Chapter 15
A History of Watershed Research in Experimental Forests of the Interior Highlands

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Abstract The history of watershed research in the Interior Highlands can be divided into four periods: Initial Start and Stumble (1930s–1950s), Reestablishment and Renewal (1960–1980), Partnerships and Expansion (1980–1990), and New Scales and Paths (1990–present). While each of these periods was marked by different societal concerns and scientific questions, experimental forests played a central role in accomplishing watershed research during all of these periods. Unlike other regions of the country, there was no dominating theme or inspirational leader to focus watershed research in one particular experimental forest; rather the work shifted between several experimental forests over time. Despite many changes in personnel and research direction, a significant body of knowledge has been developed over the past 70 years that has benefited scientists, forest managers, and the public. Fundamental knowledge has been gained regarding the components of the hydrologic system and how these components are affected by natural disturbances. Timber harvesting impacts on soil and water resources have been quantified and shown to be short-lived. Concerns about acid rain and road erosion also have been addressed and shown to be less severe than initially thought. These findings, coupled with the discovery that, in general, small watersheds responded in similar ways across the Interior Highlands, have been the basis for forest planning across the region. As new research challenges arise, experimental forests will continue to play a critical role in addressing these needs.

Keywords Interior Highlands · Forest hydrology · Paired watershed · Experimental forest · Research history

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15.1 Introduction

The Interior Highlands is a fascinating and diverse region that spans large portions of Arkansas, Oklahoma, and Missouri in the central USA. The forests of this mountainous region have sustained inhabitants for thousands of years, and do so today by providing wood products, recreation, clean water, and economic livelihood. This region presents a unique setting that has challenged scientists in their efforts to understand the region's forest environments and ensure the continued health of these forests.

In our efforts to better understand the forests of the Interior Highlands, watershed studies have played a major role. "Watershed studies," as used here, refers to research on soil and water resources—research that investigates where these resources occur, what are their characteristics, how do their related processes operate, and how are they affected by forestry practices. Watershed studies have been conducted since research first began in this region in the 1930s. To date, over 120 scientific publications have resulted from these studies. Central to the accomplishment of most of this research has been the use of experimental forests.

Experimental forests provide the outdoor laboratories where streams and soils can be examined and measured, and where forests can be manipulated so as to understand how soil and water resources react. Within the Interior Highlands, experimental forests have been created and used not only on US Department of Agriculture Forest Service lands but also on private lands as well. Some have been permanently designated as experimental forests, and are still used as such today, whereas others were assigned this role for a limited period of time and reverted to their previous status when research was completed. Whether permanent or temporary, federal or private, the availability of these experimental forests in the Interior Highlands has been critical in obtaining the significant store of knowledge that we have.

This chapter tells the story of how watershed research evolved in the Interior Highlands and how experimental forests were used to accomplish this work, and summarizes key knowledge we have gained through this effort. The history of watershed research in the Interior Highlands varies from that of other regions in many ways that make this history interesting and unique. Here, societal interactions played a noticeably visible role in affecting which research questions were pursued. Like elsewhere, the research "society" within the Interior Highlands consists of forest managers, the public, and scientists. These groups share many interests about soil and water resources within forests: where it occurs; how much there is and what is its quality; and how soil and water properties and processes are affected by timber harvesting, fire, or recreation. Perhaps more so than elsewhere, the citizens of the Interior Highlands have often expressed their opinions concerning the forests to which they have always been so closely connected. Related interests in watershed resources have caused these groups to interact—sometimes directly, but other times indirectly. In the Interior Highlands, this interaction or dialog has greatly influenced the topics that scientists have investigated and the types of results that have been produced.

In contrast to many other regions of the country, there has been no consistent geographic nexus of watershed research effort within the Interior Highlands; rather work has shifted between several experimental forests over time. No dominating theme or inspirational leader acted to center the work to a particular experimental forest; instead the location changed over time with the shifting interests of the participants and logistical constraints of different sites. Together with uneven funding, vagaries in staffing, and sporadic administrative reorganizations, these circumstances inhibited the development of centralized infrastructure or long-term commitment to a single site.

Along with other influences, the evolving dialog within and between interest groups coupled with the shifting geographic focus produced four distinct periods of watershed research in the Interior Highlands: Initial Start and Stumble (1930s–1950s); Reestablishment and Renewal (1960–1980); Partnerships and Expansion (1980–1990); and New Scales and Paths (1990–present). Each of these four periods is marked by different societal concerns, scientific questions, and locations of research effort. During these periods, the goals of forest managers changed from protecting and resurrecting the forests to "improving" forests, and to restoring ecosystems and maintaining forest integrity, and each of these goals has affected our thinking about watershed resources and research needs. At the same time, public concerns about the effects of forestry practices have shifted from concerns about soil erosion and floods to water pollution and acid rain, to cumulative impacts and to ecosystem restoration.

The remainder of this chapter is organized as follows. First, a brief description is given of the Interior Highlands region and its environmental characteristics. Then, each of the four research periods is examined. When appropriate, a description of the forest conditions at the beginning of the period is given and then the opinions and concerns of forest managers and the public during that time are summarized. How scientists responded to the challenges given them is examined next, and important research results are summarized. Throughout this chapter, our intent is not to exhaustively catalog the studies undertaken and their results; rather we aim to explain the context in which the science occurred, the fundamental role that experimental forests played, and what general lessons have been learned.

15.2 Interior Highlands Environment

The Interior Highlands consists of four distinct subregions: the Ouachita Mountains, the Springfield-Salem Plateau, the Boston Mountains, and the Arkansas River Valley (see Fig. 15.1). The Ouachita Mountains are a series of east–west-trending, parallel ridges composed of alternating sandstone and shale beds that are highly folded and faulted. The Springfield-Salem Plateau consists of flat-lying sedimentary rocks composed primarily of limestone and dolomite, and exhibits karst drainage features with low-relief rolling uplands dissected by entrenched streams with steep valley walls. The Boston Mountains are an east–west-trending range predominantly

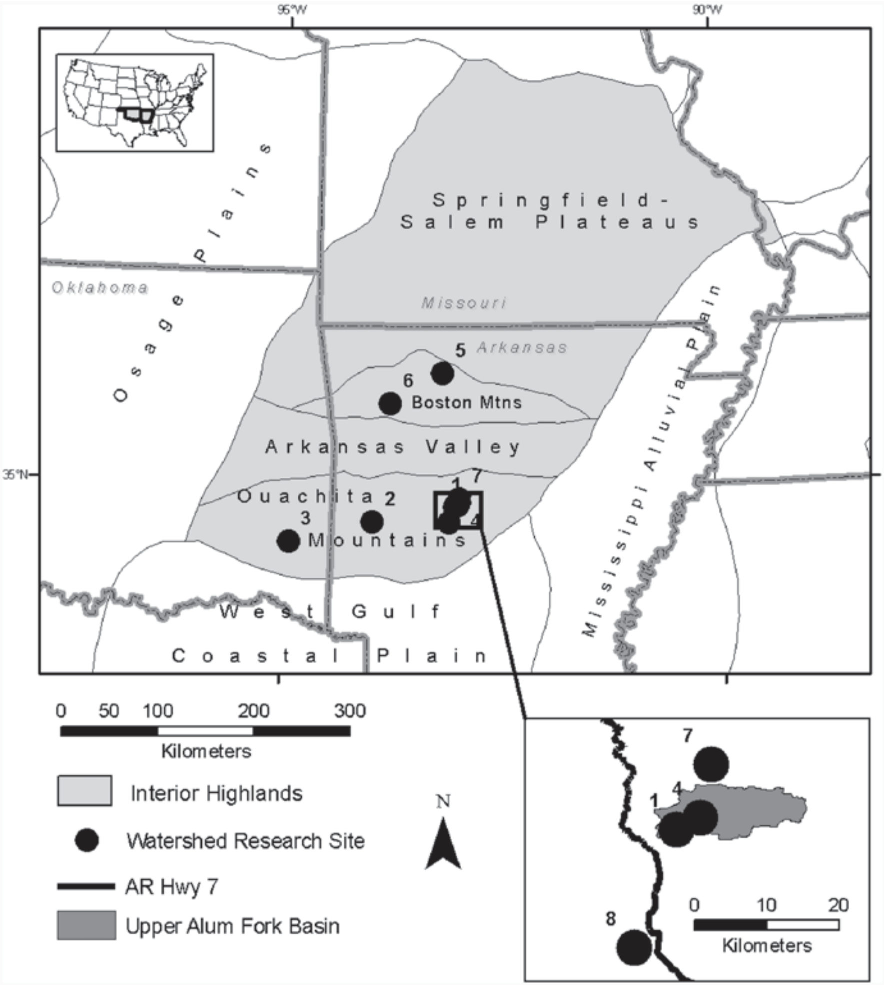

Fig. 15.1 Subregions of Interior Highlands and locations of experimental forests and research areas used for watershed research. Location codes: *1* Alum Creek Experimental Forest, *2* Irons Fork Experimental Forest, *3* Battiest research area, *4* Alum Fork research area, *5* Koen Experimental Forest, *6* Fleming Creek research area, *7* Cedar Mountain research area, and *8* Little Glazypeau research area

underlain by flat-bedded sandstone and shales. The Arkansas River Valley is composed of flat-topped mountains and rolling hills that descend to the Arkansas River, which bisects the subregion.

The Interior Highlands is an old landscape, comprising mostly Paleozoic rocks that were first exposed and began eroding over 300 million years ago. Today, relief within major valleys is around 150 m, slopes angles are typically less than 30%, and mass erosion events are rare. Forest vegetation covers much of the region, and consists of intermixed oak–pine, oak–hickory, and pine forest types with hardwoods increasing in number as one moves northward.

The region possesses a dynamic climate that is very conducive to weathering and erosion. Winters are mild while summers are hot and humid. Precipitation is relatively high (100–140 cm/yr) and evenly distributed throughout the year, with almost all of it occurring as rain. The Interior Highlands is located where dry, cold continental air frequently interacts with warm, moist Gulf air masses, making possible intense thunderstorms, ice storms, tropical storms, or tornados. The combination of this dynamic climate with the highly varied terrain produces a complex set of forest environments across the region.

15.3 Initial Start and Stumble (1930s–1950s)

15.3.1 Land-Use History Prior to 1930

American Indians' occupation of the Interior Highlands dates back at least 10,500–12,000 years (Sabo et al. 1988). Of the impacts that Native Americans had on the Interior Highlands environment, one of the most significant was through their extensive use of fire to clear land and improve game habitat. The combination of natural fires (lightening caused) and Native American burning produced forest conditions in the Ouachita Mountains subregion that were more open than those that typically occur today (Foti and Glenn 1991), though the effect in the Ozarks is less certain (Tucker 1991). By the time Euro-American settlers arrived in the early 1800s, annual burning of forest areas by Native Americans was common (Strausberg and Hough 1997), and was later adopted by the settlers. Still, the Interior Highlands forests remained largely intact and healthy until the late 1800s when increasing population and improved transportation led to the advent of commercial logging in the region (Fig. 15.2).

Commercial logging became firmly established by 1879 in the Interior Highlands with the extension of new rail lines into the region (Strausberg and Hough 1997; Bass 1981). From 1879 until the end of World War II, commercial logging occurred extensively throughout the region. Most logging companies gave no thought to conserving forest resources, leaving cutover areas denuded of vegetation and often severely eroded (Smith 1986). Small farmers added to forest decline by cutting down and selling high-valued trees to supplement their income, repeatedly burning forests to clear land or improve livestock grazing, and then abandoning farm areas to erode once the thin forest soils played out (Strausberg and Hough 1997; Bass 1981). The combination of all of these abusive land-use practices left much of the Interior Highlands' forest in poor condition (Record 1910) and led, in part, to the creation of the National Forests within the region.

Fig. 15.2 Shortleaf pine stand ca. 1931 in Irons Fork Experimental Forest. We speculate that the forest conditions shown here are probably similar to those that existed in typical stands prior to extensive commercial logging in the Ouachita Mountains from 1890 to 1945. The mixed ages, fairly open understory, and lack of dense shrubs suggest frequent, low-intensity burning and natural regeneration. The age of the overstory trees in this photograph predate the beginning of commercial logging in the area

15.3.2 Forest Management Goals and Public Concerns

The first half of the 1900s was a period when growing national concerns for conserving forest soil and water resources were both embraced by some and resisted by others. Within the Interior Highlands, citizens held a great many diverse, and often opposing, attitudes about the best use of public lands and forests, and about the value of the soil and water resources contained within these forests.

National concern for sustaining water supplies from forests was one of the motivations that led to the first laws in the late 1890s establishing the forest reserves that would become the National Forest System (Steen 2005). Recognition of the role that forests play in regulating downstream river flows was the basis of the Weeks Act of 1911 that permitted federal purchase of private lands for national forests in the East. Controversy over the role that forests play in regulating streamflow peaked after the great flood of 1927 in the lower Mississippi River valley, and motivation grew to better understand this role (Douglass and Hoover 1988).

Partly in response to regional forest depletion, the Ouachita and Ozark National Forests were created in 1907–1908. From 1919 to 1941, hundreds of thousands of acres of land, most of it cutover and burned (Bass 1981), were purchased and added to the Ouachita and Ozark National Forests. Forest managers' emphasis on National Forest lands was more on protection and rehabilitation than harvesting timber for its economic value (Strausberg and Hough 1997). By the early 1920s, private forest landowners in the Interior Highlands had begun to change their attitude as well, and began to adopt the idea of managing their lands to sustain timber production (Smith 1986).

Recognizing the damage from past logging and repeated, uncontrolled burning, foresters prescribed methods to rehabilitate forests, regenerate growth, encourage desired species, and restore the forest to a healthy productive state (Smith 1986). Shortleaf pine (*Pinus echinata* P. Mill.) was the desired species, due to its higher economic value, and even-aged management was considered the best way to produce the greatest annual yields (Mattoon 1915).

For generations, small landowners had used the Interior Highlands forest as open lands from which they could freely take timber and over which they could graze their livestock. Initial support for the establishment of the Ouachita and Ozark National Forests was replaced by resentment and vandalism when neighboring landowners realized such practices would now be illegal (Strausberg and Hough 1997). In the generally poor economy of the times, "job fires" were a continuing problem as locals deliberately set the forests ablaze so that they would be hired to put out the fires (Bass 1981). Others advocated that the newly created national forests be made into national parks to better support a nascent tourism industry (Strausberg and Hough 1997).

15.3.3 Interactions and Research Response

In 1921, the Southern Forest Experiment Station was established by the Forest Service in New Orleans, LA, with an area of responsibility that included the Interior Highlands. Initial scouting to identify a suitable location for an experimental forest on the Ouachita National Forest occurred in 1931. However, it was not until 1936, and after repeated urging from the Forest Service Branch of Research in Washington, DC (Munns, personal communications 1932a,1932b,1936), that work began in what would become the first experimental forest in the Interior Highlands—the Irons Fork Experimental Forest, located near Mena, AR.

An ambitious work plan was implemented in 1936 in which research studies were initiated immediately while support infrastructure, such as laboratory, residence, and work buildings, were being constructed onsite. Using Works Progress Administration (WPA) and later Civilian Conservation Corps (CCC) work crews, work commenced in 1936, but it was not until 1940 that the 3,600-ha (9,000-ac) Irons Fork Experimental Forest was officially established.

Though forestry research was the initial impetus behind establishing the Irons Fork Experimental Forest, scientists realized prior to 1935 that watershed research was just as pressing a need (Meginnis 1936). Scientists at the time were just

Fig. 15.3 Structure installed in Irons Fork Experimental Forest to divert streamflow from ephemeral channel to adjacent hillslope where it was spread out and reabsorbed into the soil. The objective was to reduce the amount of and speed at which streamflow from headwater streams moved downstream

beginning to understand how forests and water interact. With the charge to rehabilitate the forests of the Interior Highlands came the realization that no one knew with confidence what effect the proposed forestry practices would have on soil and water processes. Furthermore, basic information was needed on such things as whether existing forest cover was working effectively to control runoff from rainfall, and what roles did surface runoff, shallow seepage, and ground water drainage play in generating flood flows within Interior Highland watersheds.

Research on the experimental forest was conducted from 1936 to mid-1943 and involved a number of studies assessing all aspects of forest watershed science. Plot-scale studies were undertaken to measure the proportion of overland flow from the forest surface within four different condition classes, and to assess the subsequent effect of fire and litter removal on surface runoff and soil erosion. A paired-watershed study was implemented to measure the effects of different forestry practices on streamflow behavior and soil erosion. Another study was devised to evaluate the effect of different engineering structures on reducing downstream peak flows from headwater streams (Fig. 15.3). Road bank erosion and stabilization techniques were assessed in yet another study. To quantify elements of the hydrologic cycle, basic measurements were initiated of precipitation, plant transpiration, soil water content, and water-table depths.

Fig. 15.4 Columbus deep notch weir ca. 1936 built by WPA and CCC labor and used to measure streamflow in Irons Fork Experimental Forest

To accomplish this ambitious research program, crews consisting of either WPA personnel or CCC enrollees were engaged to construct 177 km (110 miles) of trails to access all the study plots, string 18 km (11 miles) of telephone lines, and install over 100 rain gauges, 2 full weather stations, and 2 lysimeters. These men installed rock masonry water control structures, lined stream channels above and below the controls with riprap, and completed a 4.6-m weir used to measure streamflow (Fig. 15.4). The weir alone accounted for 900 bags of concrete. All of this work was conducted from late 1936 to March 1942.

Engaging with the public and management personnel on the Ouachita National Forest was an integral part of the research staff's work. The lead researcher was expected to give talks to local groups, contribute regular articles for the Mena newspaper, and prepare an educational brochure for the public. "Show-me" trips were organized for agencies such as the Arkansas State Planning Board, Water Resources Committee, and Flood Control Commission. Other trips involved Forest Service personnel from the Washington, DC, and regional offices. On April 29, 1941, a Forestry Study Day attended by over 125 individuals was held with the assistance of the Arkansas Extension Service. Individuals attending included the state forester, members of the logging industry, the Soil Conservation Service, and members of the Mena Lions Club.

15.3.4 Research Findings

Despite its energetic start and the clear, pressing need for the information promised by its research, the work at Irons Fork Experimental Forest was never completed. Funding was always a problem. All staff with the exception of the assistant forester was funded from either CCC or WPA funds. As the flow of those funds slowed, the work at the experimental forest was modified or curtailed. In 1939, the CCC program was cut back. By the summer of 1940, the WPA workforce was cut from 42 to 16 men, and in the following year those 16 slots were lost. With the outbreak of World War II (WWII), the situation for Irons Fork went from bad to worse. During the war, both the CCC and WPA programs were ended. The Forest Service staff was reassigned to war duties or, in the case of the project leader, died. Measurements on all watersheds, weather stations, and other field studies ended on July 1, 1943. No other research was conducted on the Irons Fork Experimental Forest after that time. Proposals to restart the research at Irons Fork continued periodically through the late 1950s and early 1960s, but were never implemented. The Irons Fork Experimental Forest was officially disestablished and its lands returned to unrestricted National Forest status in 1969.

While the premature closure of the Irons Fork Experimental Forest precluded completion of the watershed studies, the effort did produce some useful knowledge. Interception data measured at Irons Fork were used by Helvey and Patric (1965) and Helvey (1971) to determine throughfall and stemflow rates for southern hardwoods and conifers, respectively. Practical knowledge was gained concerning how best to measure processes such as plot runoff and streamflow. Initial assumptions about how long it would take to establish relationships between precipitation inputs and streamflow outputs (2 years) were quickly disproved. Later research within the Interior Highlands would benefit from this knowledge.

15.4 Reestablishment and Renewal (1960–1980)

15.4.1 Forest Conditions

The period of WWII and its aftermath saw an interruption in both watershed research and active national forest management. Participation in the war effort and elimination of prewar programs like the CCC and WPA had greatly reduced Forest Service replanting efforts and fire protection within the Interior Highlands. As the postwar economy developed and the workforce returned to the woods, they encountered forests exhibiting reduced productivity and increased fire vulnerability (Strausberg and Hough 1997).

15.4.2 Forest Management Goals and Public Concerns

As the decade of the 1960s began, forest managers saw their primary goal to be increasing forest productivity (Strausberg and Hough 1997). This desire was driven by two expectations: (1) that lumber demand would continue to increase nationally and (2) that new areas would not be converted to forest production. To meet this goal, forest managers sought to reduce forest mortality through suppression of fire, pest, and disease occurrences, and to "improve" stand quality. The most efficient way to improve stand quality was thought to be through the use of even-aged forestry practices that utilized clearcutting, intensive site preparation using herbicides, and replanting with preferred species (shortleaf or loblolly pine; Strausberg and Hough 1997). New harvesting equipment was developed to accomplish this work at reduced cost, but being heavier, this equipment created a greater potential for increased soil erosion (Bass 1981).

The period of 1960–1980 saw a transformation of the public's role in forest management, both nationally and within the Interior Highlands. The period began with passage of the Multiple-Use Sustained-Yield Act of 1960 by Congress, which mandated equal consideration of nontimber resources like soil and water. Over time in this period, the voice of the public grew as concerns about forest soil and water resources were increasingly expressed and argued.

Both the national and regional concern over the role of forest management in reducing floods carried over from the previous period, as evidenced by passage of the Watershed Protection and Flood Prevention Act in 1954. This act mandated that the Forest Service cooperate with state and other federal agencies on flood control (Strausberg and Hough 1997, p. 22). In addition, local communities were very concerned about managing forests to ensure adequate streamflow for recreation and municipal water supplies in the Interior Highlands.

Use of the forest for livestock grazing exemplifies the conflicting attitudes during this period. Livestock owners' desired access to national forest lands for grazing, a common practice in pre-WWII times, but forest managers resisted over concerns about livestock eating or destroying pine seedlings. Hunters also protested that grazing decreased wildlife food sources and spread disease (Strausberg and Hough 1997).

In the 1970s, new federal laws (e.g., the National Environmental Policy Act and what would later become the Clean Water Act) provided still more avenues by which public concerns and values regarding the region's forests could be expressed. Individuals and interest groups increasingly decried the use of clearcutting, which they found aesthetically displeasing and environmentally unsound (Strausberg and Hough 1997). Objections to herbicide use were equally strong (Bass 1981).

15.4.3 Interactions and Research Response

Research scientists in the Forest Service, and later those in universities and in private industry, renewed their efforts to provide answers to the questions and concerns raised by forest managers, users, and the general public. These scientists, like their predecessors, were trained as foresters, and they employed a multidisciplinary approach to their research. Studies that examined how soil and water resources responded to given forestry practices often contained a component evaluating whether the vegetation response to those practices produced the desired productivity improvements. Another feature of the watershed research was a continuing effort to determine basic characteristics (e.g., nutrient amounts within undisturbed soils and streams) and process rates (e.g., precipitation intensity, runoff magnitude, and volume), in addition to how these characteristics and rates changed in response to harvesting. Moreover, these scientists made a fundamental decision: They chose to focus on very small basins that lacked well-developed stream channels (i.e., stream paths had no pronounced incision or features like bars or bedforms) so that the responses they observed could be logically inferred to result from process changes on the surrounding hillslopes and not from in-channel processes such as bank erosion or bed scour.

Recognizing that important environmental differences existed within the Interior Highlands, new experimental forests and watershed research areas were established as representations of intraregional differences. The Henry R. Koen Experimental Forest was established in 1948 within the Springfield-Salem Plateau subregion (see Fig. 15.1). The Koen Experimental Forest is a 4,400-ha area of the Ozark National Forest located near Jasper, AR, in the headwaters of the Buffalo River and covered by a hardwood forest consisting of oaks (*Quercus* spp.), hickories (*Carya* spp.), and white ash (*Fraxinus Americana* L.). In 1959, the Alum Creek Experimental Forest was created within the eastern Ouachita Mountains in the headwaters of the Saline River. Located within the Ouachita National Forest near Jessieville, AR, the Alum Creek Experimental Forest is about 810 ha and is predominantly covered by a mixed pine-hardwood forest type with shortleaf pine, white oak (*Q. alba* L.), and assorted hickories being the dominant species. Late in this period, yet another research area was established in the western Ouachita Mountains on Weyerhaeuser Company lands near Battiest, OK (Fig. 15.1). While not a Forest Service experimental forest, the Battiest research area was used in the same way as the Koen and Alum Creek Experiment Forests. Vegetation cover within the Battiest area was similar to that in the Alum Creek Experimental Forest.

The watershed studies implemented in all three of these research areas were similar in that they used essentially the same experimental design, the same monitoring equipment, and the same type of research sites. The experimental design utilized measurements taken both before and after a change or “treatment” (e.g., clearcutting followed by herbicide application) was imposed on the research sites, and simultaneous measurements taken at both “control” (i.e., undisturbed) sites and “impacted” sites. Instrumentation at each area included precipitation and streamflow gauges, and weather sensors (Fig. 15.5). The type of research sites used were very small watersheds (0.4–3.2 ha in all cases) located at the heads of small, ephemeral streams. Slopes were moderately steep (15–30 %), forest cover was continuous, and no roads were constructed within the watersheds. Each site was assigned a different treatment which was applied across the entire watershed. What differed between research areas was the underlying geology, the forest type, or the specific management treatments used in each study.

Fig. 15.5 Monitoring installation used to measure streamflow amount and collect water samples on Watershed 2 in the Alum Creek Experimental Forest. The H-flume (device with triangular opening in *lower center*) is used to measure the depth of water, which can then be mathematically converted into the streamflow rate (volume per unit time). A Coshocton wheel (device offset from flume outlet) is used to capture 1 % of the streamflow, which is stored in a container for later analysis. Similar installations were used at sites in Koen Experimental Forest and Battiest research area. Photograph was taken prior to the upstream basin being cut and shows typical conditions after 40+ yr of fire suppression: high density of overstory trees and thick shrub and understory growth

15.4.4 Research Findings

Results from the early studies at the Battiest research area and the Koen and Alum Creek Experiment Forests provided important insights into both natural processes and their response to forestry practices. Several of the basic components of the hydrologic cycle in forest ecosystems were documented for the first time in the Interior Highlands. They included streamflow amounts and rate, canopy interception and throughfall, soil water storage, and nutrient concentrations in streamflow (Lawson 1967; Rogerson 1971; Lawson and Hileman 1983). Despite differences in the environment and forestry practices used, these studies showed that small watersheds in the Interior Highlands responded in similar ways. Water yields generally increased

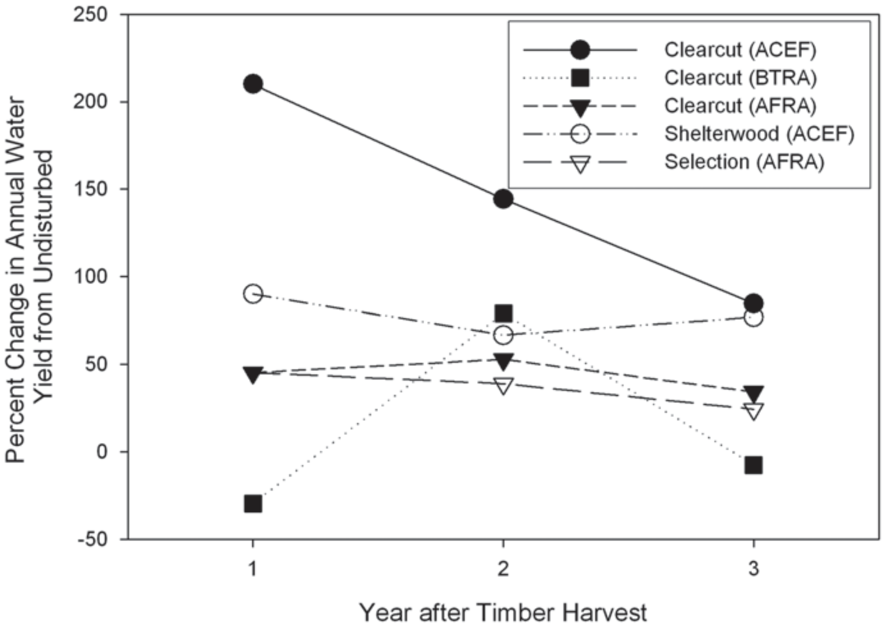

Fig. 15.6 Percent change in annual water yield after timber harvesting within Interior Highland watersheds. Percent change is based on the difference between paired undisturbed watersheds at each location for the same year. Location codes and data sources used: *ACEF* Alum Creek Experimental Forest (Rogerson 1985); *BTRA* Battiest research area (Miller 1984); *AFRA* Alum Fork research area (Miller et al. 1988)

in the 1st year after harvest, but returned to near undisturbed levels by the 3rd year (Fig. 15.6), unless revegetation was suppressed through herbicide applications (e.g., Rogerson 1985). Sediment production also consistently increased in the 1st year following harvest, but returned to undisturbed rates even more quickly than water yield (generally by the 2nd year; Fig. 15.7). Somewhat less consistent was nutrient response. Most nutrient concentrations in streamflow were unchanged by harvesting. The exceptions were nitrogen and phosphorus, which did change, but in variable ways that make the relation to silvicultural methods unclear (Lawson 1985).

15.5 Partnerships and Expansion (1980–1990)

15.5.1 Forest Management Goals and Public Concerns

The 1980s opened with state agencies and the public frequently challenging Forest Service decisions on how best to manage national forests in the Interior Highlands. Nonpoint source (NPS) pollution, particularly from sediment and herbicides, had

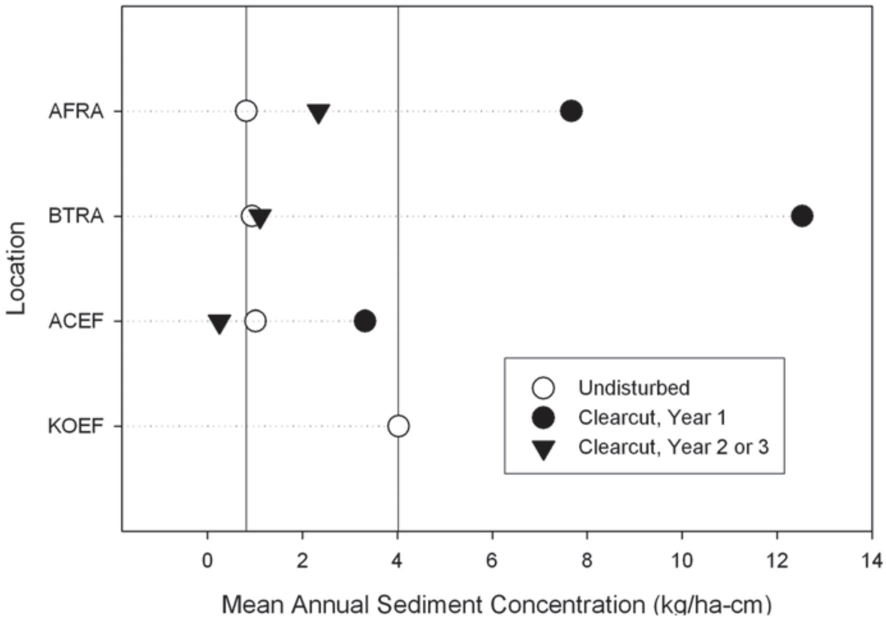

Fig. 15.7 Changes in mean annual sediment concentration after clearcut harvest within Interior Highland watersheds. Only clearcut harvest is shown as it produces the greatest change. *Vertical reference lines* enclose range of observed undisturbed sediment concentrations. Mean annual sediment concentration is computed from the mean annual sediment yield (kg/ha) and mean annual water yield (cm) for all similarly treated watersheds at each location (see Marion and Ursic 1993 for explanation). Same location codes as in Fig. 15.6. (Data sources: ACEF, Rogerson 1985; Lawson 1985; BTRA, Miller 1984; AFRA, Miller et al. 1988)

become a major public concern. Passage of the Clean Water Act in 1985 mandated that states identify their polluted waters and the land uses that were contributing to NPS pollution; yet little information was available about how such pollution was affected by forestry practices. Continued and growing objection to the frequent use of clearcutting and associated herbicide use led to numerous appeals of Forest Service actions through the 1980s (Strausberg and Hough 1997). Another issue of growing concern was acid rain and its effects. Massive fish kills in the northeastern USA had resulted from the acidification of water by dilute sulfuric and nitric acid entering the lakes through rain and snowfall. Both sulfate and nitrate are produced by coal-fired power plants, oil refining, and vehicle engines. At this time, no one knew whether or not acid rain fell within the Interior Highlands, but it was suspected due to its location downwind of major metropolitan and oil-refining regions in Texas, Louisiana, and Oklahoma.

Public dissatisfaction with clearcutting forced Forest Service managers to reexamine uneven-aged forestry practices as an alternative to even-aged methods. Little research was available at the time on how uneven-aged practices affected soils and streams in the Interior Highlands as studies in the prior period had focused on even-aged methods. Private landowners and the forest industry decided to continue their reliance on even-aged methods, but they, along with state forestry agencies, wished to demonstrate that such methods could be used and still meet NPS requirements. Thus, federal, state, and private forest managers needed new information from research.

15.5.2 Interactions and Research Response

This period saw an overall expansion in research effort and important changes in how research was accomplished. Perhaps the most important change was in the marked increase in partnerships between Forest Service, academic, and industry scientists to address mutual research needs in coordinated studies. All parties recognized that working together on joint studies would be more economically and logistically efficient, and increase the likelihood of public acceptance of their research results. This cooperation also would permit the number of sites used for paired-watershed studies to be increased to obtain greater statistical power. Another change was the decision to increase the size of research watersheds from that used in the past. Whereas the previous period focused on basins of 0.4–3.2 ha, new studies would evaluate 4.0–12.1-ha basins to better match with the size of harvest units being used. Yet another important change was in the addition of process-based studies to complement traditional paired-watershed investigations. These process-based studies would measure the amounts and movement of water and its constituents within a given watershed rather than just monitoring what came out at the outlet. And, once again, experimental forests would play a key role in developing the information to answer the questions posed by both the public and forest managers.

To compare the effects of clearcutting (even-aged) and selection harvest (uneven-aged) practices on water quantity and quality, a cooperative watershed study was initiated by the Forest Service, University of Arkansas at Monticello, and Weyerhaeuser Company in 1978. Oklahoma State University joined the effort in 1988. This study utilized nine small watersheds ranging from about 4.0 to 6.1 ha in size (Fig. 15.8). Six of the watersheds were in the Alum Creek Experimental Forest while the other three were on industrial lands a few kilometers to the north near Cedar Mountain (Fig. 15.1). Data were collected for a year prior to harvesting to establish pretreatment behavior, and 5 years afterwards to evaluate the forestry effects.

The Boston Mountains subregion had yet to receive attention from watershed researchers. This knowledge gap was addressed in another research partnership, this time between scientists with the Forest Service and University of Arkansas at Fayetteville. In 1972, a new paired-watershed study was established at the Fleming Creek research area near Brashears, AR. Through an agreement with the Ozark National Forest, four small basins, 6.1–13.4 ha each, were set aside to study the hydrologic response to forestry practices intended to increase pine productivity in a mixed pine–hardwood forest. Though started prior to 1980, the Fleming Creek study fits best with research of the later period because of the size of the watersheds used.

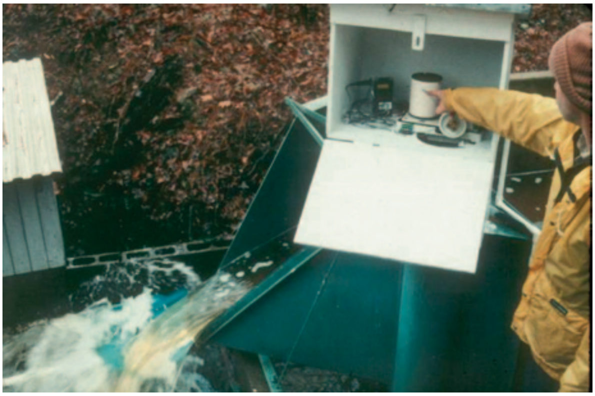

Fig. 15.8 Monitoring installation used to measure streamflow amount and collect water samples on Watershed 11 in the Alum Creek Experimental Forest. Device being pointed to records the water depth on a paper chart while the device immediately to the left records the same data in a digital file

Each basin was instrumented to monitor precipitation, streamflow, water chemistry, and sediment. A meteorological station was installed to measure precipitation, air temperature, and barometric pressure. Clearcutting, thinning, and thinning with herbicides were all tested along with natural regeneration and pine seedling planting. Forestry treatments were applied in 1982 and data collection completed in 1992.

The possible occurrence and effects of acid rain were assessed by another study using the Alum Creek Experimental Forest. The Ouachita and Boston Mountains were both thought to be especially vulnerable to acid rain because the soils and bedrock are naturally acidic and lack acid-buffering minerals such as calcium carbonate. Did acid rain fall in the Interior Highlands? Was there a potential for water and soil acidification in the region? If so, what would be the effect on aquatic life, drinking water supplies, and forest ecosystems? To start answering these questions, a number of small studies were installed and carried out on the Alum Creek Experimental Forest. The Alum Creek Experimental Forest was an ideal place to do this work because information on the geology, soils, vegetation, climate, and hydrology were already available. The small watersheds also allowed investigators to track changes in water chemistry as it entered the watersheds as rainfall, passed through the vegetation and soils, and became streamflow. Work was performed utilizing both undisturbed (control) watersheds as well as the managed watersheds.

Process-based studies were used to better understand the biogeochemical cycle and the relationship of rainfall to streamflow. Past research in the region demonstrated that streamflow occurs very quickly following the onset of rainfall. Past work also indicated that timber harvesting did not increase the streamflows resulting from large storms that produce floods. Since surface runoff outside of streambeds was only observed to occur on highly disturbed areas such as roads and landings, the most likely mechanism by which rainfall could move through watersheds and into streams of the region was by lateral (i.e., subsurface) flow through the soil. In 1989, two stations were installed in an undisturbed watershed on the Alum Creek Experimental Forest to measure subsurface flow and water chemistry. Collectors placed across the slope and at different depths in the soil profile intercepted

Fig. 15.9 Installation for measuring sediment production from a forest road. Equipment is the same as that shown in Fig. 15.5 and 15.8, but has an extended approach section between the flume and the road which collected the bed load sediment eroded from the road. Total sediment was the combined amount deposited in the approach section and the suspended portion that flowed over the flume and was measured using the Coshocton wheel samples

subsurface flow and routed it to flumes where flow rates were measured and water samples for chemical analysis were collected.

Forest roads were recognized as having great potential to erode and deliver sediment to streams. In another process study, Forest Service, University of Arkansas at Monticello, and Weyerhaeuser Company scientists measured sediment production over 17 months in 1982 and 1984 along four road segments in the Bread Creek watershed (Fig. 15.9). The Bread Creek watershed lies adjacent to the Alum Creek Experimental Forest, and would later become part of a larger research area used in the next research period. The measured data were then combined with an inventory of road lengths and conditions throughout the basin to estimate total sediment delivery from roads to the stream system.

15.5.3 Research Findings

The cooperative watershed study showed that 4.0–6.1-ha basins responded much like 0.4–3.2-ha basins. The response patterns were the same: Export of streamflow, sediment, and important nutrients (nitrogen and phosphorus) all increased in the first 1–3 years following harvesting, but then all returned to undisturbed levels as vegetation became reestablished (Figs. 15.6 and 15.7). The study also revealed some new insights into forestry effects. Moderate storms produced higher peak streamflow rates in the postharvest years, but peaks from large storms were unaffected by harvesting. Large storms apparently produce so much water that forest soils become saturated regardless of whether the site was harvested or not (Miller

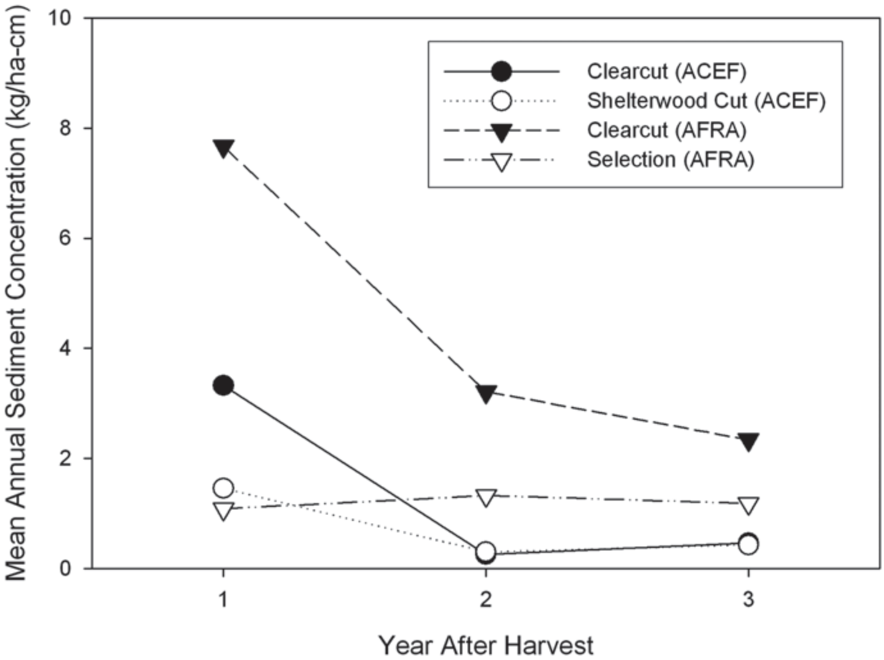

Fig. 15.10 Comparison of mean annual sediment concentrations after harvest for different harvest methods. See Fig. 15.7 for how concentrations were computed, location codes, and data sources

et al. 1988). Another insight was that sediment increases corresponded to the degree of vegetation removal, with clearcuts producing greater increases at a given location than shelterwood or selection cuts (Fig. 15.10). However, it was also clear that none of the forestry practices resulted in sediment increases comparable to those produced by agricultural uses like row crops or pasture. Data from the cooperative watershed study also showed that since nitrogen and phosphorus increases were approximately equal to inputs from the atmosphere, the observed increases reflected the short-term change in vegetation uptake, not actual nutrient depletion of the soils.

Data from studies within the Alum Creek Experimental Forest, Fleming Creek research area, and elsewhere in the Interior Highlands demonstrated that acid rain did occur within the region (Wheeler et al. 2000; Kress et al. 1990; Beasley et al. 1988). However, comparison to nutrient pools measured at the Alum Creek and Fleming Creek sites indicated that excessive leaching of nutrients did not occur. The analyses also showed that nutrient losses following various forestry practices would not deplete soil nutrients or significantly reduce soil productivity.

Subsurface flow research at Alum Creek Experimental Forest revealed much about how water moves through forest soils in the Interior Highlands. This work found that subsurface flow is generated within a few minutes following the onset of rainfall, with flow rates rising and falling in close synchrony with streamflow, and that subsurface flow accounted for all of the flow from the hillslopes.

The rapidity of subsurface water delivery to streams and the correspondence in streamflow chemistry with that of subsurface flow demonstrated the critical role that macropores play in forest hydrology. Macropores are flow conduits within the soil greater than 1 mm in diameter which are formed by old root channels and insect, earthworm, and animal burrows. Macropores form preferential flow paths through which water and its constituent chemicals can travel quickly to streams without being absorbed or transformed by the soil. Studies carried out on the Alum Creek Experimental Forest demonstrated that the potential movement of chemicals like herbicides through macropores to streams was significant under certain conditions (Turton et al. 1995). Thus, the fact that during storms macropores in forest soils can rapidly deliver water and dissolved contaminants to Interior Highland streams is an important consideration for forest managers deciding whether or how to apply fertilizers and herbicides.

Results from the Bread Creek road study were particularly important. This was the first and only study to date that has measured sediment production from forest roads within the Interior Highlands in Arkansas. Prior to this study, road sediment production had been estimated to average almost 390 t/road km/yr for this area, but these estimates were made without the benefit of actual measured data. This study found that road sediment production for the same area was actually 41 t/road km/yr and sediment delivered to the stream system was about 4.5 t/road km/yr (Miller et al. 1985). This study clearly demonstrated that while roads were a potential problem, the magnitude of the problem was far less than was initially thought.

15.6 New Scales and Paths (1990–present)

15.6.1 Forest Management Goals and Public Concerns

The current period of watershed research in the Interior Highlands began with the national public continuing to express frequent dissatisfaction with Forest Service management decisions. Clearcutting was particularly disliked as more people came to value the scenic qualities of their national forests (Robertson 2004). Interest groups increasingly challenged in the courts the tradeoffs inherent in the multiple-use strategy to forest management, using environmental laws like the Endangered Species Act, the National Forest Management Act, and the National Environmental Policy Act. Public objections also led to Congressional inquiries. These factors, plus new thinking among researchers (Franklin 1989), caused the Forest Service to rethink its approach to forest management. From this reassessment came the new management paradigm of “ecosystem management.”

Those concerned about national forest management in the Interior Highlands were particularly effective in communicating their opinions through their legislators. US senator David Pryor of Arkansas specifically requested that the Forest Service find ways to eliminate use of clearcutting on the Ouachita National Forest. This request led to the famous "walk in the woods" meeting on the Ouachita National Forest in August 1990 between Senator Pryor, Forest Service Chief Dale Robertson, local Forest Service managers, and research scientists (Robertson 2004). In searching for a compromise acceptable to both the public (represented by Pryor) and the managers, input from scientists regarding alternatives to clearcutting proved significant. An agreement was reached that new harvesting methods would be used on the Ouachita National Forest, and that research would work closely with management to assess how these methods affected other resources like water (Robertson 2004). This initial decision quickly evolved into a 1992 Forest Service-wide directive to do the same throughout the NFS.

Adoption of ecosystem management meant using natural regeneration to restock forests and uneven-aged forestry methods to harvest timber (Guldin 2004). Use of controlled burning would increase, both to replace herbicide use for competition control during forest regeneration and to restore fire as a natural process in the forest. Moreover, the new management paradigm abandoned the past approach of making stand-based decisions for one that encompasses larger areas. It was evident that knowledge gained in the previous periods from small-watershed studies would be insufficient in answering questions about how watersheds would respond at larger spatial scales and to multiple disturbances over time. The effects of this new "landscape" scale of management were largely unknown; thus, a clear need existed for new research.

15.6.2 Interactions and Research Response

The degree of direct interaction between the public, forest managers, and scientists in this period was unprecedented. Through numerous formal and informal meetings among these groups, a program of research work emerged to address the new information need. From the start, new watershed research was recognized as a primary need. A team was formed consisting of scientists from the Forest Service, universities, and private industry, along with hydrologists and soil scientists from the Ouachita National Forest. Bigger scales required bigger research areas. With the cooperation from the Ouachita National Forest, the entire Alum Fork basin upstream of Lake Winona (and including the Alum Creek Experimental Forest) was set aside for use in new research studies (Fig. 15.1). Within this expanded area, three basins became the focus of watershed research: (1) the South Alum Creek watershed, which drained most of the Alum Creek Experimental Forest; (2) North Alum Creek; and (3) Bread Creek. These watersheds, each roughly 600–1,500 ha in area, were selected as good candidates for ecosystem management practices with South Alum serving as a relatively undisturbed situation, Bread Creek as the example of past stand-based forestry, and North Alum as capable of being converted to a historic ecosystem (shortleaf pine-bluestem grass, *Andropogon* spp.) that had disappeared after decades of fire suppression. Furthermore, the Weyerhaeuser Company, an active player in this research, designated one of their nearby watersheds, the Little

Fig. 15.11 Phase III monitoring station on South Alum Creek showing footbridge for high-flow sampling and container for computer-controlled pump sampler (*lower right*). Personnel are measuring streamflow using a sounding weight (*red device* below bridge) and current meter (obscured by vegetation)

Glazypeau Creek basin (Fig. 15.1), to represent a fourth option, industrial forest management. An extensive network of monitoring stations was established within these four watersheds to measure precipitation, air temperature, streamflow, and water temperature (Fig. 15.11). Data collection began in 1996, harvest treatments were applied in 1999–2000, and prescribed burns conducted in 2002. In addition to watershed studies, these four basins also serve as the "core" research area for numerous ongoing studies of geomorphic, aquatic, floral, and faunal studies associated with Phase III of the Ecosystem Management Research Program in Arkansas; thus, the basins are together referred to as the "Phase III Watersheds."

The defining feature of this new research period was the consideration of new and larger scales. Research in the previous periods had focused on the small watershed scale, first at 0.4–3.2 ha then at 4.0–13.4 ha. This new work would evaluate treatments applied to 400 ha (1,000 acres) or more, and assess responses at several scales (e.g., 200 ha, 600 ha, and larger). For the first time in Interior Highlands' research, how responses change as one moves downstream would be examined, providing new insight into how scale affects soil and water processes. At these larger scales, new questions arose. In addition to evaluating streamflow amounts and soil and water quality attributes, new studies were undertaken to assess natural disturbance frequencies (e.g., ice storms and tornados), bed load transport properties, and road conditions.

15.6.3 Research Findings

Findings from this latest research period have only begun to be published, but early results are already having an effect. Whereas results from the previous periods led to developing general guidelines or "best management practices" for limiting negative impacts, new findings from this latest period are allowing more effective application of these practices. One example is a new model for predicting peak flow magnitudes from small watersheds (Marion 2004) which permits more accurate sizing of drainage structures. Another is a study on the effect of aerial fertilizer

Fig. 15.12 Communicating research results to participants in 2006 road erosion modeling workshop. This location was one of the monitoring sites used for the Bread Creek road erosion study during 1982–1984

applications on stream chemistry in an industrial forest which is improving streamside buffer designs (Liechty et al. 2006). Workshops have been offered to more quickly communicate these and other improvements in operational methods and thinking to resource managers and the public (Fig. 15.12).

Results from other studies are expanding our understanding of how soils, streams, and forests coevolved in the Interior Highland forests over time. Bed load transport rates have been quantified for the first time in small forest streams within the Interior Highlands, illustrating a complex relationship between bed load and the channel bed during peak flow events (e.g., Marion and Weirich 2003). Unexpected changes in nutrients have been shown in studies of the long-term effects of pine-bluestem conversion on Ouachita Mountain soils (Liechty et al. 2002). The importance of natural disturbance processes on watersheds and the underappreciated role that forest trees play in soil evolution in the region have been revealed (e.g., Phillips and Marion 2006).

15.7 Summary and Final Thoughts

Over 70 years of watershed research in the Interior Highlands has provided numerous benefits to scientists, forest managers, and concerned citizens. To scientists and others in their related disciplines, this body of research has helped clarify how water, sediment, and nutrients move through forested watersheds. Fundamental knowledge has been gained of the magnitude and flux of interception storage, throughflow, soil–water balance, streamflow, and sediment production throughout the year. The important influence of macropores on subsurface flow and chemical routing through forest soils has been demonstrated, and the important role of natural disturbance events and the primary role that trees play in soil development have both been elucidated.

To forest managers and the public, this research has established the impacts associated with different harvesting methods, and demonstrated that harvesting and site preparation produce only short-term impacts when carefully executed. Knowledge of relative impacts from different forestry practices, coupled with the conclusion that, in general, small watersheds responded in similar ways across the Interior Highlands, have been the basis for forest planning across the region. Research has directly addressed public concern about acid rain, demonstrating that it does occur over the Interior Highlands, but also showing that at present rates, acid rain does not cause excessive nutrients leaching from forested watersheds. Concern about road erosion rates has also been investigated, with research showing that, while certainly deserving of concern, road erosion rates were much less than predicted.

Much has been learned over the past 70 years about the soil and water resources in the forests of the Interior Highlands and how these resources respond to different forestry practices. Scientists have been challenged not only by the varied and dynamic landscape of the region but also by the changing opinions and desires of forest managers and the public. While such challenges are not unique to the Interior Highlands, the degree of advocacy by and interactions between interests groups has been particularly energetic here. In meeting these challenges, scientists have relied heavily on experimental forests as locations for observing how soil and water resources are constructed and how they work, and for manipulating the environment so that their reactions can be assessed. Unlike many other regions, no one experimental forest has served as the primary focus of research activity; rather a number of both permanent and temporary experimental forests have been used. Each has served its purpose to varying degrees. What seems certain is that experimental forests will continue to play a vital role in future watershed studies as scientists continue to build upon and add to this rich legacy of research in the Interior Highlands.

While much has been learned, there remains still more to do. The need for basic scientific investigations into how natural processes occur, operate, and interact will continue, as new understanding inevitably leads to new questions about how the parts work. Such work will logically produce better tools for predicting specific process rates like streamflow and road erosion. However, we think that research into how watershed components and processes interact at larger scales, and predicting their responses given multiple disturbances and condition states over time and space, will grow in importance in the decades to come. This need will be driven both by the desire for sustainable production of forest ecosystem services (e.g., wood products, clean air and water, recreation) and by the desire to restore altered or degraded ecosystems. This research frontier will likely demand new approaches and new concepts to deal with the multiple factors, states, and nonlinear dynamics that watershed systems exhibit. It will need new qualitative and quantitative models to better assess and integrate the critical interrelationships between variables, and increased use of spatial analysis methods and geographic information systems to investigate hydrologic responses at larger scales. However, it will also require continued use of experimental forests to investigate these questions and supply the needed answers.

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