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Programmatic Background, Site Description, Experimental Approach and Treatment, and Natural Disturbances

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Introduction

This volume is a synthesis of a long-term interdisciplinary study of watershed ecosystem responses to a forest-management disturbance. Specifically, a commercial clearcut cable logging experiment was initiated on Watershed 7 (WS 7) at the Coweeta Hydrologic Laboratory in 1975 to elucidate ecosystem structure and function by testing hypotheses associated with the hydrologic, biogeochemical, and ecological processes of mixed deciduous forests. Practical forest-management objectives were also integral to the research.

The study as originally proposed evolved from earlier collaborative ecosystem research between the United States Department of Agriculture (USDA) Forest Service and University of Georgia Institute of Ecology investigators as part of the Eastern Deciduous Forest Biome of the US International Biological Program (IBP). The IBP research at Coweeta was conducted on watersheds that had been disturbed 7 to 13 years prior to the initiation of nutrient cycling studies. Therefore, pretreatment and early response data in the IBP studies, along with associated data on mechanisms responsible for ecological responses, were lacking.

In contrast, the WS 7 study was based on a consistent conceptional foundation and theoretical structure. There was also a period of pretreatment calibration. Conceptually, ecosystems were viewed as hierarchical biogeochemical systems in which observable macroscopic properties (solute export, streamflow, leaf area index, etc.) of natural ecosystems were related to their stability (Waide 1988). Theoretical constructs were organized around the resistance-resilience model of

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ecosystem relative stability across scales of time and space and response to disturbance (Webster et al. 1975; revised by Waide 1988). This model guided both terrestrial research (Monk et al. 1977) and stream research (Webster et al. 1983) at Coweeta, as well as the evaluation of long-term forest responses to intensive management (Waide and Swank 1976; Swank and Waide 1980). A synthesis and thorough discussion of ecological theory derived from the WS 7 experiment is provided by Webster et al. in chapter 14 of this volume.

During the initial 5-year period (1980–1985) of the Long-Term Ecological Research (LTER) Program at Coweeta, the studies on WS 7 provided the centerpiece for ecosystem investigation at the site. Some components of this study have continued up to the present, but new projects were also initiated to address critical gaps in knowledge relative to the structure and function of southern Appalachian ecosystems. The research was then organized according to the 5 core research areas common to all LTER sites: (1) pattern and control of primary productivity, (2) spatial and temporal distribution of populations representing trophic structure, (3) patterns and control of organic matter accumulation in surface layers and sediments, (4) inorganic inputs and movement of nutrients, and (5) pattern and frequency of disturbance to the research site.

Research activity on WS 7 and its reference watersheds was most intense in the first 12 years following harvest, which established the early, rapid changes in ecosystem structure and function. Over the next 15 years, remeasurements of important biogeochemical processes and ecosystem attributes were conducted, along with new studies. Stream research has included long-term studies on the recovery of benthic invertebrates, particulate organic matter, and dissolved organic matter, along with research on leaf breakdown rates, seston transport rates, and nutrient uptake. Long-term components of terrestrial research include continuing measurement of precipitation and stream chemistry; measurements needed to quantify forest succession and associated primary productivity and nutrient dynamics; measurement of litter-soil organic matter and nutrient pools, along with studies on symbiotic nitrogen fixation, log decomposition; recovery of canopy arthropods; and recovery of soil macroarthropod communities and leaf litter decomposition.

The research was designed to address important forest-management issues in the region; in fact, National Forest systems played an important role in the timber sale layout and administration, road construction, and site preparation. When the WS 7 study was initiated, even-aged management (clearcutting) was a primary silvicultural method for regenerating hardwood forests in the southern Appalachians. The conventional method of harvest utilized tractor skidding, with a dense network of roads on steep slopes. An alternative harvest method was cable logging, but the logistics, economic feasibility, soil disturbance, and erosion factors and impacts on water quality were unknown for this extraction method. Research was conducted to address these unknowns and included (1) detailed economic analysis of direct costs per unit of timber volume for cable logging compared with an estimate of the unit costs of conventional logging on the same area (Robinson and Fisher 1982); (2) an intensive study of the source, amount, and fate of sediment associated with 2.95 km of newly constructed access roads (Swift 1988); (3) an evaluation of soil disturbance and erosion from cable logging; (4) a test of a regional empirical model for predicting long-term water yield responses to clearcutting (Swank et al. 2001); and (5) an assessment of harvesting effects on stream water quality. The effects of the management prescription on water, soil, and vegetation sustainability and health are described in individual chapters and synthesized by Webster et al. in chapter 14 of this volume.

Site Description

The study area is located within the Coweeta Hydrologic Laboratory, a 2,185-ha experimental area 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 Coweeta climate is classed as Marine, Humid Temperate, with cool summers, mild winters, and abundant rainfall in all seasons (Swift et al.1988). Average annual precipitation varies from 1,700 mm at low elevations (680 mm) to 2,500 mm on upper slopes (> 1,400 mm). Snow usually comprises less than 5% of the precipitation. The underlying bedrock is the Coweeta Group, consisting of quartz diorite gneiss, meta sandstone and peltic schist, and quartzose meta sandstone (Hatcher 1979, 1988). The deeply weathered regolith of the Coweeta basin averages about 7 m in depth.

WS 7, the focus of this book, is a 59-ha, south-facing catchment drained by a second-order stream (Big Hurricane Branch; figure 1.2). Hydrologic measurements began on WS 7 in 1936, shortly after the establishment of Coweeta. A summary of some of the physical and hydrologic characteristics of the WS 7 catchment and also of WS 2, the catchment adjacent to WS 7, which serves as the experimental undistributed reference for assessing many ecosystem responses to disturbance on WS 7, is given in table 1.1. WS 14 (Hugh White Creek) was the primary reference

Figure 1.1 Aerial view of Coweeta basin in 1962 (USDA Forest Service photo); arrow indicates the location of WS 7.

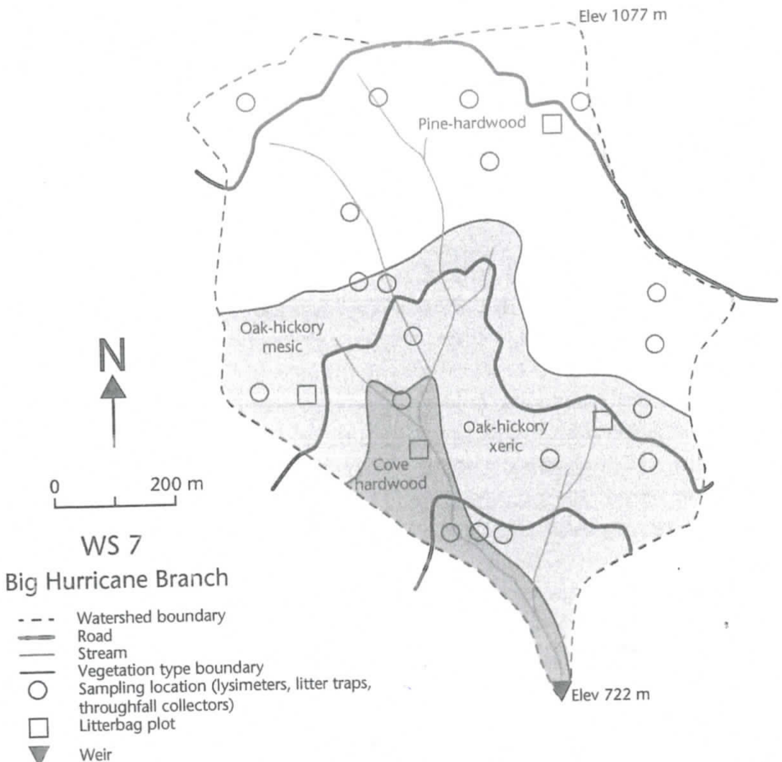

Figure 1.2 Map of WS 7 and Big Hurricane Branch showing roads, streams, major sampling locations, and vegetation types.

watershed used to assess stream biological responses; physical characteristics of this watershed are given by Webster et al. in chapter 10 of this volume. The only management disturbance on WS 7 since the Forest Service's acquisition of the land in 1924, and prior to logging in 1977, was a woodland grazing experiment. From 1941 to 1949, 6 cattle were grazed intermittently over the lower portion of the catchment, duplicating typical forest-use practices of that period. Impacts were limited to soil compaction and overgrazing in the cove forest community but were short-lived (Johnson 1952; Williams 1954). There were no measurable effects of grazing on flow characteristics or stream chemistry 25 years after the termination of the experiment (Swank and Douglass 1977).

Treatment Description

Management prescriptions for the watershed followed National Forest guidelines to achieve desired future conditions for the forested land, and management was applied in three phases: (1) road construction and stabilization, (2) tree felling and logging, and (3) site preparation. Between April and June 1976, three roads

Table 1.1 Physical and hydrologic[a] characteristics of WS 7 and WS 2, Coweeta Hydrologic Laboratory, Otto, North Carolina.

	WS 7	WS 2
Area (ha)	59.5	12.3
Slope (%)	57	60
Aspect	South facing	South-southeast facing
Elevation range (m)	724–1060	716–991
Main stream channel length (m)	1225	480
Soils	Typic Hapludult and Typic Dystrochrept	Typic Hapludult and Typic Dystrochrept
Mean annual precipitation (cm)	189	181
Mean annual flow (cm)	106	99
Range in annual flow (cm)	76–149	59–130
Range in mean daily discharge (L $s^{-1}km^{-1}$)	5–247	5–220
Mean annual quickflow volume (cm)	6.8	8.1
Mean annual evapotranspiration (cm)	83	82

[a] Based on the May-April water year, from 1966 through 1976

with a total length of 2.95 km were constructed for logging access (figure 1.2). Road construction activities incorporated Best Management Practices and some new features of road design standards were applied and evaluated for effectiveness in reducing erosion and sediment movement (Swift 1988). Roadbeds were 4.5 m wide and drained by outsloping (no inside ditches) and broad-based dips. Metal-pipe culverts were installed at three crossings on the perennial stream. Grass was seeded and commercial 10-10-10 fertilizer (N-P-K), and lime was applied on cut-and-fill slopes by a hydroseeder immediately after construction. All roads were seeded by mid-May 1976; but in the last two weeks of May, record storms (38 cm rainfall) eroded both unstable soil and some hydroseeded materials from the roads. Subsequently, the damage was repaired and some road sections were reseeded.

Timber cutting and yarding with a mobile, high-lead cable-yarding system (figure 1.3) began in January 1977 and was completed the following June (figure 1.4). The cable system yarded logs up to 250 m from roads and could suspend logs completely above the ground. Tractor skidding was used on about 9 ha, where slopes were typically less than 20%. The total sale volume was about 2,322 m^3 and this was distributed over 41 ha of the catchment. Due to insufficient volumes of marketable timber, 16 ha on upper slopes and ridges were cut but all wood was left on the ground. The relationship of newly constructed roads to vegetation types, terrestrial sampling sites, and the weir are shown in figure 1.2. Site preparation was completed in October 1977 and this operation consisted of cutting all stems remaining after logging to encourage regeneration. Following logging, most large woody material was removed from the stream channel in accordance with practices used at that time. At the conclusion of the timber sale, roadbeds were reshaped and a light application of grass and fertilizer was applied to disturbed roadbeds and ungraveled sections of the road.

Figure 1.3 View of the high-level cable yarding system on Coweeta WS 7. (USDA Forest Service photo)

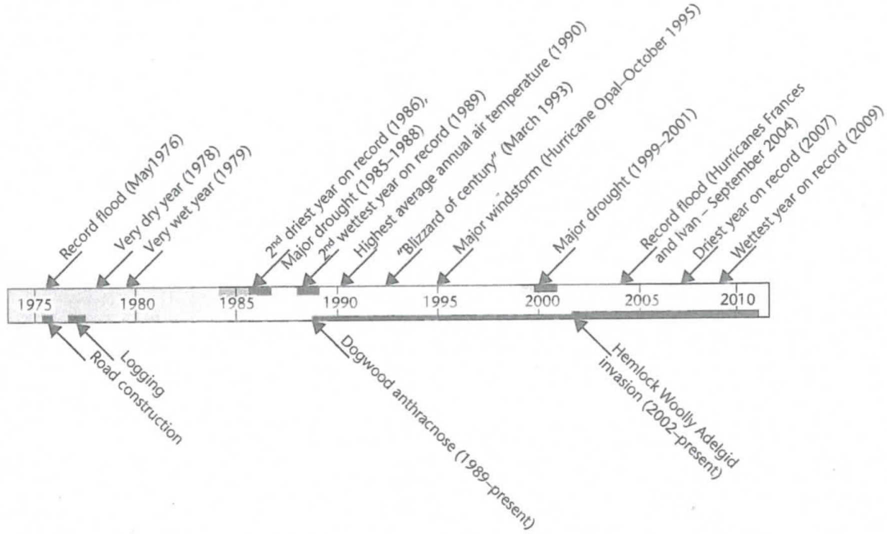

Figure 1.4 Event timeline for major disturbances on Coweeta WS 7 since the beginning of this study.

Table 1.2 Management activities and exposed mineral soil (disturbance) on WS 7, Coweeta Hydrologic Laboratory, Otto, North Carolina.

Activity	Total area of activity (ha)	Total area disturbed (ha)	Percentage disturbance
Permanent road	1.5	1.5	100.0
Cable yarded (uphill)	27.8	1.5	5.6
Cable yarded (downhill)	4.9	0.4	8.5
Tractor skidded	8.9	1.0	10.8
Felled—not logged	15.9	0	0

Source: After Swank et al. (1982)

The exposure of mineral soil associated with each prescription activity on the catchment is given in table 1.2, which shows that half of the exposed soil area was from permanent roads. These roads were also the only significant sources of surface soil compaction and overland flow during storms. It is also apparent that cable logging achieved the goal of minimal soil disturbance and erosion on logged areas.

Natural Disturbances

In long-term studies such as WS 7, it is important to recognize and consider temporal variability in natural disturbances in the context of potential influences on ecosystem processes and responses. Studies described in the subsequent chapters of this book frequently extended over a period of 20 or more years.

In the context of the 73 years of record, the experiment on WS 7, which encompasses the last 30 years, has experienced a variety of record and extreme events (figure 1.4). Beginning in May 1976, shortly after road construction on WS 7 was completed and before cutting and logging, a record storm of 38 cm of rainfall occurred (figure 1.5); this summer convective storm produced the highest peakflow rates ever measured on most of the Coweeta watersheds. The first year after cutting (1978), annual precipitation was 139 cm, or 23% below the long-term annual average. However, 1979 was quite wet, with an annual precipitation of 231 cm, or 28% above average.

Two major droughts occurred during the forest regrowth period. The first drought began in 1985, ended in 1988, and included the second driest year on record (1986), with only 124 cm of precipitation. The other 3 years in this period contained annual precipitation deficits of 33 cm to 54 cm, or 18% to 30% below average precipitation. Major reductions in forest growth and mortality occurred in this period due to water stress and associated southern pine beetle infestations. The drought was followed in 1989 by the wettest year on record (234 cm) at Coweeta. The second drought period spanned a 3-year period beginning in 1989; annual precipitation deficits over the period averaged 40 cm, or 22% above average values. As in the drought of 1985, there was significant forest mortality due to southern pine beetle infestations and reductions in growth.

Figure 1.5 James Buchanan (Jim Buck) contemplating sediment collected in WS 7 weir following record storms in May 1976. (USDA Forest Service photo)

The largest snow of the twentieth century in Macon County occurred in March 1993 and consisted of 0.6 to 1.2 m of snow, high winds, and subzero temperatures. Tree breakage was extensive due to the combined effects of snow, ice, and wind. A substantially greater catastrophic event occurred in October 1995 (figure 1.4) when microburst winds associated with Hurricane Opal created extensive forest wind throw and breakage throughout Macon County and other locations in the region. Within the Coweeta basin, more than 5,000 m^3 of down and damaged timber was salvaged from the existing road network alone. The last windstorm in Macon County approaching the magnitude of this event occurred in 1835 (Douglass and Hoover 1988).

More recently, in September 2004, Hurricanes Frances and Ivan delivered a total of 57 cm of precipitation within a 10-day period. These events generated numerous debris avalanches in Macon County, including severe channel scouring on Coweeta Watershed 37, a high-elevation catchment.

Forest diseases and insect infestations are continuing agents of disturbance in the region. The most significant disease has been the chestnut blight fungus (*Cryphonectria parasitica*), which decimated millions of hectares of its host American chestnut, *Castanea dentata* (Marshall) Borkh. Chestnut blight was first noted in the early 1920s at Coweeta, where chestnut comprised about 35% of the forest basal area (Elliott and Swank 2008). By 1930, most chestnut in the Coweeta basin was infected by the blight, and soon thereafter, most of the overstory trees died. Chestnut still sprouts from roots, but trees seldom live beyond the sapling stage because of the blight. A second disease of significance in the basin is dogwood anthracnose, which is caused by the fungus *Discula destructive* Redlin. First observed at Coweeta in 1989, dogwood anthracnose had an 87% average incidence of infestation on dogwood (*Cornus florida* L.) with a high rate of tree mortality. The disease is still present and a problem in the twenty-first century.

The southern pine beetle (*Dendroctonus frontalis* Zimmerman), in combination with drought, has frequently caused significant mortality in the Coweeta basin. The locust stem borer (*Megacyllen robiniae* Forster) has caused significant mortality in black locust (*Robinia pseudoacacia* L.) at Coweeta, particularly in regenerating stands. Infestations of the hemlock woolly adelgid (*Adelges tsugae* Annand) have spread rapidly since 2002, and high rates of eastern hemlock (*Tsuga canadensis* L.) mortality have been observed (Nuckolls et al. 2009; Ford et al. 2012).

Some of the agents of disturbance illustrated in figure 1.4 and described in this chapter have influenced and altered the structure, function, and related processes in the recovery of the WS 7 ecosystem, as is shown in later chapters of this book.

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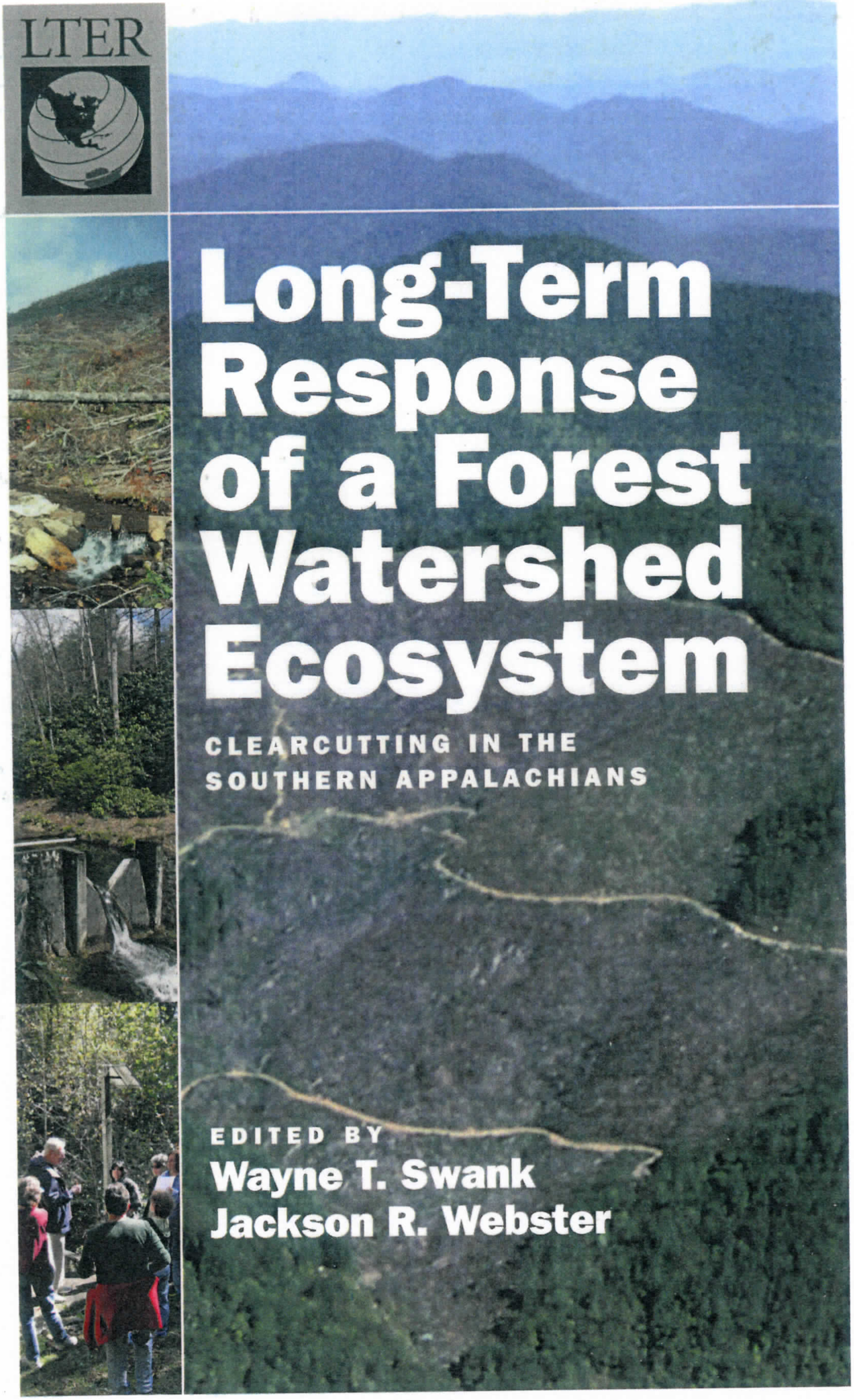
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"No serious student of forest hydrology or ecology can survive long without encountering the name "Coweeta." The Coweeta Hydrologic Laboratory in North Carolina has rightly become world-famous across a broad spectrum of environmental science. It is well over 20 years since the last compilation of Coweeta research appeared in book form, and this volume provides a very welcome update."

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Our North American forests are no longer the wild areas of past centuries; they are an economic and ecological resource undergoing changes from both natural and management disturbances. A watershed-scale and long-term perspective of forest ecosystem responses is requisite to understanding and predicting cause and effect relationships. This book synthesizes interdisciplinary studies conducted over thirty years, to evaluate responses of a clear-cut, cable-logged watershed at the Coweeta Hydrologic Laboratory in the Nantahala Mountain Range of western North Carolina. This research was the result of collaboration among Forest Service and university researchers on the most studied watershed in the Lab's 78-year history. During the experiment, a variety of natural disturbances occurred: two record floods, two record droughts, a major hurricane, a blizzard of the century, major forest diseases, and insect infestations. These disturbances provided a unique opportunity to study how they altered the recovery of the forest ecosystem. This book also shows that some long-term forest trends cannot be forecast from short-term findings, which could lead to incorrect conclusions of cause and effect relationships and natural resource management decisions.

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