Long-Term Ecological Research
in Forested Watersheds at Coweeta

Renewal Proposal Submitted to
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Biological Systems and Resources
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by

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PREFACE

This proposal for renewal of the Coweeta Long-Term Ecological Research program represents the efforts of sixteen co-principal investigators. Assembling a proposal of this magnitude within the length guidelines of the National Science Foundation (60 pages of text, 40 pages of appendices) was a major challenge. As reviewers, we applaud the efforts to keep proposals within readable lengths. In our case, to summarize 5 years of research and project 5 years into the future required brutal editing of progress reports contributed by the various PI's. We believe that this proposal contains the essence of our accomplishments and adequately explains our plans for the next 5 years. The ten-year period, the decade of the 80's, is an exciting one for ecological science. If our rate of progress continues, we anticipate that 1990 will be a time of reflection over a decade of major progress in long-term ecological research. I hope that this proposal successfully communicates our sense of accomplishment, and our excitement with the entire LTER effort.

The appendices of the proposal contain some abbreviated presentations as well. We have attempted to cite titles of publications only once. Titles given in the summary of the Coweeta Symposium Volume (Appendix I) are not duplicated in the list of Coweeta publications (Appendix II). Titles in neither of these appendices are duplicated in "Literature Cited". Reviewers seeking a citation may have to look in three places to find it, but we hope that this is a minor inconvenience for savings of space. Abbreviated Curriculum Vitae are provided for the current principal investigators; for recent publications, reference is again made to the appendices. More complete CV's are given for new principal investigators at Coweeta. We will gladly provide more complete CV's to the NSF office upon request. Only summary budgets are provided for the four subcontractors; complete subcontractor budget documents are provided separately to NSF.

Two other documents accompany our proposal: A recent Annotated Bibliography of Coweeta publications and a newly revised Guide to Coweeta Hydrologic Laboratory. We hope that they may prove helpful in evaluating our efforts.

Finally, I thank Jack B. Waide, and Lindsay Boring for their dedicated efforts in repeatedly reviewing the text of the proposal document. The entire document was herded to completion due to the valkyriean efforts of our multitalented data manager, Polly Casale. I am very grateful to all of them.

D.A. Crossley, Jr.

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I. RESEARCH APPROACH AND OBJECTIVES

Forest ecologists and others are concerned over the long-term future of forest ecosystems in the eastern United States (Bormann 1982a, 1982b, Postel 1984). The continuing wet and dry atmospheric deposition of air-borne chemicals (particularly H^+, SO_4^{2-}, NO_3^-) throughout the region may lead to long-term reductions in forest and aquatic productivity. Reductions may result both from direct impacts to sensitive species and from indirect effects brought about by alterations in forest nutrient cycles (Evans 1984, Johnson and Reuss 1984) and by substantial changes in forest stand structure. Similarly, gaseous pollutants (ozone, SO_2, NO_x) may reduce forest growth and alter species composition through impairment of physiological processes of sensitive tree species. Over the long term, impacts of gaseous pollutants may be more immediately deleterious and of greater initial concern than those of acid rain (Skarby and Sellden 1984), especially in southeastern forests.

Of equal concern to these air pollution impacts are the potential long-term effects of intensive forest management practices on forest productivity and structure (Johnson 1984, Kimmins 1977). Both empirical (e.g., Johnson et al. 1982) and simulation (e.g., Swank and Waide 1980) studies have shown that increases in the frequency and intensity of harvest may significantly reduce productivity over several rotations, especially when coupled with potentially damaging (in terms of site nutrient capital) site preparation techniques. The current challenge to ecosystem investigators is to understand forest ecosystem responses to these distinct yet simultaneously occurring anthropogenic stresses, and to discriminate between (1) forest response to human intervention and (2) natural ecosystem dynamics and responses to climatic changes and episodic events at various scales of space and time.

Meeting this challenge is extremely difficult. Among the factors which complicate understanding forest ecosystem response to human stress, and discrimination between stress response and natural dynamics, are the following: (1) dynamics of undisturbed ecosystems at broad scales of space and time are poorly understood ; (2) time histories of anthropogenic impacts on forest ecosystems are incompletely known;(3) data bases on ecosystem processes and dynamics, in pristine and impacted environments, usually do not span a sufficient time period to allow separation of temporal trends from short-term variability; (4) case studies of ecosystem responses to specific planned experiments and accidental human interventions are few in number and short in duration; (5) processes regulating both natural ecosystem dynamics across scales of space and time and system responses to specific disturbances are poorly quantified and frequently also poorly understood; and (6) anthropogenic impacts on ecosystems are confounded not only with natural episodic events and climatic changes but also with one another. Moreover, impacts are related in complex fashion to ecosystem-level response, which is not predictable from direct experimentation on ecosystem components.

In our initial LTER proposal for continuing ecosystem research at Coweeta, we outlined three broad research objectives directly related to concerns summarized above: (1) to develop data bases which will allow detection of accumulations of toxic substances within Southern Appalachian forests; (2) to develop data bases which will allow evaluation of long-term anthropogenic influences (regional industrialization, forest management) on southeastern forests; and (3) to increase our understanding of ecosystem dynamics and regulatory processes at broader scales of space and time than had been the case in earlier periods of NSF funding. The basic premise underpinning these objectives was quite simple: until we have a better underdstanding of natural ecosystem dynamics and processes regulating them across scales of space and time, we cannot hope to understand ecosystem responses to anthropogenic impacts.

The Coweeta Basin represents an excellent area for pursuing studies related to these objectives. Coweeta forests, which span a broad range of environmental conditions, are undergoing successional dynamics in response to historical logging practices and to the 1930's demise of American chestnut as the dominant tree species in the Basin. Forested watersheds are in various stages of successional recovery from past landscape-scale experiments, which are generally representative of regionally important land-use and forest management practices. Areas for future landscape-scale manipulation exist within the Basin. Although the Coweeta Basin is relatively pristine and remote from major industrial sites, it is modestly impacted by regional air pollution problems including atmospheric deposition of air-borne chemicals (Swank and Waide 1985), episodic occurrences of photochemical oxidants (Haines and Swank 1985), and low-level trace metal loadings (Ragsdale and Berish 1985). Because of anticipated future increases in regional industrialization, these impacts are expected to increase over time. Thus, ingredients required to understand anthropogenic impacts on forests, in the context of natural ecosystem dynamics across scales of space and time, are present in the Basin. Additionally, the existence of extensive, long-term data bases on forest hydrology, meteorology, composition, biogeochemistry, and productivity enhance our ability to utilize these ingredients to realize successfully our stated objectives.

The specific research projects which have been conducted at Coweeta--historically and under LTER funding--have followed logically from research objectives and unique site characteristics enumerated above. Specifically, research has been formulated: (1) to document human impacts--land-use and forest management practices, regional air pollution--on Southern Appalachian forests; (2) to document system-level responses to landscape-scale experiments; (3) to document system recovery from experimental manipulations; and (4) to explain measured system-level responses by focusing intensive research projects on hydrologic, demographic, physiological, and biogeochemical processes which regulate observed system-level behaviors. It has been the joint focus on watershed- and process-level research which has characterized our research philosophy and approaches over the past two decades.

During the initial 5-year period of LTER research at Coweeta, we made substantial progress in realizing our research objectives summarized above. This progress was documented in papers presented at the recent Fiftieth Anniversary Symposium on Long-Term Ecological Research on Forested Watersheds at Coweeta (held October 1984 at University of Georgia), and is briefly summarized by area of research in the second section of this proposal. Because of this progress, our overall research objectives and philosophy in proposing another five years of LTER ecosystem research remain essentially unaltered. We seek to continue the long-term research program on forested watershed ecosystems which has been in progress continously since it was initiated under NSF funding in 1968. We will continue to document present and future anthropogenic impacts on Coweeta forests, as well as to study forest ecosystem response to such impacts. We will continue to focus on critical process-level studies as a means of explaining and understanding ecosystem-level dynamics. And we will continue to examine ecosystem recovery from earlier landscape-scale experimental manipulations. Although our basic research objectives and philosophy have not changed, our research program has evolved as our knowledge of forest ecosystem processes and dynamics has increased.

The specific studies we seek to conduct in this second 5-year period are described in detail in the second section of this proposal. Many of these studies reflect the continuation of work initiated under our initial LTER grant. We will measure long-term trends in climatology/hydrometeorology, and in precipitation and stream chemistry. Continuous studies since 1968 have revealed recent shifts in stream chemistry in response to atmospheric deposition, so that we will begin to examine soil-mediated processes which regulate observed stream chemistry responses. We will also proceed with our integrated study of forest recovery following clearcutting on WS 7. We will integrate our work on vegetation dynamics and litter-soil nutrient cycling processes. We will expand our sampling of air quality and of trace metal inputs and burdens in Coweeta forests. In another major area, we will continue our long-standing studies of the functional roles of previously-identified canopy arthropod guilds. This data base is essential in interpreting long-term dynamics (e.g., episodic outbreaks) of canopy consumers in an ecosystem context, and may also prove invaluable in relation to the predicted arrival of the gypsy moth in southeastern hardwood forests within the next five-year period. Finally, in our integrated studies of headwater stream ecosystems at Coweeta, we will expand our emphasis on allochthonous inputs to streams, leaf breakdown and seston transport, DOC dynamics, standing crops and metabolism of bacteria associated with stream sediments, benthic invertebrate composition and productivity, and pools of organic matter in stream channels. These studies will be conducted in a variety of streams draining both reference and manipulated watersheds.

In addition to these studies, we propose several new projects in critical areas. One major project will employ methods of tree ring analysis to examine dendroecological patterns and processes on a Basin-wide basis. This study will build upon limited data from several previous studies and will provide essential information for interpreting vegetation patterns and long-term trends in the Basin. A second important new area of LTER emphasis involves studies of those physical processes which regulate water and nutrient transport through Coweeta soils on a watershed basis. This work will build upon important historical research and data bases at Coweeta. In a third area, we focus on studies of geochemical mass balances of control and manipulated watersheds. This work will build upon recent Coweeta research funded by non-LTER sources. Finally, in the stream area, we propose several new projects dealing with streambed geomorphology, debris dams within headwater streams, and DOC and nutrient uptake rates within streams.

The next 5-year period also represents an important period of research synthesis and integration. A number of long-term studies and experiments have led to enhanced understanding of forest and stream ecosystem dynamics and processes. This understanding will be synthesized in the form of both conceptual and quantitative models. Thus, we will pay major attention in the upcoming five years to the integration and synthesis of existing data sets on both a process- and a system-level basis. The proposed role of modeling in our continuing ecosystem research at Coweeta has been expanded to facilitate and enhance this synthesis effort.

In summary, we feel that our initial LTER research approach and objectives were sound, and we do not propose major revisions in the upcoming 5-year period. However, specific research projects have evolved and our understanding of ecosystem dynamics and processes has increased. Finally, the critical importance of continuing long-term research on natural and manipulated forest ecosystems at Coweeta must be stressed. A number of our long-term data sets—particularly those dealing with climatology and hydrometeorology, precipitation and stream chemistry, trace metal loadings and burdens, vegetation dynamics and biogeochemical processes in successional forests, stream biota and processes, and canopy arthropods—represent unique time histories of ecosystem dynamics and processes which are available for few other sites. Only by continuing such studies over the long-term can we hope to understand natural ecosystem dynamics and processes regulating them across scales of space and time, and to evaluate responses of forest ecosystems to diverse yet simultaneously occurring anthropogenic stresses.

II. RESEARCH PROGRESS AND CONTINUATION

In this section we summarize our research progress for the initial five-year period and discuss briefly the work to be conducted in the upcoming five years. Discussions are organized by area of research emphasis.

One important accomplishment not documented in the following pages is the recent Fiftieth Anniversary Symposium on Long-Term Research on Forested Watersheds at Coweeta. This symposium marked 50 years since the opening of Coweeta as a site for long-term research on forest hydrology and ecology. At the Symposium, over 35 papers were presented summarizing the long-term research program at Coweeta. Many papers included LTER-funded results as well as results of previous and ongoing studies funded by the Forest Service, IBP, NSF, and other agencies. The Symposium was preceded by an Open House and followed by a Technical Tour for interested scientists, both held on site at Coweeta. Appendix II provides further information on these events.

A. MODELING STUDIES

Background. In the next 5-year period, we propose to expand considerably the role of modeling studies in our research program. Specific modeling studies will be designed, first, to enhance our understanding of natural ecosystem dynamaics at various scales of space and time, and second, to evaluate and predict anthropogenic impacts on southeastern forests. Specific models will be formulated at several scales or levels of resolution, and will be focused toward addressing several distinct questions. However, all models to be formulated in these studies will be lumped-parameter process-oriented models, in that integrated behaviors of specific landscape units (plot, stand, watershed) will be predicted/modeled based on algorithmic formulations of those key processes (hydrologic, demographic, physiological, biogeochemical) which are understood to regulate system-level behaviors of interest. Moreover, models will be empirically based, both in the sense that process algorithms will be formulated based on results of process-level research at Coweeta (and elsewhere), and also in that model predictions/formulations will continually be evaluated against extant Coweeta data sets. To facilitate this latter goal, techniques of model error/uncertainty analysis will be adapted for each distinct modeling effort undertaken. Specific models to be constructed not only are important in enhancing our ability to understand and predict ecosystem dynamics in natural and disturbed states, but also will serve to integrate process research conducted at Coweeta over the past several decades.

Past Modeling Studies. Initial terrestrial modeling efforts at Coweeta focused on the dynamics of specific nutrients on several watersheds. These models integrated existing process-level information at the time of model formulation, and sought to explain gross details of nutrient circulation in natural and manipulated forests. Although preliminary models were constructed for cycles of Ca and K (Waide and Swank 1974), major emphasis was placed on the forest nitrogen cycle (Mitchell et al. 1975) and its alteration by forest manipulation (Swank and Waide 1980). Terrestrial modeling studies were paralleled by stream models, which focused not only on nutrient dynamics (Webster and Patten 1979) but also on organic matter breakdown and processing in headwater streams (Webster 1983). Several Coweeta investigators (Swank, Waide) have also been collaborating with Dr. Darrell West of Oak Ridge National Laboratory in the application of a nutrient cycling version of FORET to Coweeta forests.

The forest nitrogen dynamics model was used to examine potential effects of increased frequency and intensity of forest harvest on sustainable forest productivity (Waide and Swank, 1976, 1977, Swank and Waide 1980). This model was modified and used elsewhere (Rauscher et al. 1983). It also stimulated field research at Coweeta and elsewhere on management impacts on long-term productivity and nutrient dynamics (Swank et al. 1984, Van Lear et al. 1983), and paralleled similar modeling studies in other forested regions of North America (Aber et al. 1979, 1982; Feller et al. 1983; Sollins et al. 1983; Williams et al. 1983).

Coweeta investigators have also participated in the development and evaluation of forest hydrology models (Swank 1981). Special emphasis has been placed on evapotranspiration processes and their alteration by forest cutting (Swift et al. 1975), and on moisture evaporation from hardwood forest litter layers (Moore and Swank 1975). Hydrologic data collected at Coweeta have also been used by others to construct and evaluate steep slope hydrology models for use in mountainous, forested terrain (Sloan et al. 1983).

Proposed Modeling Research. Modeling studies proposed here represent extensions and expansions of the forest nutrient dynamics models reviewed above. Considerable process-level data and understanding of forest nutrient dynamics have been developed since these initial models were developed. This new knowledge will be incorporated into refined models. Also, these early models did not adequately formulate mechanistic controls over nutrient storage and circulation. Interactions between cycles of key forest nutrients were not modeled, nor were nutrient dynamics coupled to organic matter production and decomposition. Finally, hydrologic and climatic controls over nutrient fluxes were not explicitly modeled. Our earlier models were useful but they are not adequate for our present purposes. However, they do provide a firm foundation for new studies proposed here.

Basically, three areas of model formulation, application, and evaluation will be pursued in the coming 5 years. The first area involves the use of chemical equilibrium models. These analytically tractable models will not be used predictively, but rather to evaluate various postulated mechanisms in regulating solution chemistry in Coweeta forests. This modeling approach will be especially useful for examining processes believed to be causing shifts in Coweeta stream chemistry in response to atmospheric deposition (Swank and Waide 1985). This modeling area represents the application/extension of the work of Reuss and Johnson (Reuss 1980, 1983, 1984; Reuss and Johnson 1985a,b) to Coweeta.

The second modeling area to be pursued concern applications of a FORET-type stand dynamics model (Shugart and West 1977), modified to include above- and belowground dynamics of C, N, and Ca. This model will be used to examine, in relation to past and ongoing field studies, compositional and productivity dynamics of Coweeta forests and their response to forest cutting, intensive forest management, and air pollution stress (in the sense of Shugart et al. 1980, Kercher and Axelrod 1984). These efforts will be enhanced by continuing interaction of Swank and Waide with Darrell West of ORNL.

The third and major thrust of our modeling efforts involves development, application, and evaluation of a general modeling framework for the coupled cycles of C, N, S, Ca, and H. We intend to develop a general forest nutrient dynamics model. Aboveground components of forests will be modeled in much coarser fashion than in the FORET-type model, whereas storages and transformations of the five elements in litter and soil layers will be formulated at a much finer degree of resolution. This represents the most direct extension of our earlier forest nutrient cycling models. The model will be used to predict successional changes in forest biogeochemical dynamics following forest cutting, as well as to evaluate impacts of atmospheric deposition and intensive forest management on forest biogeochemistry and productivity.

To facilitate the careful evaluation of all models to be employed in these studies, we will develop and apply methods of model error/uncertainty analysis. In particular, methods developed for water quality models (DiToro, 1983), as well as regionalized sensitivity analysis methods (Hornberger and Spear 1980, 1981; Humphries et al. 1984, Spear and Hornberger 1980) will be carefully evaluated, compared with other approaches, and incorporated in our models as appropriate.

Throughout these modeling efforts, we will pay special attention to the scale-dependence of simulation predictions. No satisfactory means of extrapolating ecosystem model predictions to other space and time scales than those at which they were derived (i.e., than are implicitly contained in model process formulations) currently exists. We will investigate several techniques for extending model predictions across scales of space and time.

B. CLIMATOLOGY, HYDROLOGY, PRECIPITATION AND STREAM CHEMISTRY

Research Progress. Analyses of long-term precipitation and stream chemistry trends for Coweeta control watersheds (Swank and Waide 1985) and stream chemistry responses to treatment (Swank 1985) were presented at the Coweeta Symposium. The Coweeta precipitation and stream chemistry record is among the most extensive available for any single location in terms of the number of rainfall gages and watersheds sampled and the total number of water years for which data are available. Furthermore, the chemistry record includes the second highest annual precipitation amount and the driest year on record at Coweeta during the past 50 years.

Analysis of an eight-gage bulk precipitation network distributed over the Coweeta Basin shows that weekly arithmetic averages of all gages provide a reasonable means of estimating bulk solute inputs in individual watersheds. Weekly grab samples of stream water appear to be sufficiently frequent to provide adequate estimates of solute export for all ions except SO_4, which is underestimated by grab sample methods.

The chemical composition of bulk precipitation is dominated by H and SO_4 ions and is characterized as a weak solution of sulfuric and nitric acids buffered by base cations to produce a mean annual pH of 4.6. Composition of stream water representative of low-elevation watersheds shows that Na and HCO_3 are the dominant ions and that stream water is characterized as a cation-bicarbonate solution with a mean pH of 6.7. In streams draining high-elevation watersheds, SO_4 has replaced HCO_3 as the dominant anion, a result which indicates major differences in processes regulating the chemistry of low- and high-elevation watershed ecosystems. Differences among control watersheds in NO_3-N concentrations reflect the occurrence of defoliation outbreaks, whereas variability in cations and SiO_2 is related to differences in bedrock mineralogy and weathering.

Dryfall can be a major source of chemical loading at Coweeta for some ions and exhibits substantial year-to-year variability. Annual sulfate dryfall inputs have decreased about 50% over a 9-year period; a slight tendency for a decline in Ca inputs over time is also apparent.

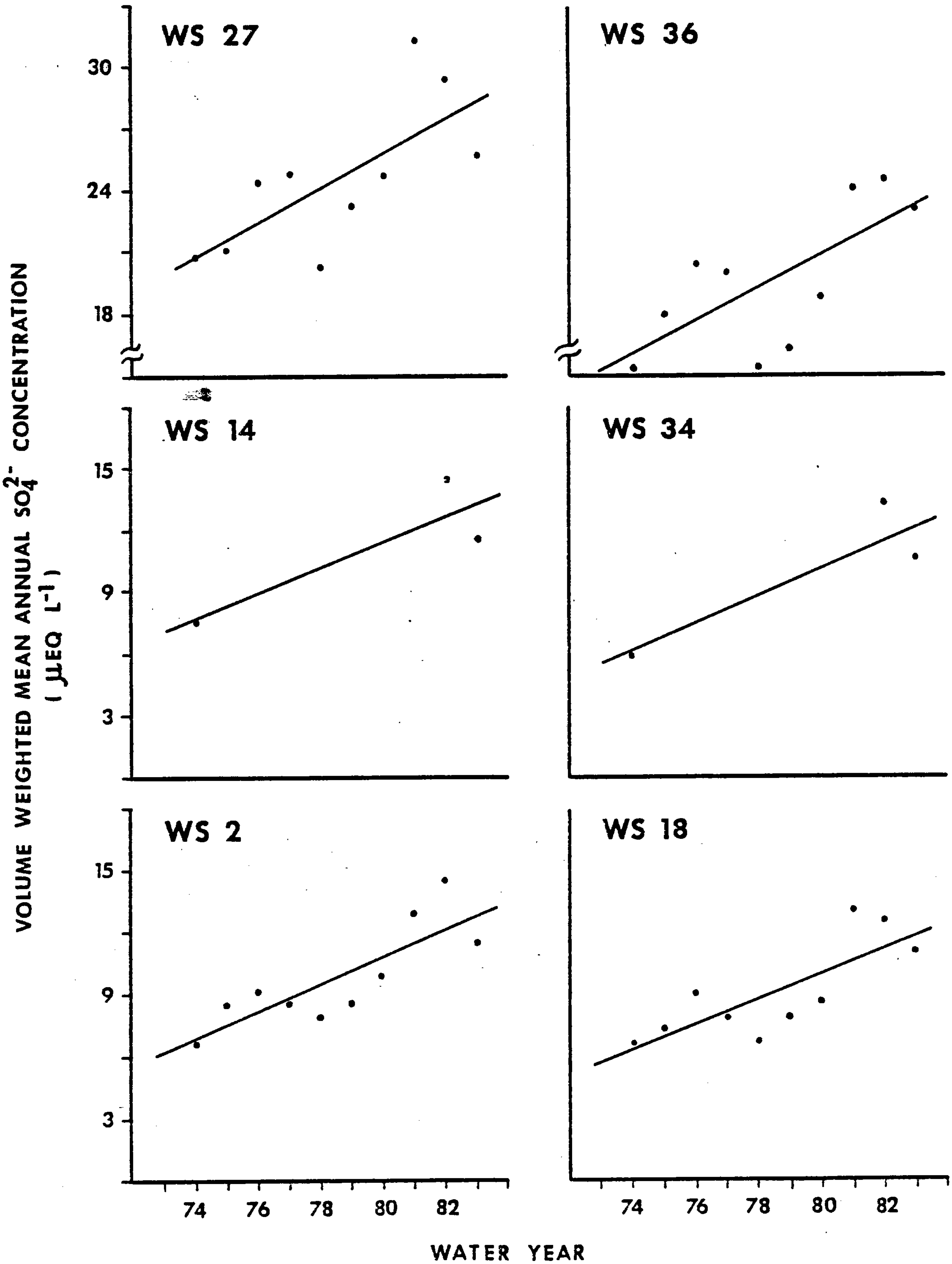
Sea salt aerosols are the major sources of Cl and Na and about 40% of Mg in bulk precipitation. Remaining ions are almost entirely of terrestrial origin. Based on stoichiometric calculations, SO_4 contributes about 74% to precipitation acidity and NO_3, 23%. The mean pH of 4.7 predicted by these stoichiometric calculations compares favorably with the measured mean pH of 4.6.

Analysis of long-term trends of mean annual precipitation and stream chemistry showed no significant trends of increasing or decreasing acidity, although annual stream water H ion concentrations were partially related to precipitation H ion concentrations. When all ions in both precipitation and stream water were examined, the most definitive annual trend was an increase in stream water SO_4 concentrations. This trend was present for all control watersheds (Figure 1) with an average increase of about 0.7 $\mu eq l^{-1} yr^{-1}$. Other trends in stream chemistry included an increase in anion deficit, and decreases in concentrations of HCO_3, Ca, and the sum of the four cations (Figure 2). The only significant trend in precipitation chemistry was a decline in concentrations of Ca and the four cations summed. Thus, Coweeta control watersheds may be in the initial phase of response to atmospheric inputs of air pollutants, even though total ion inputs to the Coweeta Basin have not increased over the period of record.

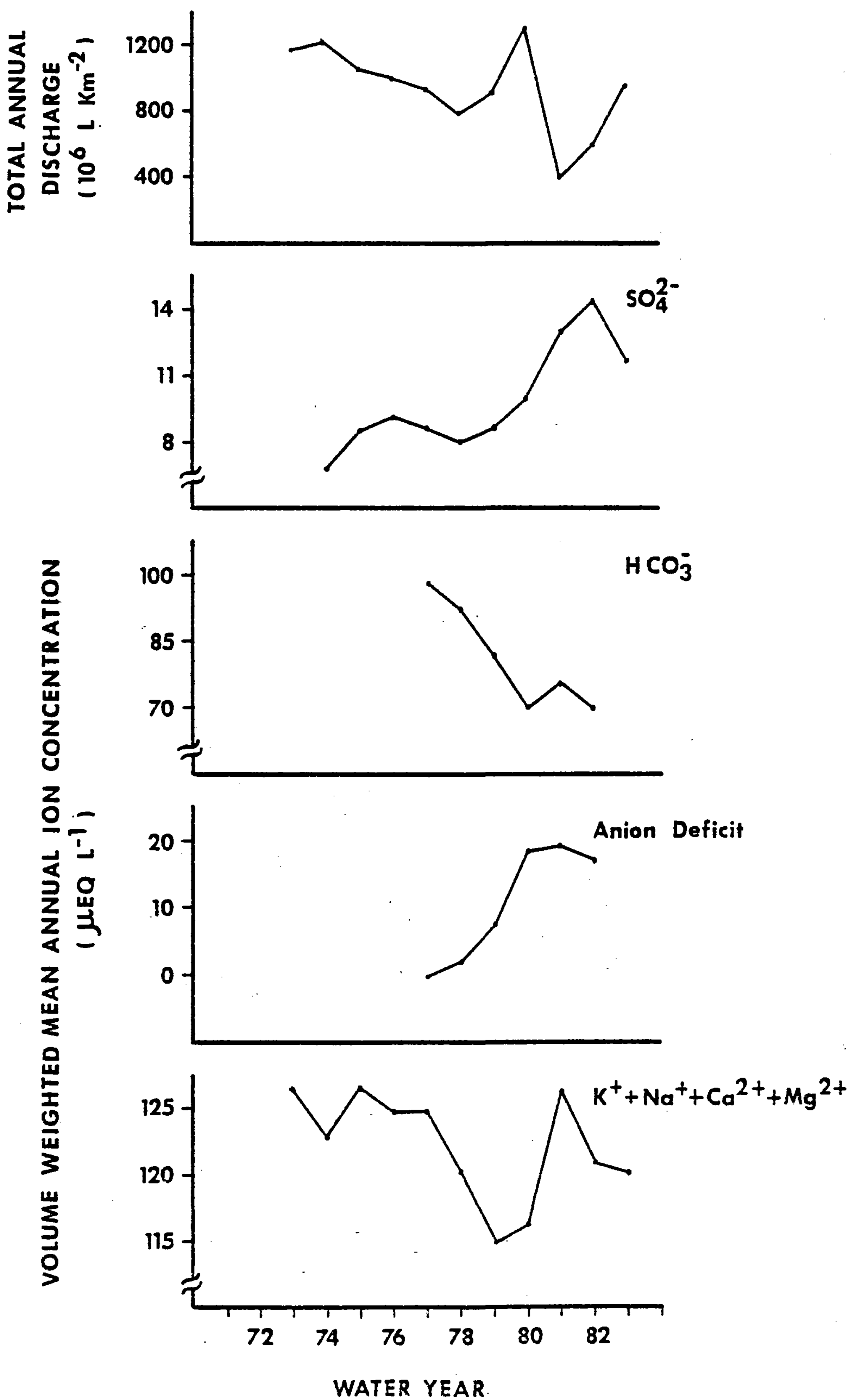
Monthly analyses of solutes in precipitation and stream water showed distinct seasonal trends for some ions. Concentrations of H and SO_4 ions in bulk precipitation peak in May through August, with lowest values occurring in late winter. Chloride

Figure 1

TRENDS IN STREAM [SO_4^{2-}], CONTROL WATERSHEDS



TRENDS IN STREAM CHEMISTRY, WS 2 FIGURE 2



concentrations in precipitation are highest throughout the winter in response to frontal storms and deposition of aerosols of marine origin. Calcium and K concentrations are minimum in winter and maximum in early spring with a second peak concentration in October. These patterns are associated with the timing of local agricultural and burning activities. Several ions (H, SO_4, K) tended to exhibit a negative relation between concentration and precipitation amount. Other ions showed no relation (NO_3-N, Ca) or a weak positive relation (Cl) between monthly concentration and precipitation amount. For these latter three ions, a large fraction of the variability in bulk precipitation inputs was accounted for by precipitation amount, whereas this was not the case for the former three ions.

Streams draining undisturbed watersheds showed distinct seasonal trends in both concentrations and export of ions which are mainly regulated by watershed discharge. Most ions showed strong negative correlation of monthly concentration with monthly flow. Furthermore, monthly flow accounted for at least 96% of the variation in monthly solute export. Nutrient export via sediments dominated the total export of nitrogen, but was relatively insignificant for other elements or ions.

Annual input-output budgets for control watersheds show net gains of NO_3-N, NH_4-N, and PO_4. Net losses occurred for Ca, Na, K, Mg, and SiO_2 in all watersheds. Chloride was in close balance for five of the seven control watersheds. Sulfate showed the most striking budgets with large apparent accumultions of SO_4 ranging from 18 to 32 kg $ha^{-1}yr^{-1}$. Differences in net budgets among control watersheds reflect differences in bedrock geology within the Coweeta Basin and in the hydrologic responses and biological characteristics of high- and low-elevation watersheds.

The long-term research on precipitation and stream chemistry for control and manipulated watersheds at Coweeta provides a valuable and extensive data base for evaluating the integrated biogeochemical function of Southern Appalachian forest ecosystems, as well as for evaluating system-level responses to natural episodic events, deposition of anthropogenic materials, and forest management practices. Such system-level measures must be integrated with detailed process-level studies to understand factors regulating ecosystem-level behaviors and responses to disturbance. An example of how the long-term data are being used to develop testable hypotheses of biogeochemical processes is given in Table 1.

Proposed Research. As a contribution to LTER, the Forest Service will continue to collect, process, and make available data on the hydrology and meteorology of the Basin. Expenses specifically associated with hydrometeorology data management for LTER will be covered by the grant. Continuous flow measurements will continue on 16 streams draining 9 to 760 ha watersheds ranging in mid-elevation from 800 to 1312 m. Data produced include stage height and flow rate versus time points, frequency of flow rates by minute summarized over months, mean daily flows, and storm parameter analyses. Precipitation is continuously recorded at 13 sites ranging from 685 to 1364 m elevation. Monthly totals are computed for all sites with hourly intensities computed at climatic stations and detailed storm analyses made for 7 gage records.

Four climatic stations representing 685 to 1189 m elevations will provide hourly values of air temperature, relative humidity, and vapor pressure in both a forest opening and under the forest canopy plus wind speed and direction above the canopy. Understory litter and soil temperatures will be measured at forested sites and solar radiation and evaporation are recorded at the Administrative Area station. Two additional climatic stations will be maintained during the grant period to support specific studies. The station on WS 7 predates the forest cutting treatment and supports the LTER studies on that area. The second, separately funded station will support an atmospheric deposition study in an adjacent Pinus strobus plantation. A side benefit will be initiation of a microclimate data set for the Coweeta pine plantations. Continuous stream temperature recordings were initiated on WS 7 and an adjacent stream before the logging. The goal of documenting temperature shifts due to changing stream exposure through the period of forest recovery has been achieved. Pending replacement of recording instruments, stream temperature measurements will continue on at least two streams specifically to support LTER aquatic research. Improved instrumentation at all climatic stations and a new high-elevation site will

Table 1. Summary of factors postulated to affect SO_4^{2-} and HCO_3^- availability and mobility in forested watersheds at Coweeta.

Factors	High-elevation relative to low-elevation watershed
Total SO_4^{2-} deposition	Higher
Potential for soil SO_4^{2-} adsorption	Lower
Rates of SO_4^{2-} incorporation and S immobilization by soil microbes	Lower
Ecosystem carbon flow[a]	Lower
Precipitation and streamflow	Higher
Quickflow[b]	Higher
Mean soil-water contact time	Lower

a Primary production, decompostion, and root respiration.

b Total amount and as percentage of total discharge.

provide a significant gain during the grant period in knowledge of wind speed and direction in the Coweeta Basin. Timing and spatial patterns of air movement will be critical information for interpreting elevational gradients in the deposition of heavy metals and other airborne chemicals. Summaries of hydrologic and climatologic data, to be published during the next 5 years (e.g., Swift and Cunningham 1985, Swift et al. 1985) will make this background information easily accessible for site participants and form the basis for intersite exchange of these data.

Long-term trends in precipitation and stream chemistry within the Coweeta Basin will be further analyzed to address critical questions relative to processes of surface water acidification. Several hypotheses were proposed by a panel convened by the National Academy of Sciences (1984) to review the topic of lake acidification. These hypotheses are based on sequential changes in sulfur deposition, sulfate concentrations in surface water, and concentrations of various cations in surface water in relation to changes in soil chemistry. The data will also be used to test and modify the conceptual framework proposed by Galloway et al. (1983) for surface water acidification.

Chemical analyses of precipitation and stream water will continue on a routine weekly basis. Concentrations of 11 solutes (Ca, Mg, Na, K, NO_3, NH_4, Cl, SO_4, HCO_3, SiO_2) comprise the long-term record. Forms of Al in stream water are currently being examined in several streams; expansion of the sampling network for this ion will be based on initial findings. Studies of stream discharge-concentration relationships for various ions during storm events will be intensified on both high- and low-elevation watersheds. Characterization of organic acids in precipitation and stream water will be conducted under separate support. A monitoring network for O_3, NO_x, and SO_2 measurements will also be initiated within the Coweeta Basin through other funding.

C. WATERSHED HYDROLOGY AND PHYSICS

Background. After reaching the forest floor, precipitation can follow many pathways on its way to a stream, including overland flow, saturated and unsaturated subsurface laminar flow, and subsurface turbulent flow. The pathways followed and the associated residence times before water reaches the stream profoundly affect water chemistry. To understand factors regulating forest streamwater chemistry, it is imperative that the complex physics of soil water flow at the watershed level be understood. Field observation at sites such as Coweeta has revealed that during most storms all precipitation infiltrates the soil and is subject to various flow pathways, regulatory mechanisms, and transit times as it moves to the stream. Consequently, better theories of watershed-scale physical processes which regulate water and solute transport through forest soils are needed if stream water chemistry is to be predicted accurately.

The variable source area concept (Hewlett and Nutter 1970) and subsequent research have suggested that various subsurface flow pathways may be active during storm events. In some watersheds, for example, macropores are important conduits for storm water. Furthermore, confounding factors such as zones of flow convergence, heterogeneity and anisotropy of subsurface flow properties, and fingering cause a mixing of distinct flow processes that need to be assessed on a watershed scale, not on a plot or hillslope segment basis.

Proposed Research. New research proposed here is directed toward studying watershed physics and understanding flow paths from a chemical viewpoint. Models of soil water flow which incorporate solute transport and transformations will be constructed, tested, and evaluated. This will provide hydrologic insight into watershed-scale processes affecting nutrient cycling, acid deposition, and solute transport.

A large amount of flow and chemical data has been collected at Coweeta. On a watershed scale, these data are frequently summarized as mass balances for specific ions, with the watershed considered as a black box. The objective of this research is to elucidate hydrologic realities of this black box. This will be accomplished in three interrelated tasks: 1) assess the suitability of existing stream chemistry data for understanding water and solute transport through forest soils, 2) utilize existing watershed data to evaluate subsurface and kinematic flow models (Loague and Freeze 1985, Beven 1981, Beven 1982), and 3) utilize time series techniques to identify hydrologic processes regulating solute transport. Emphasis will be placed on watersheds for which stream chemistry data are available for both base flow and storm flow periods. This work will complement proposed work on forest nutrient dynamics models discussed earlier.

Physically based subsurface unsaturated-saturated flow models that describe hydrologic processes with relatively long time constants are difficult to employ. By contrast, kinematic wave models are useful for predicting watershed flow, especially quick storm responses from flow in macropores or saturated areas. However, these models are empirical and cannot be used directly to examine flow paths. Both types of models will be compared with measured streamflow to evaluate their usefulness in predicting runoff response.

Because different flow processes have different time responses during storms, techniques from time series analysis will be useful in determining the relative importance of specific processes in regulating solute transport. Both time-domain (Box and Jenkins, 1976) and frequency-domain methods (Jenkins and Watts, 1968) will be employed in these studies.

D. GEOCHEMICAL MASS BALANCE

Research Progress. Geochemical mass balance studies are widely considered the most reliable means for making quantitative determinations of rates of elemental transfers in the earth's surface environment and thus are widely employed in studies of landscape biogeochemistry. To provide answers to pressing environmental questions, and to facilitate comparison between individual studies, the strengths and limitations of mass balance methods must be clarified and understood. The purpose of the proposed research is to refine existing geochemical mass-balance models of landscape biogeochemical processes at Coweeta by: (1) investigating mineralogical constraints on mass-balance calculations; (2) using new mineralogical data to extend the mass-balance approach to disturbed watersheds; and (3) further developing and refining computational tools for mass-balance studies by comparing new geochemical models against existing input-output data for both reference and disturbed watersheds.

Velbel (1984a,b 1985) constructed geochemical mass balances for seven control watersheds at Coweeta, and showed that four transformations influence dissolved element budgets in control watersheds: the weathering of three major weatherable rock-forming minerals (biotite mica, almandine garnet, plagioclase feldspar) and the uptake of mineral nutrients by forest biota. Rates of primary mineral weathering and mineral nutrient supply to terrestrial biota were calculated (Velbel 1984a,b 1985). Rates of weathering profile development and geochemical landscape modification, as well as mineral weathering rates normalized to mineral surface area (for comparison with laboratory kinetic studies), were also calculated for WS 27.

Proposed Research. Research problems not resolved in studies summarized above include the following: 1) Whether mineral weathering reactions are homogenous from one watershed on a given rock type to the next, and whether watershed disturbance results in changes in mineral weathering reactions as compared with control watersheds. This question will be addressed by geological and mineralogical studies of mineral weathering in disturbed watersheds.

2) The significance of the botanical-uptake term in the mass balance calculations. Results of calculations for WS 18 correspond closely with measured rates of biomass aggradation for the same watershed. Extension of mineral analyses and mass-balance calculations to disturbed watersheds where aggradation rates are known will be a valuable test of the validity of the approach.

3) The distribution of mineral weathering in space. Mass balance calculations presently treat the weathering profile of a watershed as a homogenous "black box." In reality, a natural hillslope weathering profile consists of two such "boxes": one accessible to terrestrial biota (rooting zone), and one inaccessible (saprolite below

rooting zone). The sum of weathering rates for any mineral in the two compartments must equal the overall weathering rate calculated from watershed mass balances. Weathering may not be distributed evenly between the two compartments, however, and the inhomogenous distribution of weathering may have significant implications for the availability of mineral nutrients released from soil minerals to biota. Therefore, the question of which compartment experiences the majority of the mineral weathering is important. The purpose of the comparisons between disturbed and undisturbed watersheds is to test for the influence of biotic activity on mineral weathering rates, thereby demonstrating whether biotic processes influence the intensity of weathering. Additional modeling will also address questions of spatial distribution by constructing different scenarios for element transfer between the two compartments of the weathering profile and by comparing model results with observed mineral distributions.

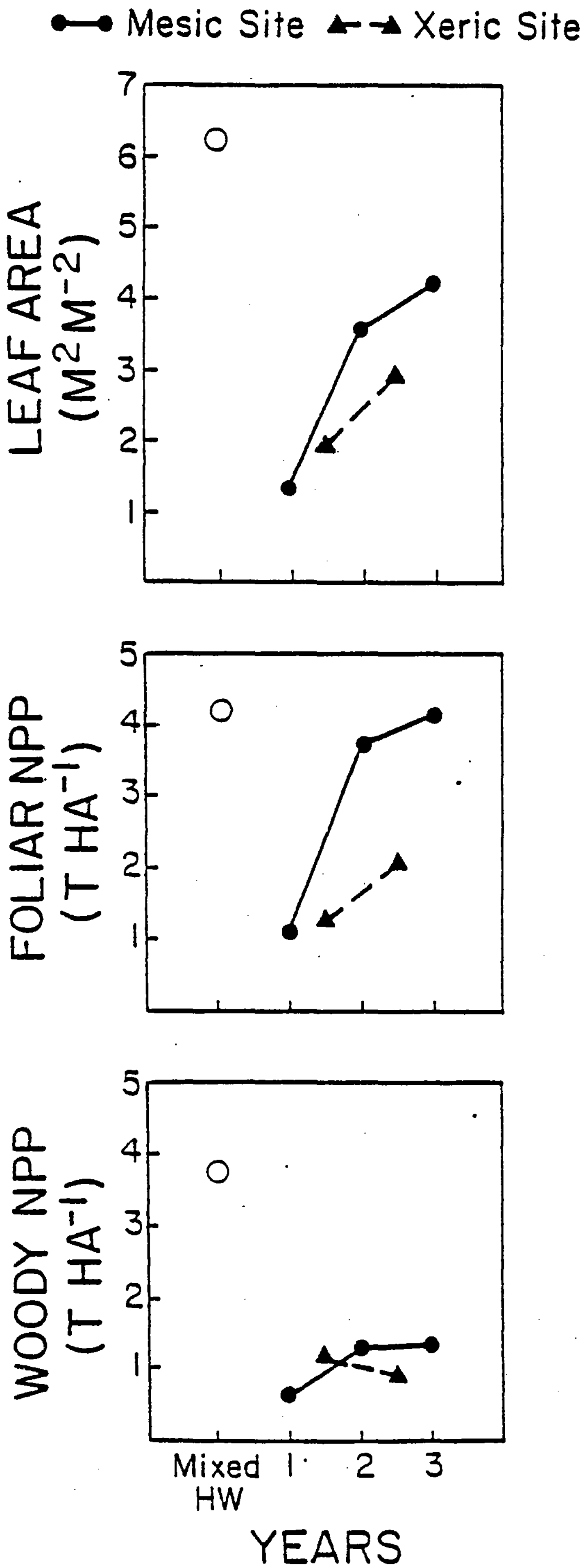
4) The distribution of mineral weathering in time. All present mass-balance models involve systems of linear equations at steady state. Natural systems are clearly not at steady state on all time scales, however; long-term and annual averages (addressed by present modeling) exist along with seasonal and event perturbations (e.g., storms). Also, the functional relationship of mineral weathering rates to time and environmental variables (e.g., flow rate, acidity) may be non-linear (Chou and Wollast 1984). The major long-term goals of this study are to elucidate rates and mechanisms of element transfer from various inorganic compartments to the biota by using existing models on data from shorter-than-annual time increments and by deriving more refined (non-linear, non-steady-state) mass balance equations for use with short-term data.

E. SUCCESSIONAL DYNAMICS OF FOREST STRUCTURE AND BIOGEOCHEMICAL PROCESSES

Research Progress. We have continued an intensive study of the physical, chemical, and biological effects of forest disturbance (clearcutting) upon the terrestrial components of the ecosystem. The investigation of vegetation processes has expanded upon past hardwood forest baseline studies conducted within the IBP (Day and Monk 1974, McGinty 1976, Day and Monk 1977a,b), and upon an earlier, short-term study of first-year vegetation response to clearcutting (Boring, Monk and Swank 1981). This has been coupled with detailed studies of changes in organic matter and nutrient pools and transformations in litter and soil layers following forest removal. Here we summarize results from the basic process studies during early succession, document progress on the most recent phases of the research and outline research objectives for the upcoming 5-year period. The long-term objectives of this study have been: 1) to examine differences in forest regeneration trends among cove, chestnut oak and xeric scarlet oak-pine sites on the clearcut watershed; 2) to compare species composition, leaf area index (LAI), biomass, net primary production (NPP), nutrient uptake and nutrient accretion during forest regeneration with values for an adjacent, uneven-aged, mixed hardwood forest; 3) to relate regeneration of forest structure to fundamental biogeochemical processes of nutrient uptake, immobilization, storage, and transfer; and 4) to define the importance of the dominant tree species, black locust (Robinia pseudo-acacia), in nitrogen fixation, and to determine its direct and indirect effects upon regenerating stand structure and mineral-cycling processes.

Based upon the initial three years of regeneration data, the recovery of LAI and foliar NPP in mesic sites was rapid (Figure 3). Regeneration was more rapid on mesic than on xeric sites due to rapid sprout growth and an abundance of herbaceous vegetation. Early successional woody species and numerous herbaceous composites (Figure 4) had higher rates of biomass production, higher tissue concentrations of N, P and K, and proportionately larger biomass nutrient pools (Boring et al. 1981, Boring et al. 1985). Annual aboveground NPP on the 3-year-old mesic sites contained a large amount of nutrients relative to that of the control, uneven-aged mixed hardwood forest (Figure 5). Xeric sites were estimated to contain approximately half of the nutrients as on mesic sites. Although large quantities of nutrients were immobilized each growing season, a proportionately large quantity was returned annually to the forest floor via litterfall and leaching.

FIGURE 3



Mesic Site
Xeric Site
LEAF AREA
(M2 M-2)
7
6
5
4
3
2
1
FOLIAR NPP
(T HA-1)
5
4
3
2
1
WOODY NPP
(T HA-1)
5
4
3
2
1
Mixed HW
1
2
3
YEARS

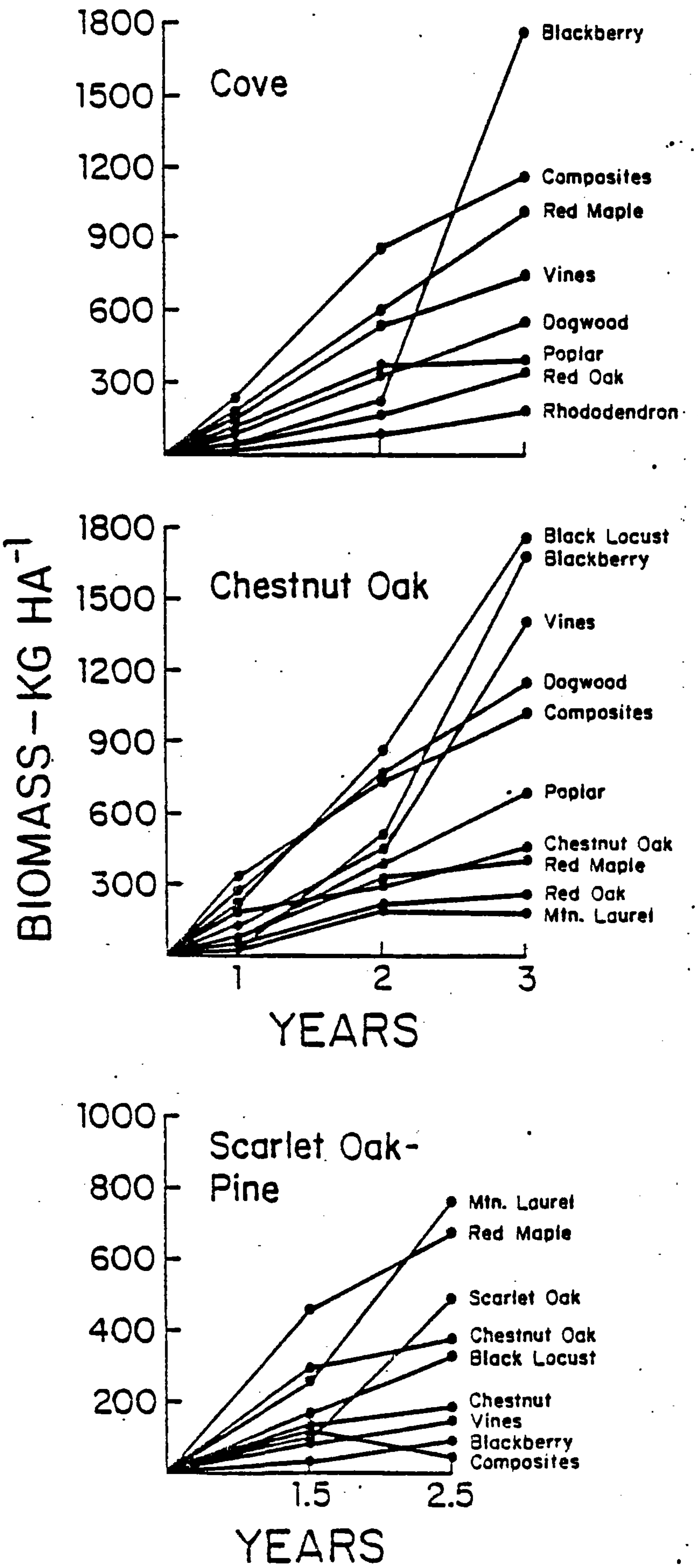
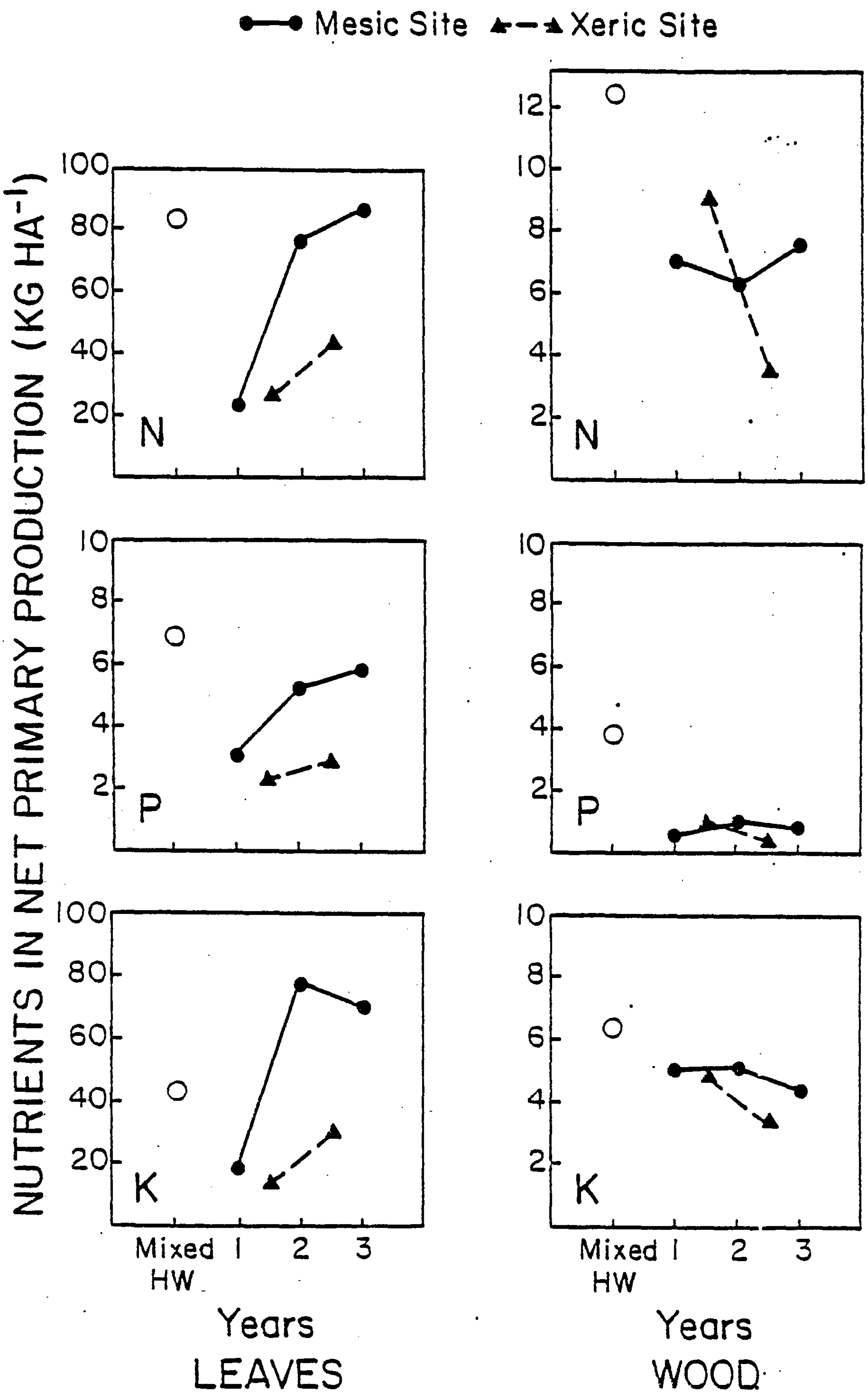

1800
1500
1200
900
600
300
Cove
Blackberry
Composites
Red Maple
Vines
Dogwood
Poplar
Red Oak
Rhododendron
BIOMASS-KG HA^{-1}
1800
1500
1200
900
600
300
Chestnut Oak
Black Locust
Blackberry
Vines
Dogwood
Composites
Poplar
Chestnut Oak
Red Maple
Red Oak
Mtn. Laurel
1
2
3
YEARS
1000
800
600
400
200
Scarlet Oak-Pine
Mtn. Laurel
Red Maple
Scarlet Oak
Chestnut Oak
Black Locust
Chestnut
Vines
Blackberry
Composites
1.5
2.5
YEARS

FIGURE 5



Mesic Site
Xeric Site
NUTRIENTS IN NET PRIMARY PRODUCTION (KG HA-1)
N
P
K
Mixed HW
1
2
3
Years
LEAVES
WOOD

The dominant woody species R. pseudoacia symbiotically fixes at least 30 kg N ha^{-1} yr^{-1} (Boring and Swank 1984b), accumulates large quantities of biomass N (Boring and Swank 1984a), and maintains elevated concentrations of other nutrients in both leaves and wood (Boring et al. 1981). The biomass of this short-lived species may be regarded as a nutrient storage sink for an intermediate span of time, approximating the life of the stand (15-40 years).

Regenerating vegetation has been sampled again in 1982 and 1984. Data sets on species composition and leaf area are currently complete, and nutrient analyses are almost finished. Approximately 175 trees from eight dominant species, ranging from six to eight years old, were destructively sampled last summer to construct regression equations to predict wood and leaf biomass. These data sets are being coupled to estimate biomass, NPP, LAI, and nutrient standing stocks in years 6 and 8.

We have simultaneously measured changes in litter-soil organic matter and nutrient pools and transformations in permanently located plots in the three vegetation zones on WS7 (Caskey et al. 1985, Waide, Todd, Caskey, and Swank, manuscripts in preparation). Table 2 briefly summarizes effects of forest removal on organic matter and nutrient pool sizes and transformation rates. Cutting led to considerable elevations of soil temperature, reductions in litter moisture, and increases in moisture content of surficial soil horizons. Associated with these changes, microbial biomass (ATP measures) and rates of CO_2 evolution were reduced, particularly in upper soil layers. However, rates of free-living N fixation and nitrification were stimulated. Litter and soil organic matter pools, as well as exchangeable soil nutrients, increased following cutting. Changes in exchangeable nutrients paralleled changes in litter-soil solution chemistry, at least in the initial years following cutting (Haines, Waide, Todd, and Swank in preparation). Although decomposition was initially slowed by the hot and dry forest floor microclimate which followed clearcutting (Abbott and Crossley 1982, Seastedt and Crossley 1981, Cromack and Waide 1985, Waide unpublished), there was nutrient enrichment of throughfall as water passed through the woody logging residue (Swank,

Table 2. Summary of select changes in litter-soil nutrient pools and transformations following forest clearcutting on WS7.[a]

Litter-Soil Variable	Change Following Forest Removal
Soil temperature	Greatly elevated, particularly in summer months
Litter-soil moisture	Reduced in litter layers, elevated in surface soil layers due to reduced evapotranspiration
Microbial biomass (ATP measures)	Reduced, particularly in surface soil layers
Organic matter pools (surface litter & soil OM)	Elevated, especially in surface soil layer
CO_2 evolution	Reduced, especially from soil layers
Nitrogen fixation rates (free living)	Stimulated, particularly in surface soil layers
Nitrification rates (population estimates, incubation studies)	Greatly stimulated, particularly in O2 and surface soil layers
Soil total N pool	Elevated, especially in surface soil horizons
Soil available nutrient pools (NO_3, NH_4, P, cations)	Elevated, particularly N species and Ca in surface soil layers

a/ (Caskey et al. 1985; Waide, Todd, and Caskey unpublished).

unpublished).

These changes in litter-soil biogeochemical processes have declined with time since cutting. Additionally, considerable spatial variability was present in these results, largely associated with differences among the three vegetation zones (sample plots were stratified by vegetation zone).

Continuation and Refinement. This research will continue to address hypotheses enumerated above and to provide information on the response of forest ecosystems to perturbation. The long-term nature of this study provides an excellent opportunity to examine interactions between changes in forest structure and litter-soil biogeochemical processes as the stands aggrade in aboveground biomass, leaf area, and nutrients through intermediate stages of succession. During aggradation there will be a rapid increase of nutrients in forest biomass, a small decrease in soil exchangeable nutrient pools, and a decrease in litter nutrients, as decomposing woody material disappears. In stands dominated by *R. pseudo-acacia*, these trends should be more pronounced, due to more rapid growth and greater nutrient demands. Periods of drought stress may increase black locust's susceptibility to insect attack, and consequently accelerate stand senescence (Craighead 1937, Hall 1942, Berry 1945). This thinning process should result in an opening of the stands, and stand dominance will shift to less-nutrient-demanding species that will utilize nutrients that mineralize over the long-term from accumulations in black locust leaf and woody litter.

This phase of regeneration, 10-15 years following clearcutting, will be a highly dynamic period in which to examine tree mortality, shifts in patterns of species dominance, competitive interactions, and relations with litter-soil biogeochemical processes. This will be an important 5-year period in terms of our understanding of forest succession. This period will include a decrease in black locust dominance, an increased mortality of sprouting American chestnut (*Castanea dentata*), and the potential competitive exclusion of overstory species by dense thickets of mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron maximum*). Therefore, an additional objective of this study is to quantify the growth of individual saplings and seedlings relative to measures of crowding from their competing neighbors.

We will inventory permanent plots again in the eleventh year following clearcutting (year 2 of proposal period). Regenerating vegetation will be sampled for biomass, leaf area, and nutrient analysis, as explained in the previous section and in Boring et al. 1985. Another set of trees will be destructively sampled in order to construct regression equations for biomass estimation (year following plot inventory).

Neighborhood indices using rank correlation techniques will be employed to study competitive interactions among tree species (Harper 1977). In approximately one-half of the permanent plots, individuals will be permanently identified with numbered tags, and their locations within the plot mapped within 0.10 m. This will permit an examination of competing vegetation at a single point in time, and provide mapped plots which will be resurveyed at approximate 5-year intervals.

In order to facilitate understanding of interactions between successional changes in stand dynamics and litter-soil biogeochemical processes, we further propose to remeasure litter-soil organic matter and nutrient (N, P, cations) pools and transformations (CO_2 evolution, free-living N fixation, N mineralization, nitrification, denitrification) during the same year in which vegetation is resampled. Sampling will be "event-oriented," during approximately six time periods, as determined by hydrometeorological conditions, and will also be conducted on an adjacent control watershed.

As this research continues, we will synthesize and integrate our studies of aboveground and belowground processes on WS 7 into conceptual and quantitative models of biogeochemical changes following forest removal. This effort will both contribute to and be enhanced by modeling studies described earlier in this proposal.

F. TRACE ELEMENT RESEARCH

Research Progress. Sampling was initiated to establish data on trace element distribution in the Coweeta Basin and to provide a baseline for detecting future changes in concentrations and burdens of both trace and metallic elements. The forest floor and soil as well as boles of hickory trees (Baes and Ragsdale 1981) were sampled in Spring 1983, within two low-elevation control watersheds (WS2, WS18). Concurrently, the ambient atmosphere was sampled in a large opening in WS6, a successional watershed adjacent to WS18, using four low volume vacuum pumps operated at a continuous flow rate of 2.55 M^3 hr^{-1}. Additional samples of O1 and O2 litter layers were collected from a high-elevation site near Albert Mountain (1700 m).

Lead, Al and Zn concentrations in Carya boles at low elevations have increased in both historical (about 1900) and recent (since 1950) times. For example, Pb averaged about 0.4 ppm from 1840 to 1870, increased by a factor of 1.5 in the 1880's, remained at approximately 0.6 ppm until the 1920's, and then increased to an average of approximately 0.8 ppm until the 1940's. Since then, Pb concentrations in woody tissues have more than doubled, with consistent increases up to the present concentrations of over 1.5 ppm. Aluminum and Zn concentrations in low-elevation hickory tree rings at Coweeta are one to two orders magnitude lower than Pb concentrations. Temporal patterns of Al and Zn concentrations are very similar to those for Pb, increasing sharply in the post-World-War-II period.

Many elements, Mn, Mg, Cu, Cd, had comparatively high concentrations in bark tissue, a region of active element transport. Concentrations of the majority of those elements, Mn, Mg, Cd, Ni, have remained generally constant since the 1800's. However, recent increases in trace-metal concentrations are the result of smaller annual growth rings, since trace metal burdens in hickory wood have remained constant throughout this century. The uniform metal burdens indicate that relatively constant quantities of trace metals are being concentrated into narrower annual growth rings and thus, decreased growth is not correlated with increased trace-metal burdens in annual wood. Our results suggest that older growth Carya may have elevated trace element burdens which correlate with the period of maximum ore smelting (1880-1900) at Copper Hill, Tennessee, 90 km west of Coweeta. This smelter released large quantities of sulfur dioxide and trace metals.

Trace element measurements in the forest floor (O1, O2, A and upper B horizon) of

WS 2 and 18 revealed lower concentrations of trace elements (Cu, Zn, Pb, and Cd) than those reported for other sites (Ragsdale and Berish 1985). Forest floor burdens of Cu, Pb, and Zn were 20 times smaller than found in forests of the industrialized Northeastern United States. The largest trace-element burden in the forest floor was for Zn. The low standing stocks of trace metals in low-elevation forest floors at Coweeta indicate that past atmospheric inputs of metals have been low.

There were no differences between watersheds for metal burdens in litter layers. The largest trace element burden in litter was for Pb (approximately 18 mg per m^2). The Cd burden was less than 2 percent of the Pb burden. Mean forest floor burdens of Cu, Pb, and Zn at Coweeta were about 20 times smaller than comparable measurements for other sites in the Eastern United States (Andresen et al. 1980).

Analyses of 0-5 cm soil samples indicated that soil carbon and concentrations of total Co, Pb and Zn were higher in WS18 than in WS2. Similarly, analyses of the deeper (25-30 cm) soil samples showed that concentrations of Co, Cu and Zn were greater in WS18 than in WS2. Higher total Pb concentrations in the soil of WS18 may be associated with greater local disturbance (vehicular traffic) near WS18.

Lead, Cd and Co concentrations were higher in the 0-5 cm soil horizon than in the deeper mineral soil. Enrichment of the upper few centimeters of soil with trace metals indicate that metal deposition was probably aerial (Burton and John 1977). In contrast, Cu, Mn and Zn concentrations were not surficially enriched; similar metal concentrations in A and B horizons indicate that present metal conentrations are primarily the result of bedrock weathering and soil forming processes. Surficial and deeper mineral soil burdens followed the trend of Mn>>Zn>Cu>>Pb>Co>>Cd for both watersheds. To date Coweeta does not have elevated trace-metal concentrations, and is relatively unimpacted.

High elevations at Coweeta differ significantly from low elevations in terms of lead concentrations in O1 and O2 litter layers. Lead concentrations in high-elevation litter samples were significantly higher than those collected at lower elevations. Lead in the Albert Mt. O1 litter samples was about 50 percent greater while O2 litter

Pb concentrations were about 130 percent larger than at lower elevations. In contrast, Cd, Co, Cu, Mn, Ni and Zn concentrations in Albert Mt. litter samples were lower than for those same metals at lower elevations. Higher lead concentrations at higher elevations result from long range transport and deposition of air-borne lead particles. Similar trace metal deposition patterns have been found for high-elevation sites in the northeast.

Average monthly particulate concentrations in Coweeta air samples exhibited strong seasonal effects, and varied from 4.4 to 14.7 mg/m^3 from March 1983 through January 1984. Highest particulate concentrations (14 mg/m^3) occurred from June through August. A second period of moderately high particulate concentration, 7 to 9 mg/m^3, occurred in September and October. Lowest particulate concentrations, about 5 mg/m^3, occurred in the winter and spring. The organic content of the particulate matter ranged from 4 to 14% of particulate mass. The particulate mass organic fraction peaked in the summer at approximately 13%. During winter and early spring, organic matter was 4-7% of the total particulate concentration.

Monthly average concentrations of Pb, Zn, Ca, Cd, Mg and K also showed seasonal patterns with maxima during summer and autumn, and minima in late fall and winter. Lead and Cd behaved similarly, with concentrations increasing to a maximum in June and with a secondary peak in October. Lead ranged from 6-13 ng/m^3 over the annual cycle. Cadmium concentrations were an order of magnitude lower than Pb with values of .05-.1 ng m^3. Both Pb and Cd are components of automobile exhaust; seasonal increases in concentration reflect periods of higher traffic density. Remaining elements each had distinctive behavior.

Lead and Cd concentrations in urban areas are known to show strong seasonality, with maxima reached in summer and minima occurring during winter (VanHassel et al. 1979). The remote Coweeta Basin shows an annual pattern of change similar to that observed in urban areas. Both Pb and Cd in the Coweeta atmosphere result primarily from automotive exhaust and represent long-range atmospheric transport of these toxic trace elements.

Continuation and Refinement. Continuing research on trace element burdens in wood tissue will focus on several species of *Quercus* (*Q. alba*, *velutina*, *rubra*, *prinus*), which will be cored to assess patterns of annual radial increment growth and of trace-element concentration. Oak species of sufficient abundance on both WS2 and WS18 will be selected for study and comparison with oak species selected for study at high-elevation sites. Individuals will be randomly selected in a stratified design. Old growth hickories will also be located in WS2 and WS18 and in adjacent areas, if necessary, to verify that hickories at Coweeta do show a period of elevated trace element concentration corresponding to the decade of highest smelting activity at Copper Basin.

Proposed new research on trace metals in forest floor layers of WS18 and WS2 include sampling of below-ground tissues of dominant trees and shrubs as well as decaying wood on the forest soil. Two locations will be randomly selected for a complete soil profile trace metal description. These additional data will allow us to complete initial trace element budgets for low-elevation Coweeta watersheds.

For purposes of trace metal sampling, two new reference plots will be established at high-elevation sites in the Coweeta Basin. At least one of these plots will be located on a high-elevation site directly exposed to regional air masses. Plots will be field marked to 5 x 5m intervals for sampling purposes. Growth (height, basal area, radial increment) and trace element concentrations will be measured in the dominant trees and shrubs in these high-elevation reference plots. Trace- and macro-element concentrations will also be measured in O1 and O2 litter layers, woody litter, roots, and two soil layers: 0-5 cm and 25-30 cm. Two soil profiles will be determined and sampled by horizon for elemental content. Sampling locations will be determined randomly within the two high-elevation reference plots. Volumetric samples will be taken; soil bulk density will be determined for conversion of concentrations to burdens. Concentrations and burdens of trace and macro-elements will be compared between high- and low-elevation reference plots. The data will be used to determine trace element budgets.

Proposed new research on trace metals in Coweeta atmospheres will involve continued measurements on WS6 for an additional year. Four low-volume air samplers will be operated on a continuous basis in a large forest opening on the north-facing slope of WS6 in the Ball Creek drainage. The four replicate samplers will collect particulates on a monthly basis. Replicate collections will be continued to establish reliable variance estimates for particulates and chemical element concentrations. Sampling intensity will be reduced to duplicate samplers following resolution of statistical questions. The pair of unused samplers will be located in a forest opening on a south-facing slope of the Shope Fork drainage to provide direct comparison between the two major air drainages at Coweeta.

The capacity to measure the atmosphere at Coweeta is severely limited by availability of AC power lines. To extend our ability to make such measurements, a portable air sampling system will be employed. Battery-operated low-volume air samplers will be calibrated against the AC line-operated low-volume samplers on WS6. Following calibration, the portable samplers will be operated in each of the one-hectre reference plots for representative time periods over 12 months. The portable air samplers will also be located at various sites along each of the ridges of the Coweeta Basin to provide a comparative estimate of the particulate burden and elemental content of the exposed, high-elevation atmosphere.

Finally, we also propose new research on trace element concentrations in stream water. We currently have no data of this sort available at Coweeta. Trace element concentrations in stream water of six watersheds will be determined. Base flow and storm flow samples from streams of two low-elevation control watersheds (WS18, WS2), two white pine plantation watersheds (WS17, WS1), and two high-elevation watersheds (WS27, WS36) over five annual cycles will be collected and analyzed for trace element concentrations. These data will provide the trace element baseline for representative watersheds at Coweeta.

G. DENDROECOLOGY

Background. Dendrochronological studies (Creber 1977, Fritts 1971, 1976) are ideally suited for long-term research because information can be obtained on historical environmental parameters in relation to tree growth. The main objective for initiating dendrochronological work at Coweeta is to determine if tree growth has declined over the past few decades and to examine possible causes for changes in tree growth patterns. Data resulting from these studies will be used to interpret long-term forest succession at Coweeta in response to: (1) historical logging practices; (2) chestnut blight in the 1930's; (3) long-term climatic shifts; (4) insect defoliation; and (5) atmospheric deposition. These studies will also better define the age structure of Coweeta forests and will build upon limited previous research at Coweeta by Spring (1973) and Iglich (1975).

Proposed Research. Generally, trees on gaged watersheds at various elevations throughout the Coweeta Basin will be cored. The following site criteria should also be met: (1) history of minimal anthropogenic disturbance; (2) proximity to weather station or rain gage. Trees will also be cored in areas of the Basin with unique geologic/edaphic features which could cause stressful growing conditions. These sites may yield good environmental correlations with tree growth (Fritts 1976, Phipps 1982). According to the geologic map of Coweeta (Hatcher 1980), Thomas Gap (an area of serpentine soils) may be supporting environmentally stressed trees.

Species to be sampled will include canopy dominant and codominant or open grown trees which are long-lived and widespread over the Basin, and which have ring porous wood (e.g., *Quercus alba*, *Q. coccinea*, *Q. prinus*, *Q. rubra*, *Q. velutina*, *Carya glabra*, and *C. tomentosa*). *Pinus rigida* will also be cored because it is common on xeric sites and its annual rings are easy to discern. Two cores will be extracted per tree, perpendicular to slope direction, at about 1 m aboveground. Cores will be stored in coded plastic soda straws in the field. At least 20 trees will be selected per site.

Tree cores will be handled and analyzed using accepted procedures established by the USGS, Oak Ridge National Laboratory, and University of Arizona Tree Ring Laboratory. Data will be transmitted to the University of Georgia mainframe computer for manipulation and analysis (Robinson and Evans 1980). Initial analyses will employ statistical programs developed at the Tree Ring Laboratory (Graybill 1979), including RWLIST (for data inspection), INDEX (for curve fitting procedures, to standardize ring widths), and SUMAC (for summaries of series of indices, analysis of variance, and cross correlation). Detailed multivariate analyses (Fritts 1976) will be performed to determine whether ring widths can be correlated with specific environmental parameters (e.g., precipitation chemistry, precipitation, temperature) routinely monitored at Coweeta.

H. CANOPY ARTHROPODS

Current Progress. In our first 5-year proposal we identified canopy arthropods and their feeding activities as an important area for long-term research. Occasional insect defoliations cause a moderate to severe perturbation in forested ecosystems. Defoliations may induce marked effects on nutrient cycling, with measureable impacts on forest floor processes and stream chemistry (Swank et al. 1981). Even nominal feeding can affect cycling of some nutrients (Seastedt et al. 1983).

While our research has centered on the importance of canopy arthropods in forest ecosystem processes, we have developed measurements in two ways. First, arthropod biomass has been measured using a trophic guild system. Second, feeding itself has been estimated by measuring leaf area removed (LAR). The use of functional or trophic guilds has allowed us to interpret shifts in arthropod groups and their impact on forest processes (Schowalter et al. 1981). During forest succession, for example, changes from leaf-chewing to sap-sucking guilds were documented, a change that we had predicted would occur following clear-cutting.

Our long-term research has pursued the objective of detecting changes in biomass of canopy arthropod trophic guilds, as a means of identifying long-term processes regulating folivory. We have sampled canopy arthropods in a series of watersheds on a rotating, three-year cycle, following our original proposal. Watersheds sampled included undisturbed hardwoods (WS 2, 18), successional hardwoods (WS 6, 7, 13), and white pine plantations (WS 1, 17). Data sets consist of estimates of arthropod mass intensities (g per kg foliage) for major tree species and biomass estimates (g per m^2) for the watershed, with weights available for each compartment in a 20-compartment model. (Leaf area removed has also been measured for all samples in the last two years). Our general hypothesis has been that long-term trends in biomass of the functionally defined trophic guilds would be detectable despite year-to-year variation. We further postulated that regular, predictable shifts would occur during forest succession and that more general long-term trends would be detectable on a basin-wide basis. Information on long-term trends or successional shifts would be essential for detecting gradual climatic or anthropogenic effects. So far, we have found surprising agreement in trophic guild structures over a 10-year period in undisturbed hardwood watersheds. Despite low variation, we have been unable to detect significant long-term trends in trophic groups for the Coweeta Basin and have accepted the null hypothesis, at least for the present. In comparisons of successional watersheds, predicted trends (Schowalter 1981) have emerged. Table 3 illustrates successional trends in arthropod mass intensities on chestnut oak. The table illustrates major shifts in aphid and caterpillar guilds through successional time, with sporadic development of other guilds such as tree crickets. These data are analyzed in detail and discussed in Schowalter and Crossley (1985).

Analysis of leaf area removed (LAR) was undertaken during three thesis projects partially supported by LTER (Hargrove 1983, Risley 1982, Yehling 1984). We had previously measured LAR in research on WS 18, 27, and 36. New methods using electronic digitizers have largely expanded our ability to measure LAR, and as a result we have begun to develop extensive data sets. Development and analysis of LAR is now funded in a separate project by NSF, and is supplementing our LTER data collection at Coweeta.

<u>Continuation and Refinement</u>. Our first 5-year program has been successful and we

Table 3. Arthropod mass intensities (mg/kg foliage) on chestnut oak (*Quercus prinus*) at Coweeta Hydrologic Laboratory, North Carolina.

	Watershed Age (yrs)			
Guild	1[a] (mg/kg)	2[a] (mg/kg)	13[b] (mg/kg)	>60[c] (mg/kg)
Phytophages				
Aphids and Aleyrodids	10	3	19	3 (3)
Other Sap-suckers	89	41	27	111 (29)
Caterpillars	21	34	397	160 (70)
Tree Crickets	268	6	60	110 (130)
Beetles	146	14	41	140 (131)
Leaf-miners	1	0	6	4 (4)
Flower-feeders	0	0	61	23 (15)
Bark and Wood Borers	1	2	0	35 (34)
Omnivores				
Ants	81	60	91	9 (8)
Predators				
Beetles	0	0	3	9 (19)
Lacewings	3	0	2	1 (1)
Flies and Wasps	4	6	5	5 (4)
Assassin Bugs	7	0	246	29 (23)
Spiders and Phalangids	9	45	84	90 (70)
Others	16	22	26	25 (33)
Total	656	233	1068	723 (130)

[a] Data from Schowalter et al. (1981).

[b] LTER data from Risley (1983).

[c] Unpublished LTER data. $\bar{x}$ + s.d.

propose to continue with the general scheme of measurement already in place. Recent developments suggest some changes in direction and some expansions which we will also attempt to implement. One is the gradual replacement of some of our biomass sampling with LAR measurement. Current results are encouraging, and suggest that LAR may prove more useful in tracking long-term trends in herbivory than are actual biomass measurements. This gradual substitution will leave room for some shifts in effort.

We will keep open the opportunity to change our sampling program in the event of a major defoliation developing in the Coweeta Basin. The Basin has been free of a major defoliation event for the past ten years; we may be overdue. Gypsy Moth traps have yielded positive results in nearby Smoky Mountain habitats. It is reasonable to suppose that the Gypsy Moth will invade Coweeta watersheds within the next five years. We hypothesize the development of phenomena similiar to those found in the defoliation of WS 27 and 36: increased nitrate concentrations in streams, increased rates of N transformations in soils, and accelerated rates of nutrient cycling generally (Swank et al. 1981).

Finally, we will increase the frequency of our sampling in evergreen watersheds. As described elsewhere, white pine WS 17 has experienced some damage from atmospheric oxidants; WS 1 has not. Canopy arthropods in these watersheds were sampled intensively in 1981 (Yehling 1984) and are now due for re-sampling. We ask whether forest stands stressed by oxidant damage become more susceptible to folivory. Also, we will initiate comparisons of Coweeta canopy arthropod biomasses, feeding and process-level effects with those being measured at H.J. Andrews. Schowalter and Crossley will cooperate in this intersite work.

I. SOIL AND LITTER SULFUR TRANSFORMATIONS

Research Progress. Sulfate has been identified as a major constituent of acidic precipitation in several regions of the United States, including western North Carolina. Studies at Coweeta show that this anion comprises about 63% of the total anion content of rain in this area (Swank and Waide 1985). Research with soil and litter from a hardwood forest (WS18) located in the Coweeta Basin indicates that microbial metabolism of sulfate to organic sulfur is a major pathway in the forest sulfur cycle (Fitzgerald et al. 1983, Swank et al. 1984). Because sulfate is immobilized by this process, organic sulfur formation could serve as a buffer against at least one negative impact of acidic deposition on forest soils—i.e., increased cation leaching.

Organic sulfur formation also generates a sulfur pool that could subsequently undergo remineralization. Release of sulfate by this means would negate the beneficial effects of organic sulfur formation by causing the mobilization of cations initially retained by forest soils. Organic sulfur generated from sulfate can be remineralized, but at rates substantially lower than those for organic sulfur formation (Strickland et al. 1984, Strickland and Fitzgerald 1984). Thus a net accumulation of insoluble organic sulfur does occur in forest soils at Coweeta.

Proposed Research. Work over the past 5 years on litter and soil from WS 18 has established a considerable data base on processes of organic sulfur formation and remineralization. We request funds to continue these analyses on samples collected on a quarterly basis from this watershed. We also wish to continue analyses of these samples for *in situ* levels of total S, adsorbed and soluble sulfate, and organic sulfur. The sulfur pool will be determined on the basis of ester sulfate, carbon-bonded sulfur, and amino acid sulfur content. The methodology for these determinations is now well established (Strickland and Fitzgerald 1984, Fitzgerald et al. 1984). Moreover, aquisition of an Ion Chromatograph under the previous LTER grant has now made it possible to determine accurately soluble and adsorbed sulfate. While organic sulfur formation and remineralization activities will be determined using ^{35}S, we also wish to explore possibilities of using ^{34}S (stable isotope) in field studies so that the long-term biological fate of sulfate can be monitored. The ^{35}S (radioactive isotope) is satisfactory for determining rates for these processes in laboratory assays; this approach has recently been verified by field incubations with this isotope (Strickland, Fitzgerald and Swank, manuscripts on *in situ* organic S formation and mineralization, in review). However, the short half-life of ^{35}S does not permit long-term studies.

J. ALUMINUM IN SOIL SOLUTION AND STREAM WATER IONS ON WS 27

Current Progress. Increased levels of aluminum in acid soils, in streamwater, and in lakes have been reported for regions of northeastern U.S., northern Europe, and Germany which are impacted by acid rain. Aluminum solubility increases with increasing H^+ concentrations. The distribution of total Al among Al^{+3}, $Al(OH)^0$, $Al(OH)^-$, $Al(OH)^{-2}$, $AlOH^{+2}$, $Al_2(OH)^{+4}$, $Al(OH)^+$, and organically bound forms changes with pH. The Al^{+3} form is most toxic to organisms. Presently we are measuring Al by species in rainwater, throughfall, soil solution, and streamwater on high-elevation control WS 27.

Proposed Research. In the upcoming 5-year period we propose to continue quarterly sampling of soil solution and streamwater. Analyses will be identical to those now in use. Briefly, samples are analyzed for pH and extracted for Al in the field. Samples are chelated with 8-hydroxyquinoline, then extracted with methyl isobutyl ketone, and later analyzed for Al by graphite furnace atomic absorption spectrophotometry. The following three fractions are obtained: (1) total Al by acidification of the sample to pH 1 for 1 hour prior to chelation, (2) monomeric Al by immediate sample chelation, and (3) non-labile monomeric Al by passing the sample through a cation exchange resin and chelating the eluant (Driscoll, 1984). Resulting data will be subjected to statistical analyses to test for time-dependent changes in concentrations of various Al fractions. If there are changes, then the search for causality would involve correlations with possible change in rainwater acidity or in the cumulative loading of H^+. Sampling will be expanded to other control watersheds if supported by other ongoing studies.

K. STREAM STUDIES

Stream studies have been an important part of the collaborative research effort between the University of Georgia and Coweeta Hydrologic Laboratory. Since the late 1960's stream research at Coweeta has been concerned with a functional understanding of streams of the southern Appalachians, with primary emphasis on effects of forest management. More specifically, our recent research has emphasized productivity by macroinvertebrate and meiofaunal communities, dissolved organic carbon (DOC) sources and dynamics, particulate organic matter dynamics (allochthonous inputs, decomposition, and seston transport), and the impact of forest management on these processes. Most of our results have been summarized in recent review articles (Webster et al. 1983, Meyer et al. 1985, Wallace 1985).

Research proposed for the next five years is in part a continuation of measurements that we have been making periodically for the past five or more years. It is essential that these studies continue if we are to develop a long-term data base that will allow us to understand processes and rates of stream ecosystem recovery from disturbance. The new work we propose is in response to two criticisms we received in reviews of our first five-year proposal and from our site review committee. The first criticism is that we need to expand our studies geographically. To meet this criticism we have proposed work on several higher elevation streams in addition to the four streams we have been studying intensively. We have also proposed parallel experiments at other LTER sites.

The second criticism is that we need to tie our stream research more closely to the terrestrial research on nutrient cycling. In response to this criticism, we propose to initiate a study of nutrient uptake in various streams at Coweeta and at other LTER sites. While measurement of nutrient spiraling length (uptake length + turnover length, Newbold et al. 1982) would be more desirable, this is beyond the scope of our resources. Simple measures of uptake length will, however, provide useful comparative measures of nutrient dynamics in various streams.

Allochthonous Inputs

Like most headwater streams in forested areas, allochthonous inputs of organic matter are the dominant energy resource in Coweeta streams (Webster et al. 1983). These inputs are altered by forest disturbance; hence one of the objectives of the LTER research has been to document the recovery of this important energy resource.

Allochthonous inputs (litterfall and lateral movement) to WS7 (throughout this section of the proposal we use watershed numbers to refer to streams and their watershed) were measured in 1974 (pre-logging), 1978, 1979, 1980, 1981, and 1983. Results of these studies show an almost complete loss of allochthonous inputs immediately after logging (Webster and Waide 1982) with a return to 80% of pre-logging levels in seven years, although the composition of allochthonous inputs was still quite different (Webster et al. in press). Measurements of litterfall have also been made for other watersheds: 6, 17 and 18 (Webster and Patten 1979) and 14 (Meyer and Tate 1983). We recently completed annual measurement of allochthonous inputs to WS 7, 6, 14, and 18 and are in the process of analyzing the results. Currently such measurements are also being made in research on WS 53, 54 and 55 under support of another NSF grant (Wallace, Effects of invertebrates on ecosystem processes).

We propose to remeasure allochthonous inputs to WS 6,7, and 14 in 1988. We will place 20 0.25-m^2 screen-bottom litter traps above or adjacent to each stream and 20 40-cm wide lateral movement traps along the banks of each stream. Traps will be emptied monthly for a year, and collected materials will be dried, weighed, and subsampled. Subsamples will be ashed to calculate AFDW.

Benthic Storage of Organic Matter

The amount of organic matter stored in stream benthos appears to be an important parameter in stream ecosystems, influencing ecosystem stability (Naiman and Sedell 1979) and the amount and pattern of organic matter export from streams (Minshall et al. 1983, Cuffney et al. in press). It is clearly affected by watershed disturbance (Webster et al. 1983, Cuffney et al. in press). Despite its importance, benthic storage of organic matter is an important measurement missing in our Coweeta stream studies. We have some measurements for a few streams (Webster and Patten 1979, Wallace et al. 1982, Webster et al. 1983, Webster 1983), but these measurements are quite incomplete. They were made only in mid-channel with 250 m^2 Surber nets and greatly underestimated the fine particulate organic matter in storage (Wallace et al. unpublished). We also have estimates of wood biomass in several streams at Coweeta.

Extensive measurements of benthic organic matter storage will be made in 1984-85 in WS 6, 7, 13, 14, and 18 as part of the current LTER grant and another NSF grant (Webster et al., Effects of forest succession on stream ecosystem stability). They are also currently being made on WS 53, 54 and 55 by Wallace et al. on another NSF-funded project (Effects of Invertebrates on Ecosystem Processes). We propose to repeat these measurements in these streams (WS 6, 7, 13, 14) in 1990 to determine how benthic storage changes with system recovery from disturbance. We will also include measurement in higher elevation reference steams, WS 27 and WS 36, to expand our geographical data base. These measures will be directly comparable to data from streams in the H.J. Andrews Forest and in other sites.

Within each stream, 10-20 random transects will be sampled for benthic organic matter using a 0.1-m^2 corer. Three cores will be taken at each transect with organic matter removed to a depth of 10 cm using a bilge pump or tin cup and filtered through 1-mm mesh net. Material remaining in the net will be dried, weighed, subsampled, and ashed to determine AFDW. Subsamples of material passing through the net will be filtered, dried, weighed, and ashed to estimate the AFDW of benthic FPOM. These surveys will be conducted seasonally for one year. CPOM collected by this coring technique will include woody material less than 1-cm. An additional survey will be conducted once on each stream to estimate the standing stock of large (>1-cm dia.) woody debris using the line intersect techniques described by Wallace and Benke (1984).

Stream Geomorphology

No efforts have been made to document any long-term changes in stream geomorphology at Coweeta. We will initiate studies comparing channel structure and form with the long-term objective of comparing streams draining a disturbed watershed (WS 7) with that of a reference catchment (WS 14). We will install 10 monumented cross sections on each stream with each site marked by permanent metal stakes on each bank. Distances below a level compass line extending across the stream will be used to measure the following parameters: 1. bank-full cross-sectional area; 2. wetted cross-sectional area; 3. hydraulic radius; and 4. wood (line intersect method [Wallace and Benke 1984] and mapping). Each monumented cross section will include maps (extending 1 meter upstream and downstream), photo documentation of sites, and notes on substratum and riparian vegetation. These will be established during the summer of 1986 and examined annually thereafter. These data will be directly comparable to information being collected at other LTER sites (e.g. H.J. Andrews).

Leaf Breakdown Rates

Rates of leaf breakdown were measured in WS 7 before, during, and immediately following logging (Webster and Waide 1982). Results of that study showed that logging significantly affected leaf breakdown rates. Leaf breakdown rates were remeasured in WS 7 in 1982 and compared with leaf breakdown rates in WS 14 (reference watershed). Also, Meyer and Johnson (1983) measured rates of leaf breakdown in WS 18 and WS 6 and attributed the faster leaf breakdown rates in WS 6 to higher nitrate levels.

To follow up these studies, we propose to measure leaf breakdown rates in these four streams (WS 6, 7, 14, 18) in 1988. We will use white oak, dogwood, rhododendron, and sweet birch leaves in WS 7 and 14; and sweet birch, black locust, dogwood, and white oak leaves in WS 6 and 18. We will use the same techniques as we have used in previous studies. On WS 6 and 18 we will identify benthic insects from the litter. These will be compared with benthic samples collected the same year (see Benthic Invertebrate section) to determine if leaf bags are serving as islands of a limiting resource (c.f. Webster and Waide 1982, Meyer and Johnson 1983).

Bacterial Biomass in Coweeta Streams

Rates of bacterial production appear to be considerably greater than primary production in Coweeta streams (Meyer et al. 1985). Hence bacteria may be an important food resource for stream-dwelling organisms, particularly the meiofauna. Bacterial abundance and production vary greatly between sites within a stream; some of the variability appears to be related to sediment organic content (Meyer et al. in press). The best way to arrive at an estimate of bacterial abundance in Coweeta streams is to clarify the relationship between bacterial biomass and sediment organic content. We propose to count bacteria in sediment samples with varying % organic matter from WS 6, 7, 14 and 18 using established techniques (Meyer et al. 1985). These will allow us to develop a good regression between % organic matter and bacterial biomass. Twenty sediment samples (top 5 cm) will be collected monthly with a corer (1 cm dia.), and bacteria will be counted using epifluorescent direct counts (Hobbie et al. 1977). Organic content will be determined by ashing the sediments. These data can then be used in conjunction with information on organic matter standing stocks in streams draining watersheds with different treatment histories (as described above) to determine bacterial biomass in different Coweeta streams.

Seston Transport

Seston is a major component of organic matter export from stream ecosystems, it is also the food resource for filtering collectors, an important functional group in Coweeta streams. Measurements of seston transport in Coweeta streams were begun in 1977 with a comparison of seston transport in WS 7 shortly after it was clearcut with seston transport in WS 14 (Gurtz et al. 1980). That study showed highly elevated seston transport resulting from logging. Subsequent measurements showed slow recovery over the next six years (Webster et al. 1983, Webster and Golladay 1984). In 1981-82 we collected monthly samples of seston from 12 Coweeta streams (including WS 7 and 14), and in 1982-83 we expanded this study to 17 streams (Webster and Golladay 1984, Webster et al. 1985). Results of these studies indicated that seston levels remained significantly above reference levels more than 20 years after a watershed disturbance such as logging.

We propose to resample 10 of these streams in 1989 to follow recovery from disturbance. These include two low-elevation reference streams (WS 14 and 18), four low-elevation disturbed watersheds (WS 6, 7, 13, and 17), two mid-elevation reference watersheds (WS 21 and 34), and two high-elevation reference watersheds (WS 27 and 36). Samples will be collected bi-monthly during non-storm periods. Sampling procedures will be the same as those used in previous studies.

Streamwater DOC

Much of the organic matter lost from Coweeta watersheds is in the form of DOC, which provides a carbon source for stream-dwelling microbes (Meyer et al. 1985). We have been sampling WS 7 and 14 since 1979 to follow changes in stream water DOC concentration as a watershed recovers from disturbance (clearcutting). During the first year of sampling (two years after disturbance), DOC concentration and export were lower in the disturbed stream than in the reference (Meyer and Tate 1982). We hypothesized that as succession proceeded and standing crop of leachable organic matter increased in the watershed and streambed, DOC concentration in the disturbed stream would increase to levels observed in the undisturbed stream. We have observed a general pattern of increasing DOC concentration in the disturbed stream over the past five years (Meyer et al. 1985). We propose to continue DOC sampling in the two streams at weekly intervals to detrmine how long it takes for this aspect of the stream ecosystem to recover.

Benthic Invertebrates

At Coweeta, we have documented large changes in benthic invertebrates in response to watershed disturbance (for review, see Wallace 1984). We have compared streams during and immediately following logging (Gurtz and Wallace 1984), and two or more years following cessation of logging (Woodall and Wallace 1972, Webster and Patten 1979, Haefner and Wallace 1981, Gurtz and Wallace and Wallace et al., unpublished data). During the next five years, we propose to continue our long-term studies on four watersheds, WS 6, 7, 14, and 18. In addition, we are completing an intensive invertebrate study of a high elevation Coweeta stream which drains WS 27.

Substrate type is an important factor regulating the response of stream invertebrates to disturbance (Haefner and Wallace 1981, Gurtz and Wallace 1984).

During the initial clear-cutting of WS 7, more taxa increased in density in larger, more stable substrates whereas more taxa decreased in smaller, unstable substrates (Gurtz and Wallace 1984). We have completed preliminary analysis of 112 quarterly samples from WS 7 and 14 which document a decline in scraper (grazer) functional feeding group densities and an increase in shredders during the last five years of recovery. However, significant differences remain between streams for a number of taxa. Furthermore, intensive sampling of moss-covered rock outcrops during 1983-85 indicates extensive differences between WS 7 and 14 with respect to invertebrate taxa, invertebrate densities per m^2 of substrate, the rapidity of organic and inorganic loading, particle size distributions trapped by the "moss," and percent ash of transported materials trapped by the "moss."

During the next five year period, invertebrate work at Coweeta will focus on the following aspects:

1. Continue long-term recovery studies of macroinvertebrate populations in streams draining WS 6 and 7, and the reference streams WS 18 and 14.

During 1988, we will initiate monthly sampling of streams draining WS 6 (treatment) and 18 (reference). This will represent 20 years of natural succession from old field (grassland) to hardwood forest. The streams were intensively sampled in 1968 (Woodall and Wallace 1972) and 1978 (Hefner and Wallace 1981). Sampling schemes established for streams draining WS 7 (clear-cut 1977) and WS 14 (reference) will also be conducted during 1987-1988 using techniques described by Gurtz and Wallace (1984).

2. Continue emphasis on contrasting patterns of secondary production of invertebrates between streams draining manipulated and reference watersheds (e.g., Haefner and Wallace 1981b, O'Hop et al. 1984, Wallace and Gurtz in press and in preparation).

3. Expand recently initiated field growth studies of invertebrates which have multivoltine life cycles or short generation times. These include chironomids, other insect taxa, and copepods. At Coweeta, we have focused on the role of invertebrates

in stream ecosystems (Wallace et al. 1977, Webster and Patten 1979, Wallace, Webster and Cuffney 1982, Webster 1983, Cuffney et al. in press). To assess this role, reasonable estimates of secondary production are mandatory. Recently initiated field growth studies for the most abundant macroinvertebrates in Coweeta streams, the Chironomidae, indicate growth rates ranging from 2% of larval AFDM/day at 0.5° C to > 20% per day at 15°c (Huryn and Wallace, unpublished data). In essence, this means that P/B ratios of this group may be up to 10X higher than previously suspected for these cool headwater streams. Benthic copepods are abundant in these streams and also have high turnover rates (O'Doherty in press). In situ growth studies of these copepods are currently being initiated. It is crucial that we measure production of groups such as chironomids and copepod that are rapidly turning over if we are to assess the role of invertebrates in Coweeta streams.

4. Complete documentation of the invertebrate fauna of a high elevation Coweeta stream draining WS 27 (currently being supported by modest funds from the U.S. Forest Service and Georgia Power Company). This study involves complete documentation of invertebrate species, densities, biomass, growth rates, secondary production by substrate type, leaf litter breakdown rates, and invertebrate taxa colonizing litterbags. The purpose of this study is to establish a data base in order to detect any long-term potential influence of acidic precipitation on high-elevation stream communities at Coweeta.

Debris Addition Experiment

Because of the documented importance of wood as a retention device in stream ecosystems (e.g., Bilby and Likens 1980), we consider it important to begin following the history of debris dams in Coweeta streams. We propose to do this by experimentally creating debris dams and monitoring long-term changes in streambed geomorphology, organic matter accumulation, log decomposition and nutrient uptake associated with these debris dams.

In three 20-m reaches of a stream, we will double the amount of wood naturally present by adding tulip poplar logs to the stream. We will establish monumented cross sections at each debris addition site (stakes on each bank at the debris dam and at 1 m intervals for 5 m upstream and 3 m downstream). We will measure cross-sectional profiles from a level compass line by extending a surveying rod (at 10 cm intervals along each level line) down to the substratum in order to obtain cross-sectional areas at bank-full width and wetted cross-sectional area. This will allow us to obtain a three-dimensional profile of each debris addition site. Measurements will be made prior to and immediately following debris additions, at 6 mo intervals during the first year and annually thereafter to assess changes in channel morphometry. Annual core samples will be made to the depth of the original stream substrate as indicated by our original measurements of cross-sectional area. Material retained in core samples will be dried and ashed to estimate inorganic and organic accumulations through time at each debris addition site. We will follow log decomposition annually by measuring diameter and density of the outer 1 cm and the rest of the log. Changes in nutrient retention characteristics with aging of the dam will be evaluated as described in experiment 4 below.

Nutrient and DOC Uptake by Streams

Elements and organic matter exported from terrestrial systems enter streams, and may be influenced by their residence in the stream prior to export at the weir. Most previous research at Coweeta has generally not attempted to distinguish the role of the stream ecosystem in regulating elemental or organic matter losses from the watershed. Swank and Caskey (1982) examined denitrification in streams and found significant losses of nitrogen from the streambed. Other studies at Coweeta have shown that concentrations of nitrogen and some other elements are higher in groundwater seeps than in stream water (Golladay and Webster, unpublished data). In addition, high rates of DOC uptake (sucrose and leaf leachate) have been measured in some Coweeta streams (Meyer et al. in press). Uptake rates for phosphorus have been measured in two small Coweeta streams (Elwood et al. unpublished data). These observations suggest that some elements are being removed from the water; hence their export from the watershed is being affected by processes occurring in the stream

(Webster and Swank in press).

With these observations in mind, we are proposing a series of nutrient and DOC addition experiments to measure uptake rates in several Coweeta streams. We predict that nutrient uptake rate will change with temperature (i.e., with season) and nature of the streambed. Since watershed disturbance changes the streambed in a number of ways such as altering algal biomass, sediment organic content, nature and number of retention devices (logs), we anticipate different uptake rates in watersheds with different treatment histories and at different stages of recovery from disturbance. On a larger scale, we anticipate differences in nutrient retention by streams in different geological regions and with different hydrologic and geomorphic regimes. To examine these differences we are also proposing nutrient addition experiments at other LTER sites.

Uptake rates for NO_3, SRP, Ca and DOC will be measured in five experiments. Concentrations of each element will be elevated in stream water to an order of magnitude above baseline concentration or to stormflow concentrations, whichever is higher. Sodium will be added as an inert tracer to allow us to calculate dilution. Nutrients will be added to the stream for periods of 2 hours. During the first hour, concentrations will be allowed to stabilize, and no samples will be taken. For the next hour, samples will be taken at 10-m intervals over a 50-m reach (20 m in some experiments) every 15 minutes and filtered immediately. To reduce the number of addition experiments that need to be done, we will add NO_3 and SRP together and add DOC (glucose) and Ca together.

At the time of each addition we will measure stream width and hydraulic radius. On one occasion we will map each reach, estimating amount of wood and percent riffle, debris dam, and granite outcrop in each reach. We will also take measures of organic matter standing stock in each stream (section on Benthic Organic Matter).
Proposed new experiments include: 1. Seasonal changes in uptake rates. We will measure uptake rates in three reaches per stream seasonally for one year. Rates will be measured in streams draining watersheds with different disturbance histories and

about which we have considerable additional data: WS 6, 18, 7, and 14.

2. Inter-site comparison. During early summer, we will measure uptake rates in three reaches of streams of comparable size to those used at Coweeta at four other research sites. We will select the sites from the following list, which includes sites that have suitable information available on stream processes: H.J. Andrews Experimental Forest, Oregon; Konza Prairie, Kansas; North Inlet, South Carolina; Niwot Ridge, Colorado; Hubbard Brook Experimental Forest, New Hampshire; and Oak Ridge National Laboratory, Tennessee.

3. Changes in uptake rate with watershed recovery. Four years after the first experiment is done, we will remeasure uptake rates during the summer in the four watersheds used in experiment 1 (WS 6, 18, 7, 14) to determine if there have been significant changes in the ability of the streambed to retain dissolved nutrients and organic matter in response to forest succession on WS 6 and 7.

4. Debris addition experiment. In conjunction with the debris addition experiment described above, we will measure nutrient uptake rates in the experimental reaches before and after debris additions during the first year and annually during the following summer.

5. Substrate-specific uptake rates. To facilitate interpretation of the data gathered in the above experiments, we will measure nutrient uptake rates over 20-m reaches of WS 14 that can be characterized as being predominantly debris dam, granite outcrop, or riffle areas. Although it would be desirable to do this seasonally, we will only have the resources to do it during one summer.

III. LTER INTERSITE RESEARCH

Accomplished. Coweeta investigators have actively pursued collaborative research and consultation opportunities with scientists at other LTER sites. During the first 5-year phase of LTER research, contacts have been established with appropriate scientists for purposes of information exchange and development of research hypotheses. Most contacts were initially informal, as might be expected during early project phases. Meetings and workshops sponsored by the LTER Steering Committee are now leading to more structured cooperative research efforts. The Coweeta project has maintained its strong ties with the H. J. Andrews LTER project, since both projects have a long history of cooperation. Coweeta personnel have frequent informal interactions with Okefenokee Swamp LTER personnel; we share laboratories and other facilities at the Institute of Ecology in Athens. Frequent informal contacts and exchanges of personnel have also developed with the North Inlet LTER project, the Konza Prairie LTER project, and to a lesser extent with the Jornada Desert LTER project.

Some specific collaborative efforts are listed as follows: Swank provided consultation on methods and opportunities for gaging streams on Konza Prairie watersheds and he will continue to cooperate on hydrologic studies. Fitzgerald, Swank and Blood initiated a cooperative study at North Inlet on sulfate dynamics in a loblolly pine stand. Previous research at Coweeta formed the basis for the hypotheses of this study which address questions of sulfate transformations to organic sulfur forms by microbial metabolism and subsequent mineralization of various organic forms of sulfur. In addition to forest floor and soil assays, the dynamics of sulfate and other nutrient transfers are being examined in the stand; the study is now in the second year of investigation. Fitzgerald and Swank have also initiated a project to examine potential sulfur metabolism and mineralization, and sulfur pools in soil and litter, at approprate LTER sites in addition to sampling in important non-LTER ecosystem types. Crossley has pursued compararisons of herbivory estimates with scientists at Konza Prairie (Seastedt) and H. J. Andrews (Lattin, Schowalter), using newly developed techniques for measuring leaf area removed (LAR). Gist and Crossley have compared arthropod guild structure in tree foliage at Coweeta and in the Okefenokee Swamp, using a trophic guild model developed at Coweeta. Bumper traps and artificial spider webs developed for use in the Okefenokee Swamp project (Gist) were evaluated on WS 6 and 18 at Coweeta (Risley).

In collaboration with H. J. Andrews, Swank and Ragsdale established two one-ha reference stands at Coweeta and completed stand measurements. Establishment of two additional reference stands is projected for 1986. Andrews scientists have provided on-site assistance in this project. Protocol provided by H. J. Andrews was used whenever possible, which should enhance comparative interpretations of stand dynamics.

Coweeta scientists working with stream systems have established effective formal cooperative efforts with stream workers at other sites, following the general LTER meeting at Las Cruces. As a result, comparability of data sets has been assured. We have planned a second workshop for September 1985 on organic matter in streams, in which available data sets will be evaluated. Specifically, Coweeta data sets which will be compared with others include: allochthonous inputs (Andrews, Konza), benthic storage of organic matter (Andrews), leaf breakdown rates (Andrews, Konza), streamwater DOC (Andrews, Niwot Ridge), and benthic invertebrates (Andrews, Konza).

Proposed. Several areas of significant intersite LTER research are anticipated for the next 5-year period. Informal contacts established with a number of scientists at other sites should become formalized, so that comparisons of existing data sets can lead to the formulation of further, cross-site research questions. Some comparisons have been completed, and during the first year of new funding we will be preparing open-literature manuscripts describing results. In new work, collaboration of Swank and Waide with Jim Halfpenny and other investigators at Niwot Ridge will focus on nutrient cycling analyses from the standpoint of ecosystem stability. This effort will be initiated through a joint meeting of interested investigators at the two sites, where nutrient recycling data sets for Coweeta will be used to illustrate concepts. This exercise should lead to the formulation of a research framework helpful in identifying priorities for process-level studies.

Several areas of close collaborative research are planned with H. J. Andrews investigators. One deals with evaluating impacts of whole-tree harvesting practices on site productivity. The Andrews site is proposing a manipulative experiment on this topic, and Coweeta has a study on the same subject that is now in the fifth year of investigation. Both studies are approached from the process level. Swank and Waide will collaborate in exchanging experience on methodology and results to facilitate future comparisons of responses and changes in biogeochemical processes. Collaboration on modeling approaches in this area is also possible. Another area of cooperation deals with comparative analyses of long-term precipitation and stream chemistry data sets between Coweeta and Andrews. This information has been summarized at Coweeta but similar analyses are not currently available at Andrews. Swank and Waide will cooperate with Dennis Harr or designated investigators at Andrews to summarize and interpret Andrew's data sets at a level suitable for system-level comparisons. A study comparing standing crops and dynamics of woody debris is planned as a cooperative effort with Andrews personnel (Harmon, Franklin) for 1987-1989. A reciprocal Coweeta-Andrews study of wood decay is planned for initiation in 1987. New research on invertebrate consumers will involve comparisons of impacts of soil animals on decomposition processes. Crossley is planning with Seastedt (Konza) and scientists at Oregon State (Lattin, Cromack) for a comparative analysis of the influence of soil invertebrates on decomposition and nutrient cycling processes. Comparative research on canopy arthropods involving Coweeta and H. J. Andrews will be continued (see: H. Canopy Arthropods).

We anticipate the continuation of the strong collaborative effort already developed between stream scientists at Coweeta and other sites. Among new studies, we propose a major intersite research effort on nutrient and DOC uptake and retention in streams. During summer 1988 Wallace, Webster, and Meyer will travel to four other research sites to measure uptake rates in three reaches of streams of comparable size to those used at Coweeta. We will use the same techniques as those used in our studies at Coweeta. We will select the sites from the following, which have suitable information available on stream processes: Andrews, Konza, North Inlet, Niwot Ridge, Hubbard Brook, and Oak Ridge National Laboratory.

IV. SITE DESCRIPTION

The Coweeta Hydrologic Laboratory is a 2185 ha experimental facility located in the southwest corner of North Carolina, in the southern Appalachian Mountains. The site is administered by USDA, Forest Service, Southeastern Forest Experiment Station and has been dedicated to forest hydrology research since its establishment in 1933. The area lies within the Blue Ridge geologic province; elevations range from 679 to 1592 meters. The diverse topography includes valley bottoms, coves, different slope positions, and ridges; sites vary from very high to very low productivity. More than 50 km of streams drain the area (Wallace 1985) and include first- through fourth-order drainages which flow to the Little Tennessee River.

The regional climate is classified as marine with cool summers, mild winters, and adequate rainfall during all seasons. Precipitation is typically cyclonic in origin with air masses frequently coming from the Gulf of Mexico and sometimes from the Atlantic Coast or subarctic regions of North America. The steep mountains produce orographic precipitation and frequent thunderstorms during summer months. Annual precipitation is high and variable over the area, with an average of 178 cm at lower elevations to over 250 cm on upper slopes. Snow typically contributes less than 2 percent to total precipitation. October is usually the driest month with an average precipitation of 9 cm; the wettest month is March, with 20 cm. Coweeta is the first major mountain range contacted by air masses moving over the industrialized Piedmont region to the south. Analyses of precipitation chemistry have shown the influence of both local and regional activities on nutrient inputs to forest ecosystems at Coweeta (Swank and Henderson 1976, Swank 1979, 1984). Changes in the form and amount of anthropogenic inputs are important to the interpretation of many ecosystem processes.

The streamflow regime follows an annual pattern which is similar to precipitation, and perennial flow occurs for watersheds as small as 6 ha. Quickflow (or direct runoff) comprises less than 10 percent of the total runoff on low-elevation watersheds, and there is essentially no overland flow on undisturbed catchments. Mean annual temperature is 13° C. The coldest month is January with a mean temperature of 3.5° C; July is the warmest month with a mean of 21° C.

Experimental areas are distributed over the wide range of environmental gradients found on the area and include both control and manipulated ecosystems. Research has been conducted on 8 mixed hardwood control areas and 13 catchments where forest management prescriptions have been applied. Past treatments include varying intensities of cutting ranging from light selection through clearcutting; conversion of hardwoods to white pine; conversion of hardwoods to grass and subsequent succession to hardwoods; multiple use management; mountain farming; and the application of herbicides and fertilizer. Research histories of each area are documented in numerous publications and reports. The history of the Coweeta Basin and research program are documented by Douglass and Hoover (1985). Swift et al. (1985) summarize the long-term climatology and hydrometeorology of the Coweeta Basin, while Swift and Cunningham (1985) describe procedures for summarizing and interpreting these long-term data records.

V. DEVELOPMENT OF FACILITIES

During the past 5 years, substantial progress was made in the development and expansion of laboratory, field, and office facilities. Resources for facilities development were provided in part by USDA, Forest Service, and in part by National Science Foundation with LTER funds.

Specific accomplishments include the following items: (1) completion of a new office building (constructed by LBJ Civilian Conservation Center) containing 2050 $ft.^2$ with six offices, library, and other facilities; (2) construction of a flammable storage and oil house (LBJ CCC construction) with 384 $ft.^2$; (3) construction of a new weir and initiation of the calibration period; (4) purchase of a gas chromatograph, carbon analyzer, ion chromatograph and other smaller items of lab equipment; (5) addition of modern data processing equipment; (6) communications improvement through purchase of a microwave system which interfaces with the National Forest system network for FTS; (7) construction of a 225 $ft.^2$ chemical storage building; (8) installation of a 6600 ft. transmission line to provide power to Watershed 17 for future research; and (9) initial construction phase of an additional office-data processing building (4300 $ft.^2$).

During the next 5 years, we anticipate the addition of several major facilities. The office-data processing building currently under construction is scheduled for completion in December 1985. Upon completion, staff and equipment currently housed in the old office will be moved to the new building. The old office (2700 $ft.^2$) will be refurbished to provide office space for visiting scientists and graduate students, herbarium display, long-term sample storage, and overnight living accommodations for 1-2 visiting scientists. The most critical need at Coweeta is a dormitory facility to house principal investigators and graduate students conducting research at the site. There are currently about 80 scientists with active on-site studies; the existing 8-person trailer facility is wholly inadequate to accommodate overnight requests. The surrounding area is strongly oriented toward tourists and rentals are quite high. Clearly, the maintenance and further development of Coweeta as a site for long-term ecological research hinges on the availability of overnight facilities. We anticipate the submission of a proposal to the Biological Research Resources Program of NSF to request support for this facility.

VI. MANAGEMENT OF SITE AND PROGRAMS

A senior technician was added in the last year of the current LTER grant to facilitate daily on-site research and management activities. Previously, these responsibilities were split between Crossley and Swank; the new alignment provided a more efficient and consistent method for managing day-to-day LTER operations. This senior staff member also had specific on-site research assignments and the responsibility for maintaining assigned intersite LTER projects. Funding was inadequate to retain this position in the 5-year renewal proposal and we will shift back to the previous arrangement with an associated reduction in effort.

Formal management of the research program will continue to be accomplished through semiannual information meetings involving PI's, students, and technicians. The experience of our group has shown that this frequency is adequate to provide the overall communication needed for integration and interaction between investigators. We will also continue to utilize our LTER advisory committee for research program guidance with 2- to 3-day meetings scheduled at 12- to 18-month intervals.

A site use form provides a formal mechanism for reviewing, approving, and tracking new studies; this procedure will continue to be used as a management tool. All substantive research projects conducted at Coweeta are under formal cooperative agreement with the Southeastern Forest Experiment Station; this legal form of management will be continued.

In the past year, the Forest Service has invested substantial effort in improving data processing capabilities. The processing center contains a Data 100 Series 70 terminal which is used as a remote job entry station connected by dial-up line to the University of Georgia. The terminal components include a card punch, card reader, 300 LPM printer, 800 BPI magnetic tape drive, 10 Mb disk drive, 4800 Baud modem, and a key station used as a key batch system using the mainframe at University of Georgia. Other additions include an Apple II+ with 64k memory, two floppy disk drives, Diablo 630 printer, Mountain Computer CPS, and a 1200 Baud modem. The Numonics Digitizer used to digitize strip charts can be interfaced with the Apple computer and climatic station cassettes are also transferred to the Apple II for data reduction. The Fischer-Porter tape translator reads ADR tapes to the Apple II for data reduction and storage on tape at Universituy of Georgia. An Apple II+ with two disk drives and a small printer are interfaced with analytical equipment in the Laboratory.

Several additional program management aids were developed at the site during the past several years. These include an annotated bibliography of Coweeta publications for the past 50 years, layman's guide to the research program, and an excellent 18-minute slide-tape program that summarizes Coweeta research activities. An IBM PC located at the Institute of Ecology in Athens is the major data management tool in use there. Communication with the mainframe and with subcontractors at Emory Univeristy utilizes a 1200 baud modem. We expect to complete a data transfer system between Athens, other subcontractors, and the Coweeta laboratory by the end of the year.

VII. COOPERATIVE RESEARCH

This section of our proposal provides documentation for some of the cooperative research currently ongoing at Coweeta. It would be impossible to list all of the informal and semiformal research contacts which continue to be made at the laboratory itself. These contacts range from casual ones by visiting scientists to 1-2 day visits or longer stays. Likewise, investigators housed at the Institute of Ecology in Athens discuss Coweeta data with other scientists and visitors.

Principal Investigators on the Coweeta LTER project are also conducting short-term research at Coweeta. Many of these short-term projects are documented in CV's for the investigators (Appendix IV). Also PI's are involved in other long-term research projects, many through the Institute of Ecology (the Horseshoe Bend Agroecosystem Project, for example). Most of these projects are also listed in CV's.

Tables provided in this Section document active Cooperative Agreements and non-LTER site use. Studies are managed through Cooperative Agreements with the Southeastern Forest Experiment Station. The non-LTER site use involves studies with infrequent sampling or those which are conducted under the master Cooperative Agreement with the University of Georgia.

Use of experimental sites at Coweeta has accelerated during the first phase of LTER and we expect the trend to continue in the next five years. Excluding LTER projects, there are a number of current studies involving many different investigators who encompass a wide variety of disciplines. Much of this research is directly related to LTER objectives and partially utilizes the data base while also contributing information to the program. An example of sub-project interrelationships for one topical research area, atmospheric deposition, is given in Figure 6. Forest Service scientists also have active cooperative studies on a national scale, which involves investigators in other agencies and institutions such as Oak Ridge National Laboratory, Hubbard Brook, Clemson University, and the University of Washington among others. Several studies have been initiated with scientists from other countries including England, Italy and Mexico.

ACTIVE COOPERATIVE AGREEMENTS

Cooperator	Number and Title	Funded by Forest Service (Lump Sum)	Collected by Forest Service (Annually)	No Money Exchange
Agricultural Research Service	Compliance agreement for disposal of soil samples			X
Department of Army	Special use of Coweeta Hydrologic Laboratory area for training of Army forces			X
Clemson University	18-409, Supplement - Study of natural variability in soil and nutrient export			X
Clemson University	18-409, Supplement - Habitat utilization of wild turkey poults in Southern Appalachian Mountains			X
Colorado State University	18-708 - National Atmospheric Deposition Program Study NC-141	4,779		
Department of Energy	DE-AI05-790R20313 - Ecosystem effects of whole-tree harvesting		25,000	
Department of Energy	DE-AI05-820R21012 - Comparative evaluation of the impacts of acid precipitation on forest soils		15,000	
Department of Energy from Electric Power Research Institute	Acidic deposition effects on forests		30,000	
Electric Power Research Institute & TVA	Evaluation of the ILWAS model which was developed for Adironadach Mountain conditions on a Southern Blue Ridge watershed at the Coweeta Hydrologic Laboratory			X
Emory University	29-034 - Acid rain interactions with forest canopies at the Coweeta Hydrologic Laboratory	32,816		

ACTIVE COOPERATIVE AGREEMENTS

Cooperator	Number and Title	Funded by Forest Service (Lump Sum)	Collected by Forest Service (Annually)	No Money Exchange
Franklin High School	Provide support for high school science projects in the Academy of Science	145		
Georgia Kraft, UGA Cooperative Extension Service	Detailed monitoring and investigation of the mechanisms of Carbofuran off-site movement in a Piedmont seed orchard			X
University of Georgia	12-11-08-876, Supplement 32 - The water, energy, and nutrient balance of small Southern Appalachian watersheds			X
University of Georgia	18-826 - Comparative studies of forested watersheds at Coweeta Hydrologic Laboratory, North Carolina (LTER)		15,000	
University of Georgia	Community regulation in stream fishes and its relationship to forest land management			X
University of Georgia	A study of plant sulfolipids as a source of sulfate in forest soils			X
University of Georgia	18-959 - Impact of acid precipitation on forested ecosystems: fate of inorganic sulfate	9,000		
University of Georgia	12-11-008-876, Supplement 67 - Fish communities in poorly and moderately buffered streams of the Blue Ridge Province	15,000		
University of Georgia	12-11-008-876, Supplement 69 - Impact of acid precipitation on forest ecosystems: organic sulfur input to and export from watersheds of the Coweeta Basin	19,000		
University of Georgia	12-11-008-876, Supplement 71 - Invertebrate population structure, secondary production, and detritus processing in a high-elevation Coweeta stream	10,200		

ACTIVE COOPERATIVE AGREEMENTS

Cooperator	Number and Title	Funded by Forest Service (Lump Sum)	Collected by Forest Service (Annually)	No Money Exchange
University of Georgia	12-11-008-876, Supplement 81 - Symposium and publication of hydrological and ecological research at Coweeta Hydrologic Laboratory	15,000		
University of Georgia	12-11-008-876, Supplement 82 - Influence of acidic precipitation on organic sulfur mineralization in soil and litter from a hardwood forest	25,000		
University of Georgia	12-11-008-876, Supplement 83 - Potential sulfur emissions from Southern Appalachian forest trees	6,000		
University of Georgia	12-11-008-876, Supplement 85 - Aluminum distribution in a Southern Appalachian forested ecosystem	8,000		
University of Georgia	12-11-008-876, Supplement 89 - Effects of atmospheric deposition on elemental accumulation, cycling, and losses in a forest ecosystem	4,000		
University of Georgia	- A study to examine the influence of invertebrates on ecosystem processes in Southern Appalachian streams using a manipulative approach		6,105	
University of Georgia	Effects of ozone on plant-water relations and net photosynthesis in a white pine plantation	12,000		
Georgia Tech	29-144 - Characterization of organic acids in forest soil environments	10,870		
Lake City Junior College	Recruising of permanent plots, establish water-shed boundaries and timber stand data			X

ACTIVE COOPERATIVE AGREEMENTS

Cooperator	Number and Title	Funded by Forest Service (Lump Sum)	Collected by Forest Service (Annually)	No Money Exchange
University of Maine at Orono	29-104 - A comparative interregional analysis of aluminum biogeochemistry in forested watershed exposed to acidic deposition		1,000	
Man and Biosphere Program	Nitrogen dynamics of forest ecosystems in the Great Smoky Mountains National Park		Continuing	
University of North Carolina	Supplement 3 - Using Plethodone experiments to provide definitive tests of important theories of how the distribution and abundance of animals are determined, and what is the critical problem of population and community ecology			X
University of North Carolina	18-967 - Biosphere reserves as reservoirs of genetic resources	58,325 1/		
University of North Carolina at Asheville	Analysis and recommendation for oxidant monitoring station	4,000		
North Carolina State University	A8fs-20,147, Supplement 146 - A study of nitrogen losses from a disturbed forest ecosystem via nitrification and denitrification			X
Soil and Water Conservation District, Macon County	Plan, apply, and maintain soil and water conservation measures where practical with research being conducted on Coweeta Hydrologic Laboratory			X
Southwestern Technical College	To assign students as field assistants and lab assistants to assist scientists in conducting forest research			X

1/ Funded by MAB and administered by SEFES

ACTIVE COOPERATIVE AGREEMENTS

Cooperator	Number and Title	Funded by Forest Service (Lump Sum)	Collected by Forest Service (Annually)	No Money Exchange
Virginia Polytechnic Institute & State University	A study of soil and nutrient losses from first order drainages, prepared for planting pine by three methods of mechanical site preparation			X
Virginia Polytechnic Institute & State University	29-040 - Population biology and acid tolerance of crayfish species in Coweeta streams	20,165		
Virginia Polytechnic Institute & State University	29-103 - Examine stability of streams in relation to forest succession by comparing nutrient budgets		6,000	
Wayah Ranger District	Spells out responsibilities of SEFES and Wayah Ranger District in regard to such things as environmental analysis statements, timber management and culture work, free uses, roads and trails, recreation, law enforcement, fire control, etc.			X
Western Carolina University	18-885 - Nitrogen and other mineral cycling studies in the Great Smoky Mountains National Park	Continuing		
Western Carolina University	29-058 - Visitor education program for Coweeta Hydrologic Laboratory	3,000		
Western Carolina University	29-085 - Multimedia interpretation of the CHL commemorating 50 years of contribution to science	5,000		
Yale University	To assess parent rock chemistry, mineralogy, and texture on dissolved and solid products of rock-water interactions during weathering			X

NON-LTER SITE USE (Not Under Formal Cooperative Agreement)

COWEETA HYDROLOGIC LABORATORY

STUDY TITLE	ORGANIZATION	PRINCIPAL INVESTIGATOR
1. A study of the decomposition rates and microarthropod fauna of leaves of three tree species on two watersheds with different treatment histories (watersheds 2 and 7).	University of Georgia	John M. Blair
2. Taxonomic Research - Entomology (Tabanids & Cerambycids & Thrips)	University of Georgia	Ramona J. Beshear & Roy Morris
3. Participation of land snails in calcium cycling in forested ecosystems. Effects of acidic forest floors on calcium utilization.	Arkansas College	Ronald L. Caldwell
4. Community Regulation in Stream Fishes and Its Relationship to Forest Land Management. Purpose: This investigation will provide information relevant to a test of two major theories which attempt to explain the organization of animal assemblages.	School of Forest Resources University of Georgia	Dr. Gary D. Grossman
5. Comparative Analysis of Trace Metal Accumulation in Forest Ecosystems - to evaluate deposition and net accumulation of selected trace metals on forested watersheds with contrasting soils and bedrock; includes Coweeta (gneiss), Walker Branch (dolomite), Camp Branch (sandstone) and Cross Creek (sandstone.)	Oak Ridge National Laboratory	Ralph R. Turner
6. Material Spiralling in Stream Ecosystems - To determine longitudinal patterns in phosphorus spiralling in first-, second-, third- and fourth-order sections of Ball Creek.	Oak Ridge National Laboratory Environmental Sci. Division	J. W. Elwood
7. "Biosphere Reserves as Reservoirs of Genetic Resources" A comparison of the ecological and genetic properties of three faunal groups between disturbed and undisturbed sites in Coweeta and GSMNP.	Univ. North Carolina, Chapel Hill & Western Carolina Univ., Cullowhee	Alan Stiven, UNC-Chapel Hi Richard Bruce, WCU-Cullowhee

Site Use Continued

8.	Collection of attached microbiota in streams. Teflon strips are colonized, returned to lab and tested for degradation of toxic chemicals.	U.S. EPA	David L. Lewis
9.	Individual leaf herbivory histories - tracking leaf consumption non-destruction.	University of Georgia	Bill Hargrove
10.	Host parasite relationships of chigger mites. Study of structural/functional coupling between chiggers/hosts/habitats.	UGA Institute of Ecology	David Ludwig
11.	Herpetology field trip to collect and identify herptiles and to study their stomach contents.	Indiana State University	Dr. John O. Whitaker, Jr.
12.	Comparative Pollination Ecology of the Yellow-Fringed Orchid.	University of Georgia	Judith L. Robertson
13.	Reproductive Studies of <u>Parnassia asarifolia</u> Purpose: descriptive ecology of phenology, pollination, dispersal of the species with an emphasis on management of natural populations.	Western Carolina University	Dr. J. Dan Pittillo Martha Lee, grad.student
14.	To collect Stipitate Hydnums of The Blue Ridge Area	University of Tennessee Department of Botany	Richard E. Baird
15.	Comparative ant research: evaluate the diversity and richness of foraging ant species at different sites and daily periods and compare these data with those from studies undertaken in South America.	Universidade Estadual De Campinas, Campinas, Sao Paulo, Brazil	Woodruff Whitman Benson
16.	A taxonomic revision of sections <u>Laxiflorae</u>, <u>Granulares</u>, <u>Oligocarpae</u>, and <u>Griseae</u> of the genus <u>Carex</u>.	UGA - Botany Department	James Robert Manhart
17.	An experimental and comparative analysis of the factors controlling nitrification and nitrate loss in forest ecosystems.	Stanford University	Peter Vitovsek
18.	Survey of surface water acidification in The Blue Ridge Mountains.	U.S. EPA	John R. Baker

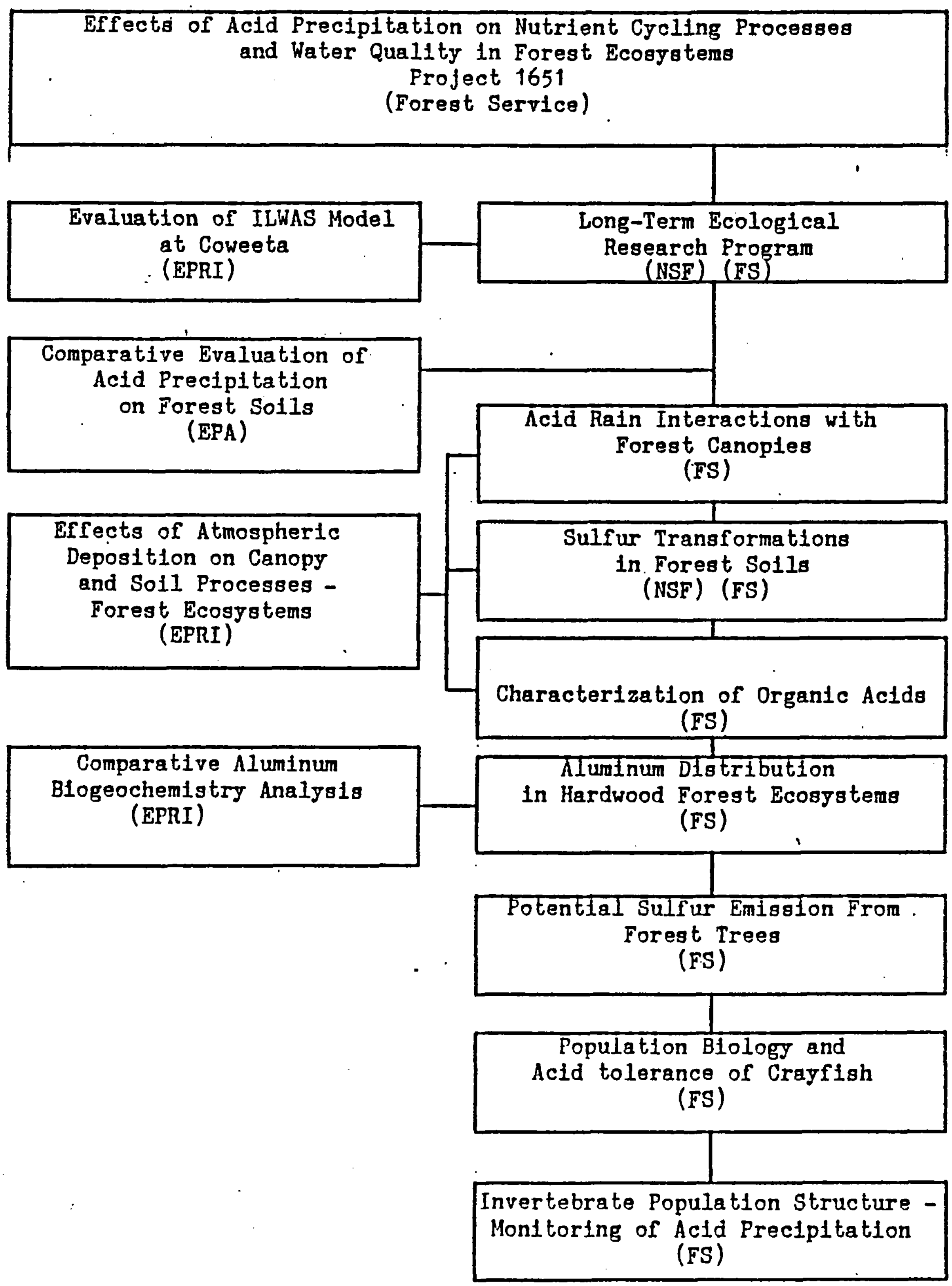


Figure 6. Topical areas of atmospheric deposition research in progress at Coweeta Hydrologic Laboratory and primary sources of support.

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APPENDICES

APPENDIX I

List of Chapters for Coweeta Symposium Volume

A symposium reviewing 50 years of research at Coweeta Hydrologic Laboratory was held in Athens, Georgia in October 1984. Proceedings will be published (W. T. Swank and D. A. Crossley, Jr., eds. Long-term Research on Forested Watersheds at Coweeta). Springer-Verlag has the volume schedules for this year (1985). This Appendix lists the chapters by authors, in alphabetical order, to assist reviewers in referencing them. We have not included these chapters in the list of Literature Cited for the text of our proposal, nor have we included them in Curriculum Vitae, in order to save space in this document.

Boring, Lindsay R., Wayne R. Swank and Carl D. Monk. Dynamics of early successional forest structure and processes in the Coweeta Basin.

Caskey, W. J., W. T. Swank, R. L. Todd, L. R. Boring and J. B. Waide. Nitrogen cycling in a forested watershed in the Southern Appalachians.

Cromack, K., Jr. and J. B. Waide. Decomposition processes in Coweeta watersheds.

Crossley, D. A., Jr., C. S. Gist, W. W. Hargrove, L. S. Risley, T. D. Schowalter and T. R. Seastedt. Canopy arthropod studies at Coweeta.

Day, Frank P., Jr., Donald L. Phillips and Carl D. Monk. Forest communities and patterns.

Douglass, James E. and Marvin D. Hoover. History of Coweeta.

Fitzgerald, J. W., W. T. Swank, T. C. Strickland, J. T. Ash, D. D. Hale, T. L. Andrew and M. E. Watwood. Sulfur pools and transformations in litter and surface soil of a hardwood forest.

Franklin, Jerry F. Past and future of ecosystem research--contributions of dedicated experimental sites.

Grant, Willard H. Debris avalanches and the origin of first order streams in Macon County, North Carolina.

Gurtz, Martin E. Effects of disturbance regimes on stream biota.

Haines, Bruce. Kinetics of nutrient uptake during secondary plant succession.

Haines, Bruce and W. T. Swank. Acid precipitation studies.

Hatcher, Robert D. Bedrock geology and regional geologic setting of Coweeta Hydrologic Laboratory in the Eastern Blue Ridge, with some discussion of Quaternary deposits and structural controls of topography.

Hibbert, A. R. and C. A. Troendle. Streamflow generation by variable source area.

Kellar, Hans. European experience in long-term forest hydrology research.

Meyer, Judy, L., Cathy M. Tate, Richard T. Edwards and M. Tad Crocker. The trophic significance of dissolved organic carbon in streams.

Monk, Carl D. and Frank P. Day, Jr. Biomass, primary production and selected nutrient budgets for a Southern Appalachian hardwood forest.

Murphy, Charles E., Jr. Modelling interception of rainfall by forests and the role of interception in the water balance.

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Ragsdale, H. L. and C. W. Berish. Trace metals in forested ecosystems at the Coweeta Hydrologic Laboratory.

Schowalter, T. D. and D. A. Crossley, Jr. Canopy arthropods and their response to forest disturbance.

Seastedt, T. R. and D. A. Crossley, Jr. Soil arthropods of Coweeta and their role in decomposition and mineralization processes.

Swank, W. T., L. W. Swift, Jr. and J. E. Douglass. Streamflow changes associated with forest cutting, species conversions and natural disturbance.

Swift, Lloyd W., Jr. Forest access roads: Design, maintenance and soil loss.

Swift, Lloyd W., Jr. Climatology and hydrology of Coweeta Hudrologic Laboratory.

Velbel, Michael A. Weathering and soil-forming processes at the Coweeta Hydrologic Laboratory.

Wallace, J. Bruce. Aquatic invertebrate research at Coweeta.

Wallace, Linda L. Comparative physiology of successional forest trees.

Webster, J. R., E. F. Benfield, S. W. Golliday, R. F. Kazmierczak, Jr., W. B. Perry and G. T. Peters. Effects of watershed disturbance on stream seston characteristics.

APPENDIX II

Publications, dissertations or theses from the Coweeta LTER project, 1981-1985 (to date). (note this listing does not include chapters in the 1984 Coweeta Sympo sium volume. They are listed in Appendix I.)

Abbott, D. T. and D. A. Crossley, Jr. 1982. Woody litter decomposition following clear-cutting. Ecology 63:35-42.

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Current and Pending Support

Name	Brief Title	Agency	Amount	Dates	Percent Effort
Boring, L.	Mechanisms of nitrate loss. . . .	NSF	$175,000	1/1/83-7/1/85	10%
	Total-tree biomass of even aged hardwood regenerations	USDA-USFS	$3,500	8/1/84-2/28/86	5%
Crossley, D.	Mineral cycling in soil and litter arthropods	DOE	$22,000	2/1/85-1/31/86	5%
	Analysis of agroecosystems (with E.P. Odum)	NSF	$199,000	7/15/82-12/31/85	10%
	Patterns of Herbivory in forest canopies	NSF	$118,000	7/1/84-6/30/87	10%
	Detritus Food Webs in agroecosystems (with Coleman, Golley, Hendrix) (pending)	NSF	$640,000	7/1/85-6/30/88	10%
Fitzgerald, J.	Inorganic-Organic sulfur transformations	NSF	$140,000	2/1/83-7/31/85	25%
	Import of acid precipitation	USDA-USFS	$19,000	4/15/83-4/15/85	5%
	Influence of acid precipitation on sulfur mobilization	USDA-USFS	$29,000	5/15/84-12/1/86	30%
	Effects of atmospheric deposition in canopy of soils	EPRI	$329,000	Four Years	---
Haines, B.	Sources of acid rain in the Amazon Basin	NSF	$39,000	12/1/83-12/1/85	10%
	Mechanisms of NO_3 loss from a watershed	NSF	$175,000	1/1/83-7/1/85	10%
	Aluminum distribution in a watershed	USDA-USFS	$8,000	24 months	5%
	Sulfur emissions from forest floors	USDA-USFS	$6,000	24 months	5%
	Aluminum distribution (Dissertation Improvement program)-(pending)	NSF	$12,600	24 months	5%

Current and Pending Support (Cont.)

Name	Brief Title	Agency	Amount	Dates	Percent Effort
Haines, B. (cont.)	Formation, translocation and loss of nitrogen (dissertation improvement) (pending)	NSF	$8,400	30 months	10%
Meyer, J.	Role of detritus-associated microbes (with S. Findlay)	NSF	$105,000	7/83-7/85	10%
	Ecological significance of meiofauna (Doctoral dissertation improvement)	NSF	$4,000	6/84-12/85	5%
	Low-Gradient Coastal Plain streams (with J.B. Wallace)	NSF	$372,000	7/84-7/87	40%
Nutter, W.	Production of short-rotation hardwood	GFC	$15,000	1 year	--
	Effects of wood harvest on nutrients	USFS	$25,000	1 year	--
	Evaluation of sewage effluent land treatment	USN	$2,800	1 year	--
	Monitoring of insecticide movement	USFS	$46,000	1 year	--
	Monitoring soil and water for herbicide	DOW Chemical	$8,500	1 year	--
Ragsdale, H. (and C. Berish)	Measurements of air pollution impact	Georgia Power	$15,000	1/1/85-12/31/85	10%
	Temporal patterns of diameter growth in trees	USDA-USFS	$40,000	2/1/85-6/30/86	10%
	Soil deposition in the Georgia Piedmont	Southern Company	$200,000/yr for 3 years	9/1/85-8/31/88	15%
Swank, W.	Impact of whole tree harvesting	DOE	$15,000	7/84-6/85	10%
	Changes in stream ecosystem stability (with J.R. Webster)	NSF	$166,000	1/1/84-12/31/86	5%

Current and Pending Support (Cont.)

Name	Brief Title	Agency	Amount	Dates	Percent Effort
Wallace, J.	Effects of Invertebrates on Ecosystem processes	NSF	$297,000	5/84-5/87	30%
	Secondary production of detritus processing	USFS - Ga Power -	$10,200 $11,000	4/83-8/85	5%
	Low gradiant coastal plain streams	(see Meyer, J.)			5%
Webster, J.	Changes in stream ecosystem stability	(see Swank, W.)			15%
Boring, Crossley, Fitzgerald, Haines, Meyer, Ragsdale, Swank, Swift, Waide, Wallace, Webster	Comparative studies of forested watershed at Coweeta	NSF	$1.47M	12/80-6/86	(5-30%)
All of the above plus Berish, Dowd, Nutter, Leopold, Velbel	Renewal of Comparative Studies (this proposal pending)	NSF	$1.7M	1/86-12/90	(5-30%)

No other support: Dowd, Leopold, Swift, Velbel, Waide.

Appendix IV.

BUDGET DOCUMENTS

Budgets, Subcontract Documents

SUBCONTRACTOR BUDGET SUMMARIES

USFS

	1986	1987	1988	1989	1990	Total
Personnel	0	0	0	0	0	0
Equipment	5450	3500	0	2000	2000	12950
Travel	5500	4000	6000	4000	7000	26500
Other direct costs	2563	6914	8414	10216	9018	37125
Indirect costs	1487	1586	1586	1784	1982	8425
Totals	15000	16000	16000	18000	20000	85000

Michigan State University

	1986	1987	1988	1989	1990	Total
Grad. Student	3610	3790	3980	4180	4390	19950
Equipment	1000	0	0	0	0	1000
Travel	1500	1500	1500	1500	1500	7500
Other direct costs	3600	3600	3800	4000	4000	19000
Total direct costs	9710	8890	9280	9680	9890	47450
Indirect costs	1785	1822	1902	1984	2027	9520
Total	11495	10712	11182	11664	11917	56970

VPI & SU

	1986	1987	1988	1989	1990	Total
Webster	3584	4014	4496	5035	5639	22768
Grad Student	10100	10700	11300	11900	12500	56500
Fringe	251	281	315	352	395	1594
Equipment	1398	0	0	0	0	1398
Travel	1500	1000	5000	3000	1000	11500
Other direct costs	1000	500	500	500	500	3000
Total direct costs	17833	16495	21611	20787	20034	96760
Indirect costs	6219	6242	8178	7866	7581	36086
Total	24052	22737	29789	28653	27615	132849

Emory University

	1986	1987	1988	1989	1990	Total
Ragsdale	4444	4711	4994	5293	5611	25053
Berish	2222	2356	2497	2647	2806	12528
½ Tech.	7405	7849	8320	8819	9348	41741
¼ Secty	3499	3709	3931	4167	4417	19723
Fringe	2987	3166	3356	3558	3771	16838
Equipment	0	0	5000	0	0	5000
Travel	4000	4000	4000	4000	4000	20000
Other direct costs	5000	5240	5487	5695	5973	27395
Total direct costs	29557	31030	37585	34179	35926	168278
Indirect costs	6059	12722	13360	14013	14730	60884
Total	35616	43753	50945	48192	50656	229162

SUMMARY PROPOSAL BUDGET Jan. 1, 1986-Dec. 31, 1986

ORGANIZATION	FOR NSF USE ONLY		
Southeastern Forest Experiment Station	PROPOSAL NO.	DURATION (MONT Proposed	Grant
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Wayne T. Swank	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	NSF FUNDED PERSON-MOS. CAL.	ACAD	SUMR	FUNDS REQUESTED BY PROPOSER	FUNDS GRANTED BY NSF (IF DIFFERE
1.				$	$
2.					
3.					
4.					
5. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
6. ( ) TOTAL SENIOR PERSONNEL (1-5)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES					
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. ( ) GRADUATE STUDENTS					
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL-CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				0	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $1,000; ITEMS OVER $10,000 REQUIRE CERTIFICATION) IBM PC-XT 4,100 Battery Powered Data Micrologger CR21 1,350					
TOTAL PERMANENT EQUIPMENT				5,450	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				3,500	
2. FOREIGN				2,000	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER					
TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,663	
2. PUBLICATION COSTS/PAGE CHARGES					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES				900	
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS					
H. TOTAL DIRECT COSTS (A THROUGH G)				13,513	
I. INDIRECT COSTS (SPECIFY) (SEFES) 11% of all budget categories					
TOTAL INDIRECT COSTS				1,487	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				15,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS GPM 252 AND 253)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 15,000	$

PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
WAYNE T. SWANK *Wayne T. Swank*	3/27/85	INDIRECT COST RATE VERIFICATION		
INST. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials - OGC
ELDON W. ROSS /for *Wayne T. Swank, PL*	3/27/85			

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPM 233)

OMB No. 3145-0058
Exp. Date 12/31/85

APPENDIX V Year 1: 1/1/86-12/31/86 SUMMARY PROPOSAL BUDGET

ORGANIZATION	FOR NSF USE ONLY		
Michigan State University	PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Michael Anthony Velbel	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	NSF FUNDED PERSON-MOS. CAL.	ACAD	SUMR	FUNDS REQUESTED BY PROPOSER	FUNDS GRANTED BY NSF (IF DIFFERENT)
1.				$	$
2.					
3.					
4.					
5. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
6. ( ) TOTAL SENIOR PERSONNEL (1-5)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES					
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. (1) GRADUATE STUDENTS 2nd year M.S. level, 3 months, 3/4 time				3610	
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL-CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)				3610	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				3610	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $1,000:) Vacuum pump and filter apparatus $1000					
TOTAL PERMANENT EQUIPMENT				1000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS) Field work & meetings				1500	
2. FOREIGN					
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ ___ 2. TRAVEL ___ 3. SUBSISTENCE ___ 4. OTHER ___					
TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1000	
2. PUBLICATION COSTS/PAGE CHARGES				100	
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES				500	
5. SUBCONTRACTS					
6. OTHER SEM, TEM, Microprobe				2000	
TOTAL OTHER DIRECT COSTS				3600	
H. TOTAL DIRECT COSTS (A THROUGH G)				9710	
I. INDIRECT COSTS (SPECIFY) MSU indirect cost rate is 41% of TMDC; however, the Univ. has approved a rate of 20.5% on this project (Per Assoc. Provost Scott, April 3, 1985)					
TOTAL INDIRECT COSTS				1785	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				11495	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS GPM 252 AND 253)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 11495	$

PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
		INDIRECT COST RATE VERIFICATION		
INST. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials - DGC Program

*SIGNATURES REQUIRED ONLY FOR REVISED

26 August 1985

ADDENDUM

LONG-TERM ECOLOGICAL RESEARCH IN FORESTED

WATERSHEDS AT COWEETA

University of Georgia Research Foundation, Inc.

Fifteen Co-Principal Investigators

Principal Investigator of Record:

D. A. Crossley, Jr.

Institute of Ecology

The University of Georgia

Athens, Georgia 30602

(404) 542-7832

____

D. A. Crossley, Jr.

This Addendum contains a response to questions raised by the NSF LTER program panel, as dictated to D. A. Crossley, Jr. by telephone on June 17, 1985. The panel requested an Addendum which would address specifically how the Coweeta group would (1) initiate a major synthesis, (2) develop an underlying theoretical structure to which integrated hypotheses are linked, and (3) document that long-term research studies are being conducted in each of the five core areas. In addition, we choose to respond to comments about the need for more below-ground work and the need for more innovative manipulative stream research.

Some of the criticism noted in the panel summary stems from an inadequate presentation of our research program in the recent continuation proposal. Research at Coweeta consists of the core projects, the basic Forest Service funding and the NSF LTER project. These two major sources of research support enable us to pursue a wide variety of secondary projects. NSF, DOE and other funding exists for research projects operated through the University of Georgia and other southeastern colleges and universities. These secondary projects are related to the core research projects, supplementing and extending them. The active cooperative agreements are listed on page 52 et seq. in the proposal, but we evidently did not present an adequate summary of this integrated research.

Comment 1. Document that long-term research studies are being conducted in each of the five core areas. Document past, present and future research in the five core areas.

Response: We address this question by providing five tables (Tables 1-5, attached), one for each of the core areas. Citations are given for publications, existing data sets and ongoing research projects. (Styles differ slightly between the five tables; they were prepared by different investigators.) As a space-saving device, literature citations refer by number to publications described in the recent Gaskin et al. (1983) Annotated Bibliography of Publications on Watershed Management and Ecological Studies at Coweeta Hydrologic Laboratory, 1934, 1984, General Technical Report SE 30 of the Southeast Forest Experiment Station, USFS, Asheville, North Carolina.

Reviewers will note that past, present and future research is reported for all five core areas. At least some current research in each of the core areas is supported by the main LTER project. Major support is provided for core area 1 (Pattern and control of primary production) and core area 4 (inorganic inputs and movements of nutrients). In core area 2 (trophic structure) the LTER project supports research on soil arthropods, canopy arthropods and stream invertebrates. In core area 3 (pattern and control of organic matter accumulation in surface layers and sediments), LTER provides support for a variety of stream studies for terrestrial litterbag studies, and for studies of the successional recovery of decomposition-related biogeochemical processes on WS 7. Core area 5, pattern and frequency of disturbance, constitutes a major organizing framework of our entire LTER project (see Comment 3).

Comment 2. Initiate a major synthesis.

Response: We have made a major step towards accomplishing such a synthesis. In October 1984 we held a major symposium reviewing USFS and NSF research at Coweeta. We have signed a contract with Springer-Verlag to publish the proceedings of that symposium. The draft is 90% complete (30 of 33 chapters are on disk and in the hands of Swank and Crossley). We confidently expect a first final draft by

September 15, 1985. NSF reviewers and panel have not seen this work, of course, but it does answer in part the need for synthesis.

There is another step needed now -- to proceed beyond the individual project summaries presented at the Symposium and to work towards a major integration of the information. We believe that this integration is the one the panel is looking for. We intend to proceed as follows: An all-Coweeta project meeting is planned for late October, 1985. At that time we will develop an initial outline for a synthesis effort. Project leaders will be charged with developing concepts of control in their core areas. Six months later (March 1986) a follow-up meeting will attempt to integrate the concepts of the project leaders into a unified whole. We view these activities as the normal progression of scientific activities in our Coweeta project. As a group, we tend to view the proposed integration-synthesis effort as the culmination of the thrust began last year with the symposium development.

In addition to this specific synthesis effort, we would again emphasize (see Proposal pp. 5-7) that the expanded role of modeling proposed for the second 5-year period of LTER research will contribute substantially to the synthesis and integration of research results, at both process and system levels.

Comment 3. Develop an underlying theoretical structure to which integrated hypotheses are linked.

Response: Because of length restrictions imposed on LTER renewal proposals, we did not develop fully the conceptual foundations of our continuing ecosystem research. It would be erroneous to conclude, however, that such a foundation does not exist. In fact, quite the opposite is the case: continuing ecosystem studies at Coweeta have been based on a consistent and continuous conceptual foundation and theoretical structure. In 1973, we initially sought funding for the core Coweeta research program independent of IBP, and outlined the theoretical structure which has guided our research program since then. These ideas were refined and extended in subsequent proposals submitted in 1974, 1976, and 1978. Key features of these ideas were summarized in our initial LTER proposal in 1980, but were only alluded to briefly and incompletely in our recent renewal.

Thus, continuing ecosystem studies at Coweeta are based on a consistent conceptual foundation and theoretical structure, which have (1) provided the essential organizational framework for our research, (2) provided an overall research approach or philosophy which includes coupled watershed- and process-level studies, (3) generated specific objectives for individual studies (we have found it more useful to frame studies around specific objectives rather than formal hypotheses as such), and (4) provided (and will continue to provide) a mechanism for synthesizing and integrating results of process research. This central conceptual foundation and theoretical structure has two key components.

First, we view ecosystems as hierarchical systems, in which system organization is reflected by the frequencies at which observable ecosystem behaviors occur. This hierarchical model of ecosystems has provided us with our overall research approach, wherein detailed studies of biogeochemical and ecological processes within experimental watersheds (or streams) provide a means for explaining integrated system-level behaviors measured at defined ecosystem boundaries. Moreover, as stressed in our renewal proposal (pp. 1-6), this model of ecosystem organization and function has forced us to broaden our focus to examine ecosystem dynamics and the processes controlling them across scales of space and time. This conceptual approach has been and will continue to be useful in synthesizing process-level research results into an integrated picture of ecosystem biogeochemistry.

Second, a large fraction of our specific studies has been organized around the resistance-resilience model of ecosystem response to disturbance. Based on this theoretical model, we have developed specific ideas concerning mechanisms which regulate ecosystem response to and recovery from disturbance, and have implemented ecosystem-level experiments to test both these ideas and the underlying model. Moreover, the theoretical model itself has provided a useful framework for synthesizing results of recent and historical watershed-scale experiments.

These conceptual and theoretical ideas have not only provided an organizational framework for our research, but have also served as a focal point for the integration of our research results. For example, Monk et al. (Bibliography #246) stressed the central role of these ideas in the Coweeta research program. Responses of Coweeta streams to disturbance have been discussed and integrated in this context (Bibliography #379, 380, 384, 467). Also, the hierarchical and resistance-resilience models have provided a framework for synthesizing information on terrestrial nutrient cycles, and for using this information to evaluate management impacts on long-term forest ecosystem behaviors (Bibliography #166, 321, 363, 364).

Recently, the resistance-resilience model was reformulated in the context of an expanded hierarchical focus on ecosystem dynamics across scales of space and time (Waide, Coweeta Symposium Volume).

To summarize, we feel that the long-term program of ecosystem research at Coweeta is based on a consistent and sound theoretical structure. We do recognize the need not only to refine and update these theoretical ideas as research results continue to accumulate, and also to utilize this central conceptual foundation as a means of synthesizing process studies. At present, we anticipate that the hierarchical model of ecosystem organization and dynamics will play a central role in the synthesis effort described earlier. But, we currently see no need to scrap the existing theoretical basis for our work and develop a new one, including "integrated hypotheses." We simply failed to communicate the theoretical basis for our work in our most recent proposal.

Additional comment: In general, suggestions often emphasize the need for more below-ground work common to the LTER sites.

Response: We certainly agree about the importance of below-ground parts of the ecosystem. Our past research has included nutrient and water content and transport belowground, soil invertebrates, and root dynamics (see Bibliography). Present research (under the aegis of the LTER project) includes the following (additional projects funded by other agencies are also in progress):

Work by Berish and Harker. The objective of this ongoing investigation is to determine fine and coarse root nutrient storages

(C,N,P and cations), fine and coarse root decomposition and nutrient release rates, and phenology and production of fine roots in two contrasting early successional forests. This project complements an ongoing investigation by Haines and Boring in which mechanisms of nitrate loss from two distinct forest types on WS 6 are being investigated. In addition, Berish is investigating three different procedures for determining fine root decomposition rates.

Work by Blair and Crossley. This research is using litterbag methods to isolate the soil invertebrate species associated with different phases of leaf litter decomposition (WS 7 and 2). The work is a followup of the Seastedt-Crossley research on responses of soil arthropod communities to clear-cutting.

Work by Waide, Swank, Boring and Haines. As explained in our LTER renewal proposal (see pp. 18-22), we are continuing our long-term study of the successional recovery of the forest ecosystem on WS 7 since clearcutting in 1977. A large fraction of this work focuses on belowground components and processes, particularly organic matter and nutrient pool sizes and transformations.

Planned investigations on below-ground processes include research on fine root production, mortality and decomposition, as well as nutrient accumulation and mineralization in fine root tissues (Berish). In addition, Dr. David Coleman, a Research Professor recently added to the faculty of the Univeristy of Georgia, has expressed an interest in rhizosphere studies at Coweeta.

Additional comment: Plan for more innovative manipulative stream research.

Response: This comment caught us by surprise. The stream research at Coweeta is both innovative and manipulative. This is evidently a failing of our proposal, that we did not adequately convey the extent or depth of stream research at Coweeta. We do not agree with the comment.

In addition to the follow-up research in the watershed manipulation experiment, two additional manipulations are proposed: A woody debris addition and nutrient/organic carbon enrichment experiments. In addition, there are four ongoing stream research projects at Coweeta that are each funded through separate NSF-Ecosystem Studies grants which were not addressed in th LTER proposal due to space limitations. These projects are outlined below:

1. Findlay and Meyer (NSF-Ecosystem studies). "Role of detritus-associated microbes and non-living substrate in detritivore nutrition." We feel that the methods employed in addressing this subject matter are innovative. Isotopes are used to label bacteria and fungi, in order to assess the assimilation of bacteria and fungi by invertebrates. This work is getting to the core of some important questions concerned with detritus-microbe-invertebrate reltionships fundamental to understanding trophic pathways in Coweeta streams.

2. Webster, Benfield and Swank (NSF-Ecosystem studies). "Changes in stream ecosystem stability during forest succession as measured by nutrient retention during storms." This study is specifically focusing on nutrient concentrations and export during storms, an area where there are many unanswered questions. By

measuring subsurface nutrient concentrations, throughfall, and export, they are comparing instream nutrient budgets for streams draining watersheds of contrasting vegetation. The hypothesis being tested is that forest streams are least stable, i.e., less retentive of nutrients, during the intermediate stages of forest succession. At that time particulate organic matter accumulations are minimal. This study is also manipulative in that experimental studies are also being conducted in a natural stream channel where both discharge and organic matter storage are being manipulated. This study also provides a linkage between terrestrial and aquatic nutrient studies at Coweeta.

3. Wallace (NSF-Ecosystem studies). "Influence of invertebrates on ecosystem processes in southern Appalachian streams: a manipulative approach." As implied in the title, this study includes an ecosystem-level manipulation. The project is an extension of a previous experiment where the application of an insecticide reduced aquatic insect densities and biomass by 90%. This reduction resulted in (1) massive invertebrate drift; (2) subsequent changes in invertebrate community structure; (3) significant reductions in fine particulate organic matter export to downstream reaches (all compared with measurements in an adjacent reference stream, as well). Ongoing research has documented the restoration of invertebrate functional group recovery and the restoration of key ecosystem processes such as leaf litter processing rate and restoration of seston export to downstram reaches. A similar manipulation will be conducted during the coming year on the former reference stream. This study is obviously both manipulative and long-term since a number of taxa have

not yet returned to the treatment stream four years following the initial manipulation.

4. Meyer (D. Perlmutter) Ecosystem Studies Program. Dissertation Research: "The ecological significance of a meiofaunal organism in a stream ecosystem." The objective of this project is to determine if meiofauna play a significant role in litter decomposition in streams. It is clearly innovative in that meiofauna have rarely been studied in other streams and their functional role in the ecosystem is unknown.

We feel that the four NSF-studies supported above are innovative and manipulative. They were not specifically addressed in the LTER proposal but they certainly involve ongoing, long-term research in Coweeta streams. None of the projects could be pursued without the existing LTER funding to build upon. While some LTER supported stream research at Coweeta might be described as routine, it is providing many essential parts of the total stream picture. The baseline data collections may not have the appeal essential for independent funding, but they are an integral part of our research effort. Those routine collections should not be taken to represent our entire research effort in streams.

RESEARCH AT COWEETA HYDROLOGIC LABORATORY IN CORE AREA 1

Pattern and Control of Primary Productivity

Category	Past	Present/Future
Baseline Hardwood Forest NPP		
Aboveground	NPP and phenology (1,3) NPP and nutrients (2, 3, 11)	Permanent Reference Stands (30)
Below ground	NPP and nutrients (8, 25)	Fine root production, mortality, nutrients (31)
Baseline Pine Plantation NPP		
Aboveground	Biomass, leaf surface area, and NPP (4, 5)	Biomass, leaf surface area, and NPP (32)
Belowground	NPP and nutrients (25)	
Regenerating Forest NPP		
Aboveground	Clearcut regeneration (6, 9) Importance of black locust (23, 24) Oldfield regeneration (26)	Modeling NPP and nutrients (33) Clearcut regeneration (34) Oldfield regeneration (35) Whole tree harvest regeneration (36)
Belowground	Comparison w/mature hardwood (27) Calcium uptake kinetics (28)	Oldfield root dynamics (37)
Stream NPP	Algal NPP (12)	
Controls of NPP	Canopy arthropod effects (13, 14, 15) Acid rain solution effects (22) Trace metal effects (29)	Atmospheric oxidant effects (38) Growth trends and heavy metals (39, 40) Gypsy moth outbreak (41) Canopy arthropod effects (42) Environmental controls (43)
Related Vegetation Studies	Long-term permanent plot data (20, 21) Environmental gradients (16, 19, 3, 10) Species responses (7, 16, 17, 18, 19, 20, [illegible]	Long-term permanent plot data (44) Root decomposition (37)

FOOTNOTES

1. Bibl. #36
2. Bibl. #37
3. Monk, C. D. and F. P. Day. 1985. Vegetation analysis, primary production and selected nutrient budgets for a Southern Appalachian oak forest: a synthesis of IBP studies at Coweeta. Forest Ecology and Management 10:87-113.
4. Bibl. #320
5. Bibl. #331
6. Bibl. #10
7. Bibl. #438
8. Bibl. #104
9. Boring, L. R., W. T. Swank and C. D. Monk. 1985. Dynamics of early successional forest structure and processes in the Coweeta Basin. In D. A. Crossley and W. T. Swank (editors), Coweeta Symposium.
10. Day, F. P., D. L. Phillips and C. D. Monk. 1985. Forest communities and patterns. Coweeta Symposium.
11. Monk, C. D. and F. P. Day. 1985. Biomass, primary production and selected nutrient budgets for a Southern Appalachian hardwood forest. Coweeta Symposium.
12. Bibl. #419
13. Bibl. #296
14. Bibl. #420
15. Bibl. #286

16. Leopold, D. J. and G. R. Parker. 1985. Vegetation patterns on a Southern Appalachian watershed after successive clearcuts. Castanea 50: in press.

17. Leopold, D. J., G. R. Parker and W. T. Swank. 1985. Forest development after successive clearcuts in the Southern Appalachians. Forest Ecology and Management: in press.

18. Bibl. #268

19. Bibl. #38

20. Phillips, D. L. and W. H. Murdy. 1985. Effects of Rhododendron maximum on regeneration of southern Appalachian hardwoods. Forest Science 31:226-233.

21. Bibl. #258

22. Bibl. #100

23. Boring, L. R. and W. T. Swank. 1984. The role of black locust (Robinia pseudoacacia) in forest succession. Journal of Ecology 72(3):749-766.

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42. Crossley, D. A., W. Hargrove and L. Risley. Ongoing studies examining the effects of low-level canopy arthropod consumption upon forest leaf production.

43. Leopold, D., L. Swift and W. T. Swank. Ongoing study of climatological effects upon long-term forest productivity.

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RESEARCH AT COWEETA HYDROLOGIC LABORATORY IN CORE AREA 2

Spatial and temporal distribution of populations selected to represent trophic structure

Category	Past	Present/Future
Soil-litter microarthropods	Oribatid mite distribution (1)	Litterbag studies (2) WS 49 (new studies) (3) Root studies (6)
	WS 17 - WS 18 comparisons (4) WS 18 populations/biomasses (5) Collembolans on WS 2 - WS 7 (7) Response to clear-cutting (8,9) Effects on litter decomposition (10) Two-year decomposition study (11) Review of all data sets (12)	
Soil-litter macroinvertebrates	Densities/biomass in WS 18 (13) Densities/biomass in WS 7 - WS 27 (15) Densities/biomass in WS 7 - WS 2 (16)	Snail Studies (14) WS 49 studies (3)
Canopy Arthropods	Species diversity (17) Community structure (19,20) Herbivory on ROBINIA (22) Community structure on WS 6, 18 (24) Effects of clear-cutting (25,26) Defoliation on WS 27 (27)	Densities, biomass (18) Feeding (21) Effects on greenfall

FOOTNOTES

1. Bibl. #2
2. Blair 1985
3. Crossley (new work on decomposition and nutrient dynamics)
4. Bibl. #18
5. Bibl. #86
6. Berish 1985 (litterbag studies of root decomposition)
7. Reynolds 1976 (MS Thesis)
8. Bibl. #291
9. Bibl. #293
10. Bibl. #294
11. Bibl. #296
12. Seastedt et al. 1985
13. Bibl. #87
14. Caldwell; current work on snails
15. Crossley, unpublished data sets
16. Reynolds, unpublished data sets
17. Bibl. #21
18. Crossley, current LTER sampling design
19. Bibl. #21
20. Bibl. #30
21. Hargrove, current research on LAR in ROBINIA
22. Hargrove 1982 (MS Thesis)
23. Risley, current research on arthropod effects on greenfall
24. Risley 1982 (MS Thesis)
25. Schowalter et al. 1981, Biblio #286
26. Bibl. #286
27. Bibl. #322

b. Aquatic Trophic Structure

Category	Past (Bibliography Numbers)	Present/Future
Energy Sources		
Allochthonous	379, 384, 385, 242	Webster et al. in press, proposed on WS 6, 7, 14 f 1988, Wallace and Cuffney on WS 53, 54, 55
Autochthonous	419, 379	
Decomposition		
Litter Decomposition	240, 374, 385,	Cuffney et al. 1984, Wallace et al. submitted Cuffney & Wallace unpubl. Huryn et al. unpubl.
Wood Decomposition		Webster and Golladay, in progress
Bacterial Biomass and Production		Meyer et al. in press, Crocker and Perlmutter, in progress
Stream Invertebrates General (Functional Feeding Groups)	95, 384, 392, 417, 418, 467, 470	Gurtz and Wallace 1984, Cuffney et. al. 1984 Wallace et al. submitted, Huryn and Wallace unpub. Wallace et. al. unpubl., F. Cuffney and Wallace, u
Mineral Pathways, Nutrient Content	384, 383, 391,	Webster and Swank 1985
Invertebrates Associated with Litterbags	240, 374,	Cuffney et al. 1984, Vogel 1984, Wallace et al. submitted, Huryn et al. unpubl., Cuffney and Wallace unpub.
Influence of invertebrate feeding on litter decomposition and DOC	90, 240, 241, 367, 374, 470, 385	Cuffney et al. 1984, Wallace et al. 1986 O'Hop et al. 1984, Cuffney & Wallace, unpubl.
Feeding Mechanisms and Food Selection	5, 85, 90, 233, 239, 366, 367, 368, 370, 371, 372, 375	Huryn and Wallace 1985, Wallace and Gurtz 1985 Perlmutter (meiofauna), in progress
Bioenergetics	5, 90, 380, 383	Findlay and Meyer in press and in progress, O'hop, unpubl.
Secondary Production	5, 94, 280, 281, 380, 382, 444	Georgian and Wallace 1983, O'Hop et al. 1984, O'Doherty 1985, Wallace and Gurtz 1985, Huryn and Wallace 1985, submitted, in progress
Trophic Basis of Production	5, 94, 280, 281, 382, 384	O'Hop et al. 1984, Wallace and Gurtz 1985, Huryn and Wallace 1985, Wallace & Gurtz in progres
Invertebrate Predators		Wallace et al. in progress (influence of prey manipulation)
Salamanders (general feeding)	470,	
Fish (general feeding)		Grossman et al. and Jeff Barrett, in progress

RESEARCH AT COWEETA HYDROLOGIC LABORATORY IN CORE AREA 3

Pattern and control of organic matter accumulation in surface layers and sediments

Category	Past	Present/Future
	I. AQUATIC STUDIES	
Organic matter decomposition		
Leaf litter	Effect of disturbance (1) Nutrient effects (2) Invertebrate effects (3)	Litterbag studies (2) Meiofauna (5)
Wood		Stick decomposition (6)
Dissolved organic matter		
Water column	Effect of disturbance (7, 8) Role of invertebrates (10)	Disturbance effects (9)
Interstitial	Relation to organic matter (8)	Relation to bacteria and organic matter (11)
Particulate organic matter		
Benthic storage		Variation between watersheds (12)
Bacterial biomass	Relation to POM (8)	Relation to POM (13)
Role of woody debris	Impact on transport (14)	Debris addition (15)
Water column POM	Seston studies (16)	Seston studies (14, 17)

Category	Past	Present/Future
	II. TERRESTRIAL STUDIES	
Organic matter and nutrient inputs to surface layers and soils		
Leaf litter	Undisturbed hardwood forests; WS 2, 7, 18, 36 (18, 19, 20) White pine forests; WS 1, 17 (18, 19) Successional changes following clear-cutting; WS 13, 37 (19)	Impacts of and recovery from cankerworm defoliation; WS 27 (20, 21) Influence of black locust and locust stem borer; WS 6 (22) Successional changes following clearcutting with and without residue removal; WS 7, 48 (20) Ozone impacts on white pine forests; WS 1, 17 (23)
Woody litter	Undisturbed hardwood forests; WS 18 (18) White pine forests; WS 17 (18) Logging residue remaining following clearcutting; WS 7 (20, 24)	
Roots	Undisturbed hardwood forests; WS 18 (25) White pine forests; WS 17 (25)	Influence of black locust and locust stem borer; WS 6 (26)
Organic matter and nutrient standing crops in surface layers and soils		
Leaf litter	Undisturbed hardwood forests; WS 2, 7, 18 (18, 27, 28, 29) White pine forests; WS 17 (18, 28, 29) Successional changes following clear-cutting; WS 6, 13 (19, 29) Impacts of cankerworm defoliation; WS 27 (21, 27)	Influence of black locust and locust stem borer; WS 6 (22) Successional changes following clearcutting with and without residue removal; WS 7, 48 (20, 27, 32) Impacts of atmospheric deposition; WS 1, 2 (23)

Category	past	present/Future
Woody litter	Undisturbed hardwood forests; WS 18, 48 (18, 20)	Successional changes following clearcutting; WS 7 (20,24)
Soils	Undisturbed hardwood forests; WS 2, 7, 18 (27, 29, 30, 31) White pine forests; WS 17 (29, 30) Successional changes following clearcutting; WS 6, 13 (29) Impacts of cankerworm defoliation; WS 27 (21, 27)	Influence of black locust and locust stem borer; WS 6 (22) Successional changes following clearcutting with and without residue removal; WS 7, 48 (20, 24, 27, 31, 32) Impacts of atmospheric deposition; WS 1, 2 (23)
Rates and controls of organic matter decomposition		
Leaf litter	Undisturbed hardwood forests; WS 2, 7, 18 (18, 33, 34, 35) White pine forests; WS 17 (18, 35) Successional changes following clearcutting; WS 7 (34, 35) Impact of cankerworm defoliation; WS 27 (21, 27) Climatic and microarthropod regulation (36)	Successional changes in decay rates and microarthropod abundance; WS 7 (37) Influence of black locust and locust stem borer; WS 6 (22, 33)
Woody litter	Successional changes following clearcutting; WS 7 (38)	Decay of logging residue; WS 7 (24)
Other	Decay of arthropod remains (39	

Category	Past	Present/Future
Microbial processes in surface organic layers and soils		
C mineralization and CO_2 efflux	Undisturbed hardwood forests; WS 2, 7, 18 (20, 24, 27,29) White pine forests; WS 17 (29) Successional changes following clearcutting; WS 6, 13 (29) Impacts of cankerworm defoliation; WS 27 (21, 27)	Successional changes following clearcutting with and without residue removal; WS 7, 48 (20, 24, 27, 32) Techniques for assessing available soil C (40)
Nitrogen fixation	Undisturbed hardwood forests; WS 2, 7, 18, (20, 27, 29, 31, 41, 42, 43) White pine forests; WS 17 (29, 42) Successional changes following clearcutting; WS 6, 13 (29) Impacts of cankerworm defoliation; WS 27 (21, 27)	Symbiotic fixation by black locust in successional forests (31, 44, 45) Successional changes following clearcutting with and without residue removal; WS 7, 48 (20, 27, 31, 32)
Denitrification	Comparison of methods (46) Undisturbed hardwood forests; WS 2, 18 (20, 29, 31, 47)	Successional changes following clearcutting with and without residue removal; WS 7, 48 (20, 31, 32) Study of factors regulating denitrification rates; WS 6, 18 (48) Method for assessing source of N_2O losses from soils (49)

Category	Past	Present/Future
Nitrification and N mineralization	MPN microtechnique (50) Relation to stream nitrate losses (51) MPN assays of nitrifier populations on diverse watersheds (27, 29, 31)	Factors regulating nitrification and nitrogen leaching from successional forests (52, 53) Successional changes following clearcutting with and without residue removal; WS 7, 48 (20, 31, 32) Gaseous N losses via nitrification (48, 49)
Sulfur transformations		Incorporation of SO_4 into organic S in surface organic layers and soils (54, 55, 56, 57, 58, 59, 60) Mineralization of organic S in surface organic layers and soils (54, 56, 57, 58, 59, 61, 62) Forms of adsorbed and soluble S in surface organic layers and soils (54, 57, 58, 63)
Microbial enumeration, biomass, and element content	SEM studies of microbes (64) Element accumulation by litter-soil microbes (65) Enumeration of microbial populations on diverse watersheds (29)	Microbial ATP pools in surface organic layers and soils (27, 32)

FOOTNOTES

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2. Bibliography #240.

3. Bibliography #374, 382; Cuffney, T. J., J. B. Wallace, and J. R. Webster. 1985. Pesticide manipulation of a headwater stream: invertebrate responses and their significance for ecosystem processes. Freshwat. Invert. Biol. 4: 153-171.

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6. Webster, in progress.

7. Bibliography #242, 343, 373.

8. J. L. Meyer et al., in press. The trophic significance of DOC in streams. Coweeta Symposium volume.

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11. M.S. Thesis in preparation, M. T. Crocker.

12. Measured on WS 6, 7, 13, 14, 18 as part of Webster et al. Effects of forest succession on stream ecosystem stability; measured on WS 53, 54, 55 by Wallace et al. as part of Effects of invertebrates on ecosystem processes; proposed for WS 6, 7, 13, 14, 27, 36 in 1990 on LTER.

13. Proposed for 1986 in LTER.

14. Webster et al. Effects of forest succession on stream ecosystem stability.

15. Proposed for 1986 on LTER.

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17. Proposed for 1989 in LTER.

18. Bibliography #26, 403.

19. W. T. Swank, unpublished data in Coweeta files.

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22. D. White, Thesis research in progress, Litterfall and litter decomposition dynamics in early successional forests at Coweeta, University of Georgia.

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27. J. B. Waide and R. L. Todd, unpublished data in Coweeta files.

28. Bibliography #394.

29. R. L. Todd, unpublished data in Coweeta files.

30. Bibliography #393.

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32. Proposal pp. 20-22.

33. J. B. Waide, J. R. Webster and R. L. Todd, unpublished data in Coweeta files.

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35. K. Cromack, Jr. and J. B. Waide. Decomposition studies on Coweeta watersheds. Coweeta Symposium volume.

36. Bibliography #29, 291, 294, 297, 390.

37. J. M. Blair, Thesis research in progress, Decomposition rates and microarthropod fauna on two Coweeta watersheds with different treatment histories, University of Georgia.

38. Bibliography #1.

39. Bibliography #299.

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41. Bibliography #19, 349.

42. Bibliography #353.

43. Bibliography #439.

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46. Bibliography #350.

47. Bibliography #326.

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49. E. A. Davidson et al., Distinguishing between nitrification and denitrification as sources of gaseous-N production in soil, in preparation.

50. Bibliography #282.

51. Bibliography #274, 351, 361.

52. F. Montagnini. 1985. Nitrogen turnover and leaching from successional and mature ecosystems in the Southern Appalachians, Ph.D. Dissertation, University of Georgia.

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55. Bibliography #78, 80, 328.

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61. Bibliography #311.

62. J. W. Fitzgerald and T. L. Andrew. 1984. Mineralization of methionine sulphur in soils and forest floor layers. Soil Biol. Biochem. 16: 565-570.

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64. Bibliography #13, 345, 348.

65. Bibliography #24, 25, 27, 28, 346, 352.

Inorganic Inputs and Movement of Nutrients

Solution Compartment	Past	Present	Future
Precipitation	Eight-gage bulk precipitation network (1,2,3)	Temporal & spatial variability of precipitation chemistry over Coweeta basin(2,3,4) LTER intersite analyses of chemistry(9)	Detailed studies of the magnitude and form of dry deposition to hardwood and white pine canopies(5) Continuation of bulk precipitation network for trend analysis(5) Trace metal inputs(6)
Throughfall	Characterization of throughfall chemistry in hardwood & conifer ecosystems for selected solutes(7,8)	Temporal & spatial dynamics of throughfall chemistry in hardwood & conifer ecosystems(4)	Influence of dry deposition on canopy processes and throughfall chemistry(10) Effects of ozone damage in white pine on throughfall chemistry(10) Characterization of organic-S forms(11)
Soil Solution	Examination of temporal trends in chemistry of baseline forest ecosystem(12,13)	Effects of whole-tree vs. conventional harvesting on soil solution chemistry(10) Long-term baseline chemistry(12)	Changes in solution chemistry during storm events and relationship to flowpaths(14) Long-term baseline chem.(12) Aluminum speciation for baseline ecosystems(15)
Streamflow	Establishment of baseline chem. for selected ecosystems(1,2)	Continuation & expansion of solute analyses(4,16) Changes in solute conc. & export associated with man-induced disturbances (4,16,17)	Continuation of long-term stream chemistry trends(4) Changes in stream chemistry of high & low elevation control watersheds during storm events (10) Influence of riparian processes on stream chemistry(10) Trace metal outputs(6) Stream chem. responses associated with natural & man produced disturbances including recovery(4,16,17)

FOOTNOTES

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RESEARCH AT COWEETA HYDROLOGIC LABORATORY IN CORE AREA 5

Pattern and Frequency of Disturbance to Research Site

Natural Disturbances	Past	Future
Extending data base to before site establishment	Records for older nearby precipitation & streamflow gages(1)	Interpretation and correlation of overlapping records
Meteorological and streamflow extremes:		
Drought	50 year data base(2)	Summarize & interpret(3)
Intense rains	50 year data base(2)	Summarize & interpret(3)
Streamflushing by storms	Sediment transport(4)	Continuing(5)
	Seston transport(5)	Continuing(6)
	Benthic bacteria & invertebrates(4&6)	
Soil creep and avalanche	Survey sites and develop underlying theoretical structure	Completion of report
		Stream Geomorphology(7)
Fog		Initiate data base
Ice storms		Initiate data base
High winds		Initiate data base
Unseasonable temperatures	50 year data base(2)	Summarize & interpret(3)
Insect epidemic	Fall cankerworm(8) Locust borer(9)	Gypsy moth(10)
Disease epidemic	Chestnut blight(11)	

Man-caused Disturbances	Past	Future
Management		
History of land use before site establishment	Interviews of past residents & neighbors (12)	Dendrochronology (13)
Exploitive logging	Watershed 10 (4), (12), and (13a)	
Multiresource management	Watershed 28 (14)	
Steepland Farming	Watershed 3 (15) and (16)	
Woodland grazing	Watershed 7 (17)	
Forest cutting:	10 treated watersheds (18)	
Individual tree selection	Watersheds 40, 41, 28 and 19 (19)	
Clearcutting without product removal	Watersheds 13, 17, 22 and 37 (20) (18) (16) (21)	Debris addition to stream (22)
Clearcutting with commercial logging	Watershed 7 (23)	Forest regeneration: productivi and stream impacts (25)
Clearcutting with complete debris removal	Watershed 48	Complete report
Repeated clearcutting	Watershed 13 (27)	
Road construction, use and maintenance		
Sediment in streams	Watersheds 10, 40, 41, 28, & 7 (11) (28)	Sediment from stream crossings
Sediment and slides on forest floor	Watershed 7 (29)	
Fire	Watersheds 6 and 1 Reports in files at Coweeta	
Pesticides:		
Insecticides	Aerial application of DDT to Basin and lindane tests on WS3 by Hastings (30)	
Herbicides	Paraquat on WS6 and tordon 10K on WS19 (31)	

Man-caused Disturbances (cont.)	Past	Future
Forest type conversion		
Pine	Watersheds 1 and 17 (32)	Continue building hydrologic & productivity data bases
Grass & old field succession	Watershed 6 (33)	Continue building hydrologic & productivity data bases (34)
Atmospheric deposition		
Nutrients	Precipitation, dryfall, and stream chemistry up to 18 yrs. (26) (35)	Continue building data bases and increase modelling (36)
Acidity	Precipitation, dryfall, and stream chemistry up to 18 yrs. (37)	Continue building data bases and expand work on organic sulfur and aluminum (38)
Trace metals	Initiated data base (39)	Add high elevation sampling sites and stream sampling (40)
Ozone		Initiate data base on Watershed 1 and 17

FOOTNOTES

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6. Proposal pg. 37-38, 39-41.

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19. File reports at Coweeta and Bibliography #'s 426 and 211.

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22. Proposal pg. 41-42.

23. Proposal pg. 18-21, 35-39, and Bibliography #'s 317, 326, and 333.

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35. Proposal pg. 10-12.

36. Proposal pg. 9, 14.

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39. Proposal pg. 22-26.

40. Proposal pg. 26-29.