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Chapter *8*

LONG-TERM ECOLOGICAL RESEARCH: COWEETA HISTORY AND PERSPECTIVES

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INTRODUCTION

The Coweeta Hydrologic Laboratory-Institute of Ecology cooperative research program is one of the longest continuous collaborations on forest-ecosystem structure and function between a federal agency and academia in the country. Formally established in 1968, the program continues to mature in scientific scope, interdisciplinary expertise, administrative challenges, and relevance for natural resource and environmental management.

Our objectives in this chapter are to (1) provide a historical context that summarizes the maturation in research philosophy of the long-term research program at Coweeta, and identifies the people who led the effort; (2) discuss the benefits and contributions of the collaboration with regard to education and training; (3) and, based on these lessons, suggest some of the ingredients required to sustain successful long-term ecosystem research into the future. We are frequently asked what is "long-term" research: we consider the minimum window of investigation for forest ecosystems to include the life span of the forest of interest. This time frame usually encompasses at least one generation of scientists and frequently two or more generations.

HISTORY

Forest Service Program (The Early Years: 1934-1970)

Coweeta Hydrologic Laboratory was formally established in 1934 and, as noted by Eugene P. Odum (1988), represents the longest continuous environmental study on any landscape in North America. The first three decades of hydrologic research provided a solid foundation for the subsequent three decades of ecosystem investigation coordinated with the Institute of Ecology. Douglass and Hoover (1988) provide a detailed history of Coweeta; thus, we will only briefly summarize the earlier years here.

Charles R. Hursh, an ecologist, was hired by the Forest Service in 1926 to begin research in forest influences at the appalachian forest experiment station (later the Southeastern Forest Experiment Station and currently the Southern Research Station). Hursh (Fig. 8-1) was the principal individual responsible for the selection of the Coweeta basin as a research site and for initial development of the research program. His analysis of erosion, runoff, and soil processes (Hursh et al., 1931; Hursh, 1932; Hursh and Brater, 1941), combined with exceptionally keen scientific insights and dialogue with leading natural resource scientists across the country, formed Hursh's philosophy for research at Coweeta. Even in the early 1930s, he recognized the need for interdisciplinary science to address complex

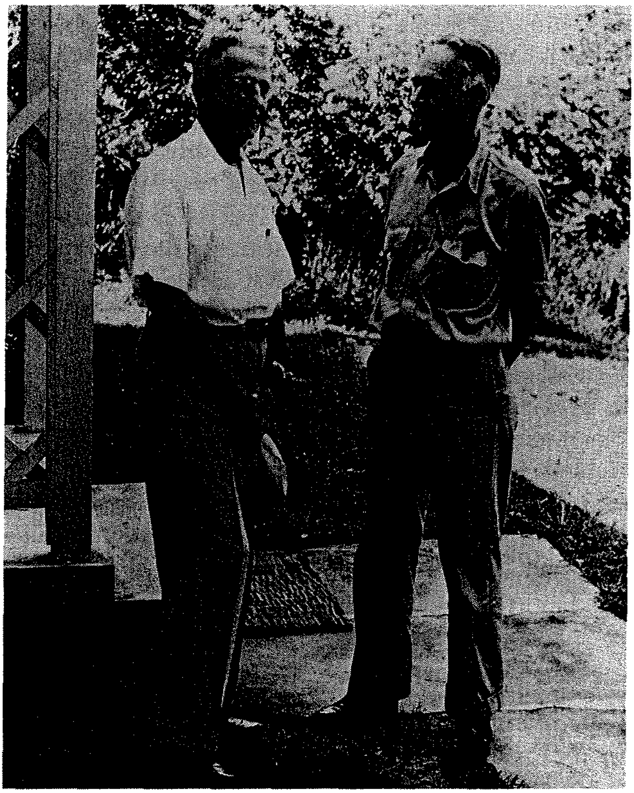

Figure 8-1. C. R. Hursh (left) selected Coweeta as a research site and was the principal architect in development of the early forest hydrology program. His extraordinary scientific insights and sound philosophy were shared and enhanced through frequent discussions with leading scientists such as P. J. Kramer (right) of Duke University (USDA Forest Service 1950, Coweeta Files).

resource problems but also recognized that, at the time, it was impractical to address all of the many factors at once (Douglass and Hoover, 1988). Instead, Hursh decided to focus on one factor that he considered as fundamental and basic — the hydrologic cycle. The conceptual model (Fig. 8-2) proposed by Hursh was the template for the research program over many decades; in fact, it is still valid today. He envisioned studying stream discharge characteristics on individual watersheds in combination with detailed information on climate, vegetation, and soils. Vegetation manipulation or management was envisioned, but only after a period of "standardization" (Fig. 8-2) or pretreatment calibration.

Hursh began implementing the program in 1932, which coincided with the establishment of the Public Works Administration, subsequently expanded to the Civilian Conservation Corps. Skilled men, from rock masons to engineers, were available during the depression years; their products are still visible and used throughout the country, particularly at Coweeta. By summer of 1936, their efforts had established 19 km of roads, 38 km of trails, 16 stream gages (Fig. 8-3), groundwater wells, buildings in the administrative area (Fig. 8-4), and ten weather stations (Douglass and Hoover, 1988). By 1939, 25 weirs were in operation, and this was increased to 30 by 1943. Data were collected for only a short time on many of the larger multiple watersheds because of maintenance requirements, while other gaging sites were discontinued after study objectives were achieved. The most recent weir installation was constructed in 1981. Today there are 17 active, permanent stream-gaging sites at Coweeta.

By 1939, sufficient records were available to begin watershed-scale vegetation manipulation and land-use experiments. Over the next four years, seven treatments were applied to elucidate the regulatory effects of forest vegetation on the hydrologic cycle and to demonstrate the impacts of typical land-use practices on water and soil resources. However, by the end of 1942, World War II had virtually eliminated the work power and supplies at Coweeta. Only through the personal efforts of Marvin Hoover (Fig. 8-5), resident superintendent and scientist at Coweeta, and the hard work provided by local residents, were the essential records and treatments maintained. This herculean feat provided the data for publications that soon followed, which established the credibility of Forest Service hydrology research throughout the world (Douglass and Hoover, 1988).

Following World War II, the original watershed experiments were continued and a variety of new vegetation manipulations were initiated to further explore the regulatory effects of forests on stream

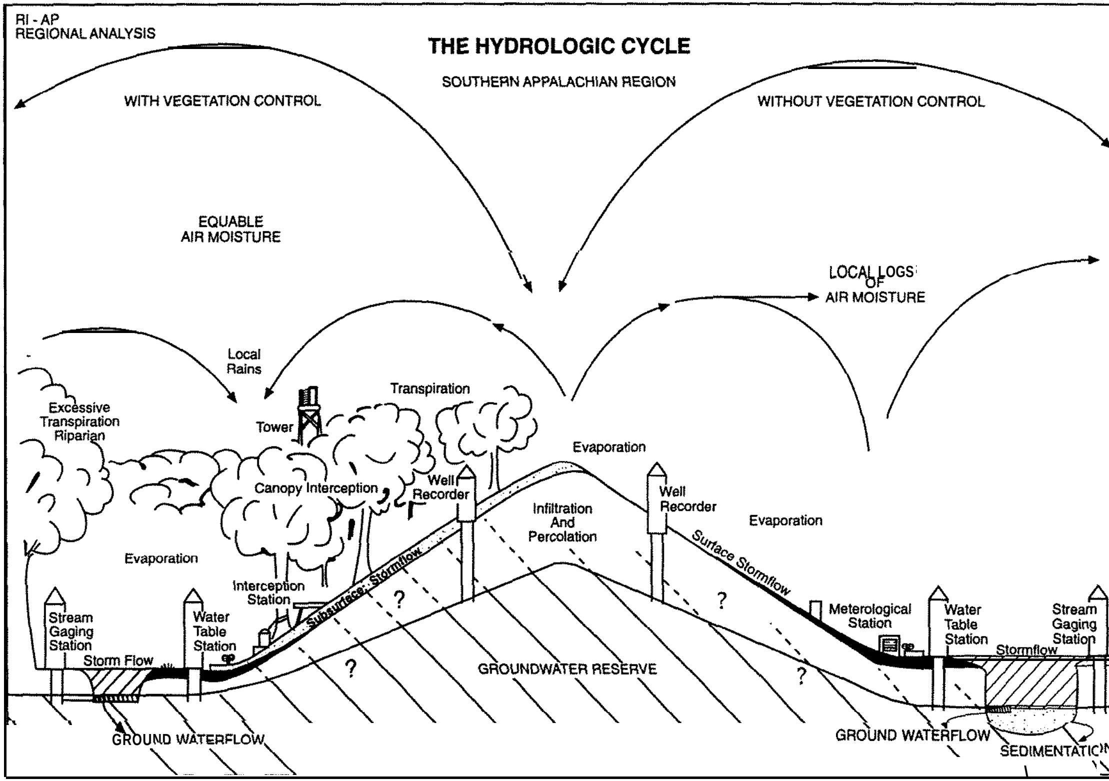

Figure 8-2. The conceptional diagram, in the original form, of the hydrologic cycle proposed by C. R. Hursh in 1938 (USDA Forest Service, Coweeta Files.).

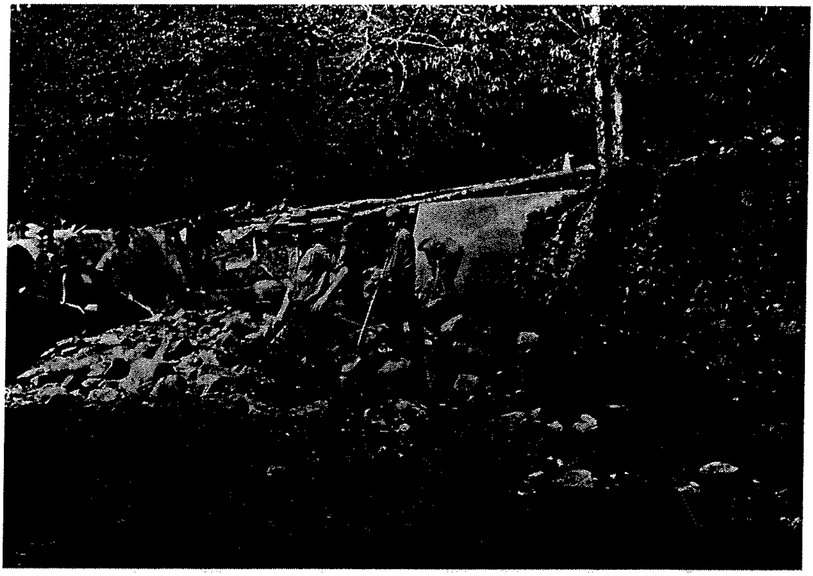

Figure 8-3. Many of the weirs at Coweeta were constructed during the period of Public Works Programs. The above view is looking downstream on Weir #9 on Ball Creek during the construction phase by a CCC crew in 1934 (USDA Forest Service, Coweeta Files).

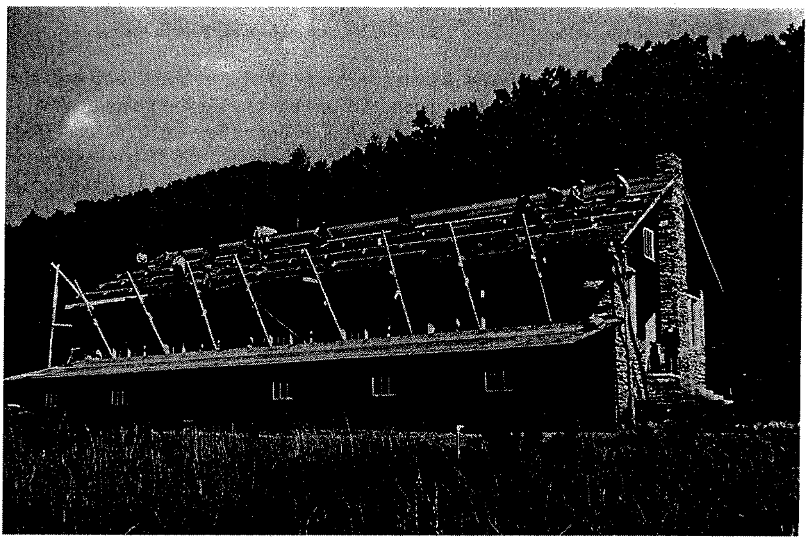

Figure 8-4. CCC personnel constructed numerous buildings at Coweeta including a machine shop, shown above, which is still in use as a shop and instrument repair facility (USDA Forest Service, Coweeta Files).

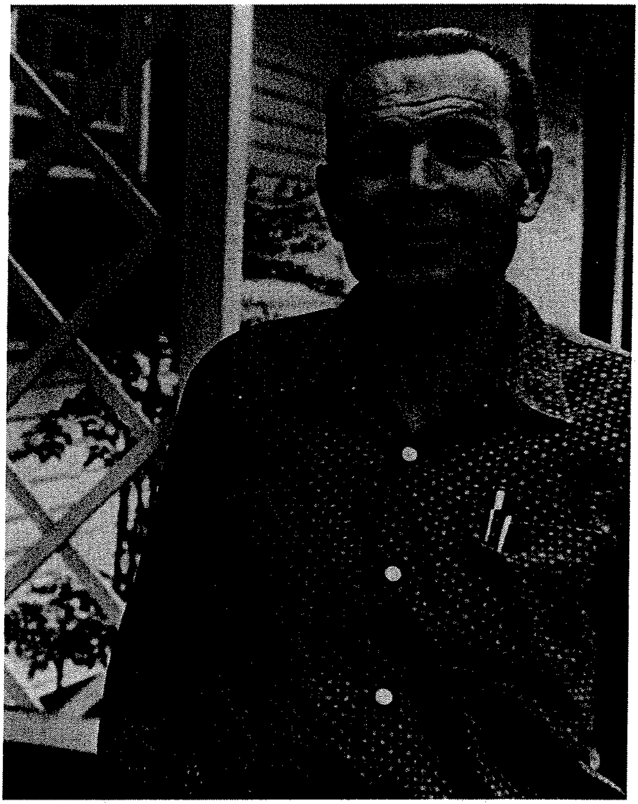

Figure 8-5. Marvin Hoover, with assistance from local residents, ensured the continuation of vital records and treatments at Coweeta during the years of WW II when men and supplies were severely reduced (USDA Forest Service, Coweeta Files).

flow. Experiments included removal of under-story shrubs, a test of narrow-strip clearcuts, selection cutting, conversions from hardwood to white pine, and forest to grass cover. By the mid 1950s, 14 experiments had been implemented and numerous visitors came to Coweeta for training on fundamentals of watershed management.

During the ensuing decade, research emphasis shifted from land management demonstrations to hydrologic processes, but the experimental watershed was still the basic tool for investigation. To provide better quantitative predictions of responses in water yield and quality, J. D. Hewlett (Fig. 8-6) organized the program to address basic research questions on plant water, soil water, stream flow, and atmospheric relations. This was a fulfillment of Hursh's original plan for forest hydrology research at Coweeta. Through the 1960s,

Figure 8-6. Kneeling (left to right), L. Metz and D. E. Whelan; standing (left to right), H. G. Meginnis, J. E. Douglass, L. W. Swift, Jr. and J. D. Hewlett. Douglass and Hewlett played key roles in programmatic development of hydrologic research at Coweeta; Swift has contributed to the research program since 1958. Others in this photograph had administrative or research roles at the Station. Photograph taken in 1959 at Union S.C. (USDA, Forest Service, Coweeta Files).

advances in scientific understanding of hydrologic processes were achieved through studies by Hewlett, J. E. Douglass, L. W. Swift, Jr. (Fig. 8-6), A. R. Hibbert, J. D. Helvey, J. H. Patric, and W. T. Swank. During this same period, the Accelerated Public Works program provided the first new funding in twenty years to implement three additional watershed treatments and to construct several new buildings and renovate existing structures. However, financial support for the scientific infrastructure remained constant and, with inflation, funds for the scientific staff were depleted. In fact, during the early 1970s there were only two (some years only one) Forest Service scientists at Coweeta. Fortunately, at the same time, the foundation for a brighter scientific future was being developed through the formal initiation of cooperative ecosystem research between the Forest Service and the Institute of Ecology. This collaboration gradually enhanced in-house support and eventually in the mid 1980s, in concert with emerging national environmental issues, such as acid precipitation and non-point source pollution, Forest Service funding increased. The current Forest Service staff includes six scientists.

Institute of Ecology/Forest Service Program (The Latter Years: 1970–Present)

The first thirty years of land-use and hydrologic research at Coweeta provided a firm base for forest ecosystem studies at the watershed scale. The chronology of Institute of Ecology and Forest Service collaboration is outlined in Table 8-1. In the late 1960s, Eugene P. Odum had two graduate students who conducted their research on small mammal abundance (Gentry et al., 1968) and bird species diversity (Tramer, 1969) on disturbed and undisturbed watersheds in the Coweeta basin. At about the same time, Philip Johnson joined the faculty at the University of Georgia and, in collaboration with Forest Service scientists, developed a proposal to the National Science Foundation (NSF) for productivity and mineral cycling research at Coweeta. This proposal was funded in 1968, and studies were initiated on four watersheds: an undisturbed or reference mixed hardwood forest (WS 18), a seven-year-old coppice hardwood forest following clear cutting (WS 13), a thirteen-year-old white pine

Table 8-1. Chronology of Coweeta Ecosystem Research

Research Theme	Years	Principal Investigators
Productivity and mineral cycling of natural and manipulated watersheds	1968-1971	P. L. Johnson; D. A. Crossley, Jr.; W. T. Swank
EDFB-IBP: Extension of nutrient budget studies to all watersheds; intensive studies of internal processes on two WS	1971-1977	D. A. Crossley, Jr.; C. D. Monk; R. L. Todd; W. T. Swank
Effects of perturbation on nutrient circulation in forested watershed ecosystems at Coweeta	1974-1979	D. A. Crossley, Jr.; W. T. Swank
LTER Program: Long-term ecological research in forested watershed at Coweeta	1980-1990	D. A. Crossley, Jr.; W. T. Swank
LTER Program: Long-term studies of ecosystem response to disturbance along environmental gradients at CHLx	1990-1996	J. L. Meyer; W. T. Swank
LTER Program: Long-term studies of disturbances as they affect ecological processes in landscapes of the southern Appalachians	1996–	D. C. Coleman; J. M. Vose

plantation (WS 17), and an old-field to forest succession treatment. W. T. Swank was appointed as the Forest Service investigator to coordinate activities with University staff; midway through the grant period D. A. Crossley, Jr., (Table 8-1) replaced Johnson who took a position with NSF. The initial grant required the development of an analytical laboratory at Coweeta for water, soil, and plant analyses. J. E. Douglass, project leader at Coweeta, was the driving force in the development of the lab facility and initiation of analyses. Protocols were developed and tested for the collection and processing of stream and precipitation samples, and input-output budgets of base cations were emphasized in this first grant (Johnson and Swank, 1973). Measurements of net primary production of vegetation were also initiated for some of the contrasting catchments (Swank and Schreuder, 1973; Day and Monk, 1974), and studies on terrestrial and aquatic insects were initiated (Coulson et al., 1971; Woodall and Wallace, 1972).

The initial studies were broadened as Coweeta became part of the Eastern Deciduous Forest Biome (EDFB) of the US International Biological Program (Table 8-1) funded by NSF. Swank continued as a coprincipal investigator, and Institute leadership alternated among C. D. Monk, D. A. Crossley, and R. L Todd. The breadth of interdisciplinary expertise increased, nutrient budget studies expanded to 16 watersheds in the basin (Swank and Douglass, 1975), and process level studies on the four watersheds were substantially expanded (Cromack et al., 1975; Webster, 1977; Wallace et al., 1977; Waide and Swank, 1977). EDFB provided the opportunity for cross-site interdisciplinary studies and offered new challenges in conducting complex ecological research; Coweeta investigators provided scientific leadership to the effort. Programmatic and scientific lessons (positive and negative) learned from the biome-oriented EDFB program were valuable training for investigators involved in programs that were to emerge during the next decade.

As IBP research was being completed, the Coweeta ecosystem team saw the need to examine more rigorously ecosystem structure and function from a nutrient cycling perspective. A proposal to study the effects of ecosystem perturbation on nutrient circulation in forested watershed ecosystems at Coweeta was submitted to NSF and funded in 1974 with Crossley and Swank as principal investigators (Fig. 8-7). Previous research at Coweeta had been conducted on watersheds that had been disturbed seven to thirteen years prior to nutrient cycling studies. Thus, pretreatment and early response data were lacking along with associated process-level data on mechanisms responsible for ecological responses. Moreover, this experiment offered basic ecological research opportunities in a context that was relevant to forest managers. A 59-ha, south-facing watershed (WS 7) was selected for a commercial clearcut, cable-logging treatment. Following two years of pretreatment study, the management prescription was implemented in 1977. The experiment demanded coordinating both science and management activities because 8 km of new roads were constructed by the National Forest System and cable-logging technology had to be introduced to the region. The study included both practical questions on forest resource management and fundamental hypotheses on hydrologic and ecological processes generated by previous ecosystem research at Coweeta. The transfer of findings to management was immediate; within two years, cable logging was required when harvesting National Forest timber on steep slopes based on environmental and economic results from the WS 7 study. The ecosystem investigation on WS 7 has continued for twenty years during the successional recovery phase and is the most intensively studied catchment in the southern Appalachians. A synthesis of results is currently in progress.

The decade of the 1980s ushered in a new era of ecological research with the establishment of the Long-Term Ecological Research (LTER) network funded by NSF. Much earlier, science administrators and investigators convened numerous meetings to discuss the development of a framework to provide dependable, stable resources to support long-term ecological research. These efforts resulted in Congress funding a new program at NSF expressly for long-term ecological research (Callahan, 1984). The first six research sites (including Coweeta) were funded in 1980. Many Institute of Ecology investigators helped forge the LTER program including F. B. Golley, who was division director for biological, behavioral, and social sciences at NSF during the implementation phase of LTER, and W. T. Swank, who was program director for ecosystem studies at NSF during the latter stages of LTER program development.

The first ten years (1980–1990) of LTER research at Coweeta (Table 8-1) continued to focus on long-term recovery from natural and anthropogenic disturbances on reference and managed watersheds in the basin. Emphasis was placed on continuing process-level research on clearcut, cable-logged WS 7 (Boring et al., 1988; Waide et al., 1988; Webster et al., 1988; Meyer et al., 1988; Schowalter and Crossley, 1988); maintenance of the long-term precipitation and stream-chemistry studies on 13 watersheds and associated interpretations for the emerging issue of acid deposition (Swank and Waide, 1988; Swank, 1988); and documentation of responses to insert defoliation of hardwood forests (Swank et al., 1981) and to a record drought in 1985-1989 (Clinton et al., 1993).

A milestone in the Coweeta program was reached in 1984, the fiftieth anniversary of research at the laboratory. We commemorated the event with a three-day symposium at the University of Georgia to summarize and highlight major contributions from Coweeta to hydrologic and ecological understanding of southern Appalachian forested lands (Swank and Crossley, 1988), preceded by an open house and tours of the laboratory. These events were well attended by active Forest Service and Institute staff, retirees, other Coweeta alumni including former scientists and graduate students, former employees of the Public Works Programs of the 1930s, and special invited speakers and guests.

In 1991, we expanded the perspective of the LTER program from a watershed to the landscape scale. The university leadership was transferred from D. A. Crossley to J. L. Meyer (Fig. 8-7), and Swank continued as the Forest Service PI. The research theme was long-term studies of ecosystem response to disturbance along environmental gradients in the basin in combination with experimental manipulation (Table 8-1). Posits for ecosystem responses to disturbance along gradients were organized into three subthemes: (1) relationship of changes in forest structure and processes to disturbance and stress along the gradient; (2) longitudinal patterns

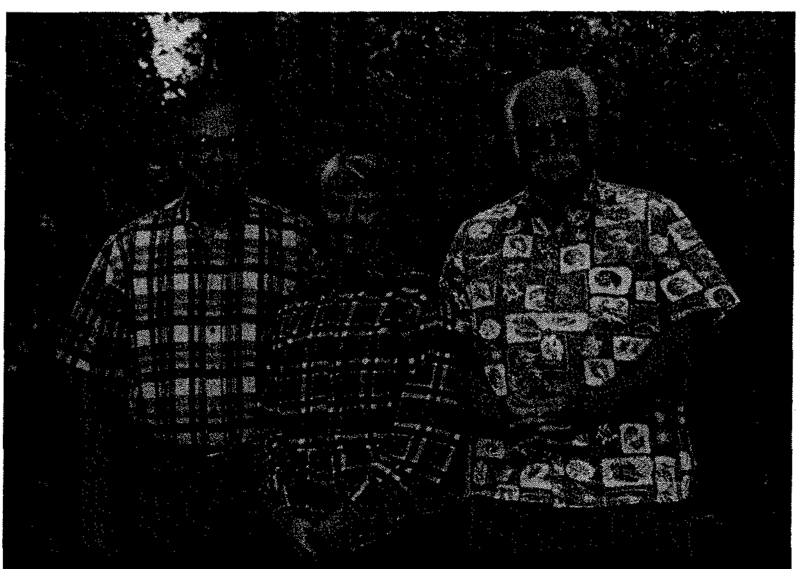

Figure 8-7. W. T. Swank, J. L. Meyer, and D. A. Crossley, Jr. (left to right) served a combined 59 years as principal investigators for the Ecosystem and Long-Term Research Program at Coweeta from 1968-1996 (University of Georgia, Institute of Ecology).

of ecosystems processes in streams controlled by changes in geomorphology and patch frequency; and (3) the riparian zone as the regulator of terrestrial-aquatic linkages.

Then, in 1994, the Coweeta LTER program was funded by NSF to develop a predictive understanding of the social, economic, and environmental factors that drive land cover change in the southern Appalachians and to investigate the ecological consequences of those changes for regional carbon cycles and for terrestrial and aquatic biodiversity. This programmatic addition greatly increased the spatial scale of research to include the southern Appalachian region. It also broadened the interdisciplinary scope of effort with the addition of social and economic scientists.

We have continued the themes of disturbance, ecological processes, and landscape and regional analysis in the present grant period which began in 1996 (Table S-1). The Institute PI leadership was transferred from J. L. Meyer to D. C. Coleman and for the Forest Service, from W. T. Swank to J. M. Vose. The present LTER program at Coweeta includes 30 co-principal investigators from eight different institutions, over 30 graduate students, and 6 support/ technical staff.

In summary, the long-term research program at Coweeta represents a continuum of theory, experimentation, and application using watersheds as landscape units for study with recent expansion to regional-scale analysis. Response to disturbance, both natural and human caused, has been a central theme and research tool for interpreting ecosystem behavior. We have consistently attempted to integrate individual research efforts into a holistic concept of watershed response. Moreover, we believe the evaluation of landscape management practices and natural phenomena, in the context of basic scientific inquiry into ecosystem structure and function, is one of the major benefits derived from research embodied in the Forest Service-Institute of Ecology cooperative program. The programmatic, scientific, and beneficial aspects of the program continue to mature; annual support from NSF has increased from $40,000 in the first grant to $1 million at present, and over 1,000 publications have been produced since the laboratory was established (Stickney et al., 1994). The maturation process is characterized by substantial enhancement and broadening of interdisciplinary expertise, scale of investigation, nature of intersite cooperation, development of support infrastructure, and relevance of science to society. More than 1,400 visitors, representing a variety of user groups, tour the laboratory each year. The long-term investigations at Coweeta continue to provide information needed to define and interpret critical environmental issues. The years ahead should be even more exciting; in the next sections, we provide some thoughts on the role of graduate education in long-term research programs and some lessons learned in sustaining such programs.

Graduate Education and Training in Long-Tern Research

One of the most significant aspects of long-term research programs at the Institute of Ecology has been their role in graduate education. Graduate students from UGA and other institutions have been an integral part of the research programs at long-term research sites like Coweeta.

A graduate student derives many benefits from being associated with a long-term research site; here we discuss six:

(1) Research at field sites often entails spending time in a communal living situation with other graduate students working at the site. Cooking, eating, and sleeping in group field facilities builds a network of colleagues that extends beyond the institution where the student is studying. At Coweeta, students from the University of Georgia live in a dorm (during the 1960s and 1970s it was a trailer) with students from Virginia Tech, Duke University, University of Minnesota, Clemson University, University of Wisconsin, and numerous other institutions. This offers the student a valuable perspective on how things are done elsewhere. Older students teach younger students about ecology and the conduct of ecological research; both are enriched in the process. Students learn about research in fields other than their own immediate specialty. They learn different ways of asking scientific questions, alternative ways of organizing data, and new ways of coordinating fieldwork. Opportunities are available for developing collaborative research projects. This is valuable training for future scientific research.

(2) A shared place of research, like a stream or watershed at Coweeta, allows the student to become a part of a scientific network of people that extends beyond the individual's time at his/her university. It provides a connection with students who worked at that site years or even decades before and those who will work at the site in the future.

(3) Doing research at a site with collaborators from many different subdisciplines in ecology offers students exposure to ideas from other disciplines and to new ideas or questions within their own discipline. Interacting with Forest Service scientists

provides a management perspective not usually available on campus.

(4) Doing research at a site with a long-term research mission provides students the opportunity to consider their work in a broader perspective. Students can put a three-year dissertation study into a longer-term context (e.g., Meyer and Likens, 1979) or use data that others collected at previous times or for other purposes to make their own study more valuable. For example, Grubaugh et al. (1996) combined the data he collected at seven streams sites with data collected at four other sites by two previous students to examine ecosystem trends along a 65-km stream gradient. John Blair was able to analyze changes in decomposition rates, nutrient dynamics and microarthropod populations in a clear-cut watershed over an eight-year period, illustrating slow recoveries of these processes (Blair and Crossley, 1988). Sankovski 09941 used a fifty-year record of vegetation data at Coweeta to compare diversity and structure of southern Appalachian and Caucasus forests in Russia with respect to historical events and present environment.

(5) Doing research at a Long-Term Ecological Research (LTER) site provides a student with connections to a broader network of research sites, and opportunities for comparative ecological research early in their career. Many of Coweeta's graduate students have used this opportunity; they have compared nutrient dynamics in southern Appalachian and Cascade mountain streams (Munn and Meyer, 1990) and have examined sulfur dynamics in soils of different geological origins and in settings with different rates of sulfur deposition (Watwood et al., 1994; Dail, 1997). It is important to the science of ecology that students are educated in the use of a comparative approach and are encouraged to see if ideas developed in one region apply in other ecosystems. Research at sites such as Coweeta, that are a part of a larger network of sites, encourages that kind of education.

(6) Doing research at long-term research sites often provides funding opportunities that normally would not be available. Long-term research sites, such as Coweeta, are to the discipline of ecology what telescopes are to astronomy, or what ships are to oceanographic research (i.e., they provide a unique opportunity to do ecological research and to train future ecologists). Several graduate students trained at Coweeta are now leaders at other LTER sites and in other large ecosystem research programs.

Having discussed the benefits, we also need to consider any disadvantages in being a graduate student associated with such a program. If the site is far from campus and the student spends several semesters off campus, a sense of distance from the institution can develop. In addition, the student would miss the intellectual stimulation of frequent seminars and have fewer opportunities to gain teaching experience. These disadvantages have rarely been encountered at Coweeta because it is only a few hours drive from the campus of most participating academic institutions.

Graduate students can make a tremendous contribution to the research productivity of a long-term research site. At Coweeta our graduate students have been one of our greatest strengths. Significant advances in our understanding of ecosystems have been made by graduate students.

Coweeta has been one of several research sites that have provided research opportunities for students in the ecology PhD program at the University of Georgia. Ecology program records reveal that each of the eight research sites affiliated with or administrated by the Institute of Ecology produced at least four PhDs to the ecology program: Coweeta, Savannah River Ecology Lab, Marine Institute on Sapelo Island, Okefenokee Swamp, Horseshoe Bend, Ogeechee River and Little River (Tifton) (Table 8-2). These research sites are a crucial part of the graduate education program at the Institute. Before 1977, 75 percent of the 32 ecology PhDs did their research at one of these eight sites; from 1977 through 1996, 63 percent of the 167 ecology graduates conducted their research at one of these sites. These numbers do not include the graduate students from programs other than the UGA ecology PhD program who did their research at those sites. The relative importance of each of the eight programs has changed over the years (Fig. S-8). For example, Coweeta, Sapelo, and Savannah River Ecology Lab were

Table 8-2. Number of Ecology PhD dissertations earned from 1977-1996 based on research done at eight satellite research sites that have been the sites of most graduate student research. Data are from files of the Ecology PhD Degree Program

Research Site	**Number of PhD Dissertations**
Coweeta Hydrologic Lab	34
Savannah River Ecology Lab	23
Marine Institute, Sapelo Island	13
Okefenokee Swamp	12
Horseshoe Bend	10
Ogeechee River	5
Skidaway Institute of Oceanography	5
Little River (Tifton)	4

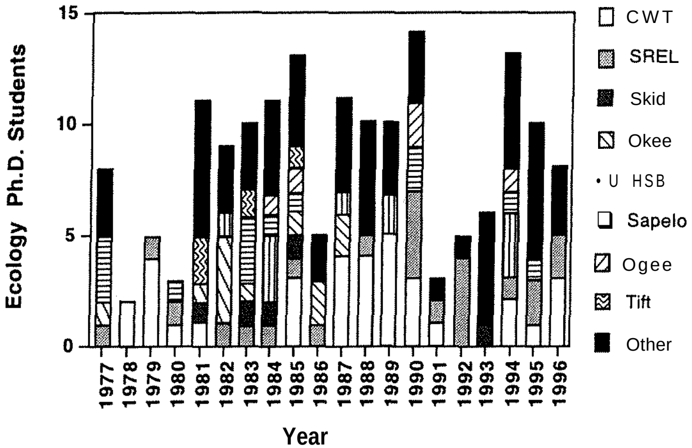

Figure 8-8. Number of students graduating each year from the Ecology PhD program after doing research at one of these sites: Coweeta Hydrologic Lab (CWT), Savannah River Ecology Lab (SREL), Skidaway Institute of Oceanography (Skid), Okefenokee Swamp (Okee), Horseshoe Bend (HSB), Marine Institute on Sapelo Island (Sapelo), Ogeechee River (Ogee), Little River at Tifton (Tift), and other sites.

major components of the graduate program before 1977, with ten, nine, and four ecology program PhDs based on research at the respective sites. During the next two decades, Coweeta and SREL continued to be major contributors to the program; a few students each year or one every couple of years have graduated after doing research at one of these sites (Fig. 8-8).

Long-term research sites such as Coweeta have not only been an important part of the graduate program of the Institute of Ecology, but the graduate students have been a crucial part of the research program at the site. Research progress at Coweeta would have been very different without the contribution of our students. From 1972-94, 36 PhD dissertations were based on research done at Coweeta by UGA students. Over the first 60 years of the lab (1934–1994), an additional 20 PhD dissertations were earned by students from 13 universities (Clemson, Duke, Emory, Georgia Tech, Michigan State, North Carolina State, Purdue, SUNY Syracuse, University of Michigan, University of Virginia, University of Washington, Virginia Tech, Yale) for research done at Coweeta.

One measure of the contribution of graduate students to the scientific program at the site is publications. Of the 465 papers published about Coweeta from 1977-1994, 27 percent had a UGA graduate student as a senior author, and an additional 9 percent had a UGA graduate student as one of the coauthors. The intellectual contribution of graduate students to the Coweeta research program has been considerable.

In summary, long-term research sites like Coweeta continue to be important in graduate education at the Institute of Ecology. The sites provide unique educational benefits to students, and the students have greatly contributed to advancing scientific understanding at the sites. Having Coweeta as a satellite in a network of research sites has greatly enhanced research and education at the Institute of Ecology.

Lessons Learned **for** *the Future*

Many factors are necessary to sustain long-term research; clearly, the foundation is productive, high quality, relevant science. The challenge is to maintain a high level of imagination, planning, and ideas that anticipate future issues. Perhaps an equally important factor is continuity and commitment of programmatic leadership and scientific collaborators. The administrative demands of large, complex programs involve numerous meetings, paperwork and coordination which are very time consuming. Thus, PI's must be willing to forego their own research and, at times, to make hard decisions concerning division of program resources. Additionally, several senior investigators such as J. B. Wallace, L. W, Swift, Jr., J. R. Webster, and B. L. Haines have been an integral part of the program for over two decades. This scientific continuity is essential for development of long-term data sets that can be used to interpret impacts of infrequent events on ecological processes and to develop realistic simulation models of complex systems. We have also found it critical to maintain a team spirit in ecosystem research and enthusiasm for achieving objectives; in short, the science should be fun.

Other critical attributes of long-term interdisciplinary research are mutual respect and trust among investigators, a willingness to compromise in difficult situations, and an open atmosphere for debate on scientific direction and other programmatic issues, The very nature of long-term research requires patience and persistence to address certain questions. For example, it requires decades to identify precipitation and stream chemistry trends or forest succession dynamics. Institutional encouragement and recognition of the value of long-term programs are important stimuli for progress. We have been fortunate to have support from the Forest Service, the National Science Foundation and the Institute of Ecology to keep the Coweeta program progressing over the past several decades.

We previously discussed the contributions of graduate students to long-term research. We also want to emphasize the importance of research support staff. A strength of the Coweeta program has always been highly competent, dedicated field and laboratory technicians, secretaries, and data processing/management personnel. These individuals are the fabric of, and provide the continuity for, any successful long-term research program. Some individuals have devoted their entire career to the program and provide valuable institutional memory in addition to their expertise. It is of paramount importance to maintain a strong support staff to fully succeed in long-term studies.

Valuable components of infrastructure are worth noting. We have found it extremely important to have an archive of historical records, preferably in a fire-resistant vault. We have frequently needed to reference details of watershed treatments, study plans, maps, photographs, the proceeding of meetings, and past land uses in order to plan experiments and interpret our results. Data archiving is an absolute necessity for both intra- and inter-site utilization. We sometimes retrieve archived plant, soil, or animal samples for subsequent analyses years after they were collected for the original objectives. Methods manuals, along with quality-assurance and quality-control protocols, are also essential in long-term research. We have also found it useful to maintain a complete file of all publications derived from research conducted at Coweeta along with an annotated bibliography (Stickney et al., 1994).

SYNOPSIS

Cooperation is clearly the essence of scientific success in long-term research projects such as Coweeta. The thirty-year history of the US Forest Service-University of Georgia cooperation at Coweeta has been successful by several standards. Our experience encourages us to offer several observations on the nature of our collaboration, and what we think to be the reasons for its success. A keystone has been mutual respect between Forest Service and University personnel, despite some difference in objectives. Modern ecology recognizes ecosystem management as an important bridge between basic and applied approaches. Students have been encouraged to follow a cooperative, rather than a competitive mode in their research activities, and this has been an important step toward their successes.

We are acutely aware of the dangers associated with increasing project size. We are still learning from *our* efforts of team research.

Internal communications require novel approaches as the project grows in size. Our hope is that the next generation of scientists on the Coweeta project are provided a sound basis of research protocols that serve as a springboard toward even better science.

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