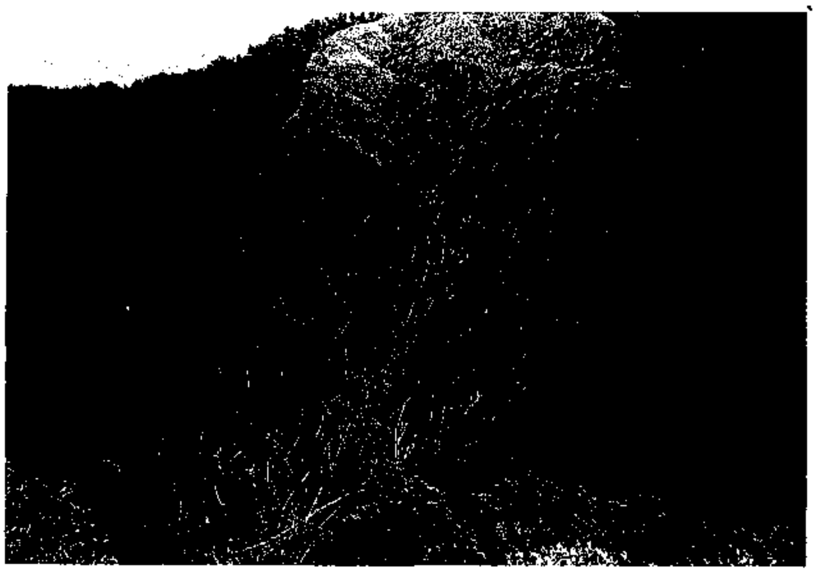


Figure 1.9. WS 7 *(left center)* was clearcut in 1977 as shown in this view and logged with a mobile cable yarding system. WS 2 *(center)* is the hardwood covered control for both WS 7 and for WS 1 *(right center)*, a white pine plantation.

Figure 1.10. The concept of multiple use forest management was demonstrated on WS 28, a 144 ha catchment. The treatment included commercial harvest with clearcutting on 77 ha and thinning on 39 ha within the cove forest. There was no cutting on 28 ha of the steeper upper slopes. Improved design and proper location of logging roads were major features of study. The resources assessed included timber, water, wildlife, and recreation.



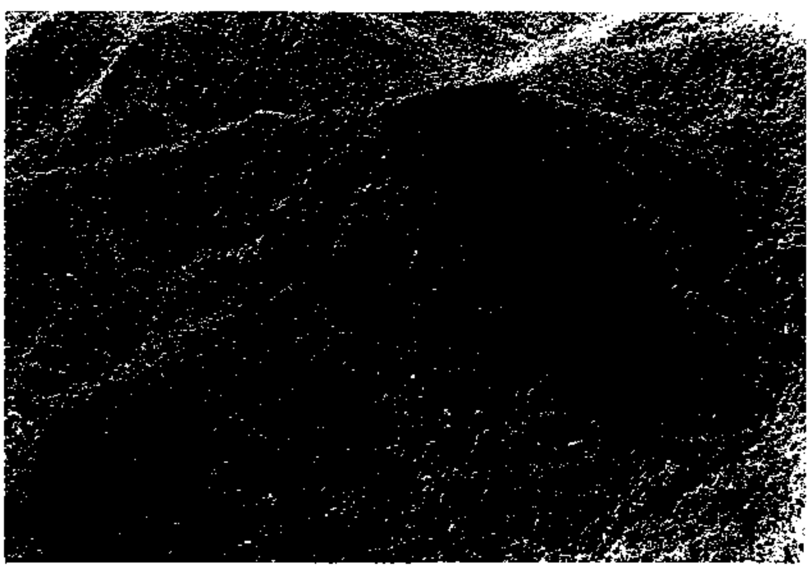


Figure 1.11. All woody vegetation was clear-felled on WS 17 in 1940 and regrowth was cut back annually for a period of years *(upper view* in 1951). White pine was planted on the watershed in 1956 and the lower view was taken when the plantation was 14 years old. WS 18 *(below)* is the adjacent hardwood covered control for WS 17.

Resource Inventories

In addition to the climatic, hydrologic, vegetation, and water chemistry assessments presented in later chapters, a variety of other baseline data are available for the conduct of research. A third order survey in the Laboratory forms the basis for two topographic maps: one at a scale of 1:7200 with 3 m (10 ft) contour intervals and one at a scale of 1:14,400 with 15 m (50 ft) contour intervals. Streams, watershed boundaries, roads, trails, control elevations, and other topographic features are accurately displayed on the maps. Vegetation analyses are aided by a variety of permanent plots, including 408 (0.08 ha) plots established in 1934 and distributed over the entire basin (supplemented by 50 plots (0.08 ha) located on specific control watersheds), two 1 ha reference stands with detailed records, and numerous plots in disturbed watersheds. A herbarium comprised of 604 taxa and represented by 327 genera of 97 families has been established at Coweeta. Documentation includes efforts to fill life-stage gaps, accurate mapping of collection sites, and duplicate specimens for many species (Pittillo and Lee 1984).

The soils within the Laboratory have been mapped several times. The most recent and detailed effort was a first order survey completed in 1985 by the Soil Conservation Service. This survey was greatly facilitated by Hatcher's (1980) map of the basin bedrock geology. Soils are mapped at the phase level (10 series) on the small scale topo-

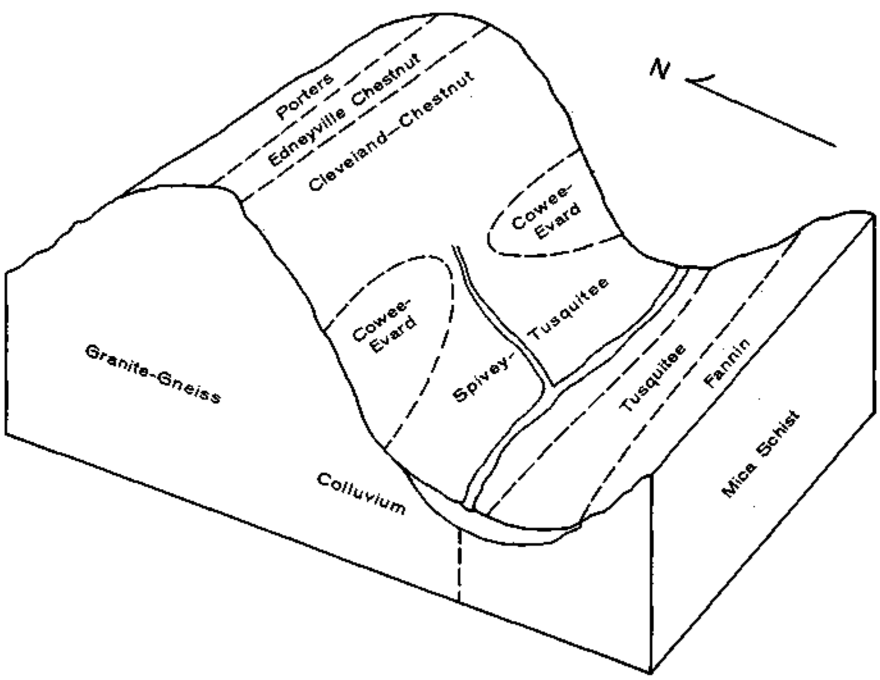


Figure 1.12. Block diagram of interrelationships between selected soil series and bedrock, aspect, and relative elevation at Coweeta Hydrologic Laboratory. (Prepared by Douglas Thomas, SCS, N.C., and Scott Keenan, N.C. Department of Natural Resources and Community Development).

Table 1.3. Selected Characteristics of Coweeta Soils

Depth (cm)	Bulk density (gm cm^{-3})	Organic matter (%)	pH	CEC[a] (meq 100 g^{-1})	B.S.[b] (%)	Exchangeable Nutrients K	Ca (mg kg^{-1})	Mg	P
0-10	1.24	15.9	4.74	11.6	17.2	22	71	18	6.2
10-20	1.30	10.0	4.89	9.4	18.8	21	21	10	5.0
20-30	1.39	7.7	5.02	6.8	19.1	15	16	13	2.5
30-40	1.42	5.8	5.11	7.2	27.7	22	18	20	3.7
40-50	1.47	5.8	5.14	6.2	16.1	19	12	18	1.3
50-60	1.52	5.4	5.13	6.0	11.7	15	14	18	1.3

[a] Cation exchange capacity.
[b] Base saturation.
Source: After McGinty, 1976.

graphic map. More refined soil boundaries are available for some individual experimental watersheds. The relative topographic position of selected soil series is given in Figure 1.12. Soils within the Laboratory fall within two orders: immature Inceptisols and older developed Ultisols. The Inceptisols found at Coweeta fall within seven "Great Groups." Umbric Dystrochrepts of the Porters series are found on steep, rocky faces at high elevations on the north- and south-facing aspect of the Laboratory. The Typic Dystrochrepts, as represented by the Chandler gravelly loam series, are found on south-facing slopes underlain by the Tallulah Falls formation. The Typic Haplumbrepts as represented by the Spivey-Tusquitee complex, are formed in colluvium of long narrow areas associated with watershed hollows and coves.

The Ultisols are represented by Typic Hapludults and Humic Hapludults. The Typic Hapludults are the largest soil group in areal extent at Coweeta and fall into two geomorphic settings: the Cowee-Evard gravelly loam series is found on strongly sloping to very steep ridges and sideslopes, and the Fannin sandy loam series is found on gently sloping sideslopes. Both soil series are formed in residuum weathered from schist, gneiss, or granite. Humic Hapludults include the Trimont gravelly loams, which are found on cool, steep north-facing slopes.

Chemical and physical analyses have been conducted for many of Coweeta soils as part of studies on specific watersheds. Soil properties vary substantially over the Laboratory as implied from the variety of soil series. However, McGinty's (1976) assessment is the most generalized soils data available, and is based on samples taken on north-facing control watersheds at eight locations over the elevational range of the Ball Creek drainage. Taken collectively, selected features in Table 1.3 generally show that soils are relatively high in organic matter and moderately acid with both low cation exchange capacity and percent base saturation, characteristics that are typical for highly weathered Ultisols.

More detailed descriptions for some of the watersheds and their ecosystem compartments are contained in subsequent chapters including the history of early land use in the Coweeta Basin (see Chapter 2).