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Many ecological phenomena occur on time scales of decades or centuries, and the need for long-term ecological research was recently emphasized in Likens' presidential address to the Ecological Society (Likens 1983). In the past it has been difficult to investigate these phenomena with financial support from funding agencies (Marzolf 1983, Callahan 1984). However, in 1980 the National Science Foundation established the Long-Term Ecological Research Program (LTER). LTER-sponsored studies are now underway at 11 sites representing different ecosystem types (Table 1). The purpose of this article is to describe briefly the general characteristics of each site involved with stream ecology and to summarize the nature and objectives of stream research at these sites. More complete site descriptions were compiled in a booklet prepared by Halfpenny and Ingraham (1984).

Though streams comprise a small fraction of the area of most watersheds, measurements of stream-transported materials provide an integrative measure of watershed ecosystem behavior (e.g., Bormann et al. 1968). Such measurements are useful in the interpretion of terrestrial system behavior, but in-stream processes significantly modify concentrations of materials in transport. Streams have been characterized as having the ability to recover rapidly following disturbance (Webster and Patten 1979). However, because of the strong linkages between streams and their watersheds (e.g., Hynes 1975),

Table 1. Currently funded LTER research sites.

Site name	Ecosystem type	Coordinating principal investigator
H. J. Andrews Experimental Forest	coniferous forest	Jerry Franklin, Forest Science Laboratory, 3200 Jefferson Way, Corvallis, OR 97331
Cedar Creek Natural History Area	oak savannah	G. David Tilman, Department of Ecology and Behavioral Biology, University of Minnesota, 318 Church Street SE, Minneapolis, MN 55455
Central Plains Experimental Range	shortgrass steppe	William K. Lauenroth, Department of Range Science and Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523
Coweeta Hydrologic Laboratory	deciduous forest	D. A. Crossley, Jr., Institute of Ecology, University of Georgia, Athens, GA 30602
Illinois and Mississippi rivers	large rivers	Richard E. Sparks, Illinois Natural History Survey, River Research Laboratory, Box 599, Havana, IL 62644
Jornada	desert	Walter G. Whitford, Department of Biology, New Mexico State University, Las Cruces, NM 88003
Konza Prairie Research Natural Area	tallgrass prairie	G. Richard Marzolf, Division of Biology, Kansas State University, Manhattan, KS 66506
Niwot Ridge/Green Lakes	alpine tundra	Patrick J. Webber, Institute of Arctic and Alpine Research, Campus Box 450, University of Colorado, Boulder, CO 80309
North Inlet	salt marsh/estuary	F. John Vernberg, Baruch Institute, University of South Carolina, Columbia, SC 29208
Northern Lakes	lakes	John J. Magnuson, Center for Limnology, North Park Street, University of Wisconsin, Madison, WI 53706
Okefenokee National Wildlife Refuge	swamp	Bernard C. Patten, Institute of Ecology, University of Georgia, Athens, GA 30602

stream response to watershed disturbance is limited by the rate of terrestrial secondary succession (e.g., Gurtz et al. 1980). In addition to this long-term response to watershed disturbances, infrequent catastrophic storms (Cummins et al. 1983) and even normal year-to-year variation in precipitation (e.g., Triska et al. 1982) can have major effects on stream organic matter processes and budgets. Thus, measurements of stream characteristics and dynamics are useful in interpreting terrestrial system behavior and in determining long-term phenomena unique to streams. Consequently, stream studies constitute an important part of the LTER research programs at many of the sites.

The institutions involved in LTER-sponsored research are committed to encouraging collaborative research with scientists at other institutions, and the LTER sites are considered national research facilities. Researchers interested in using these facilities should contact the coordinating principal investigators (Table 1) and consider submitting proposals for research support to the National Science Foundation or other funding agencies. The background of other ecological studies and existing data bases at LTER sites should facilitate new research efforts.

H. J. Andrews Experimental Ecological Reserve

The H. J. Andrews Experimental Ecological Reserve is located 25 km east of Eugene, Oregon, in the coniferous forest biome of the Pacific Northwest. This 6050-ha watershed in the McKenzie River basin on the west slope of the Cascade Range has been a U.S.D.A. Forest Service research area since 1948. LTER stream research at this site concerns the role of woody debris in streams and effects of forest management practices on streams. Research is focused on two

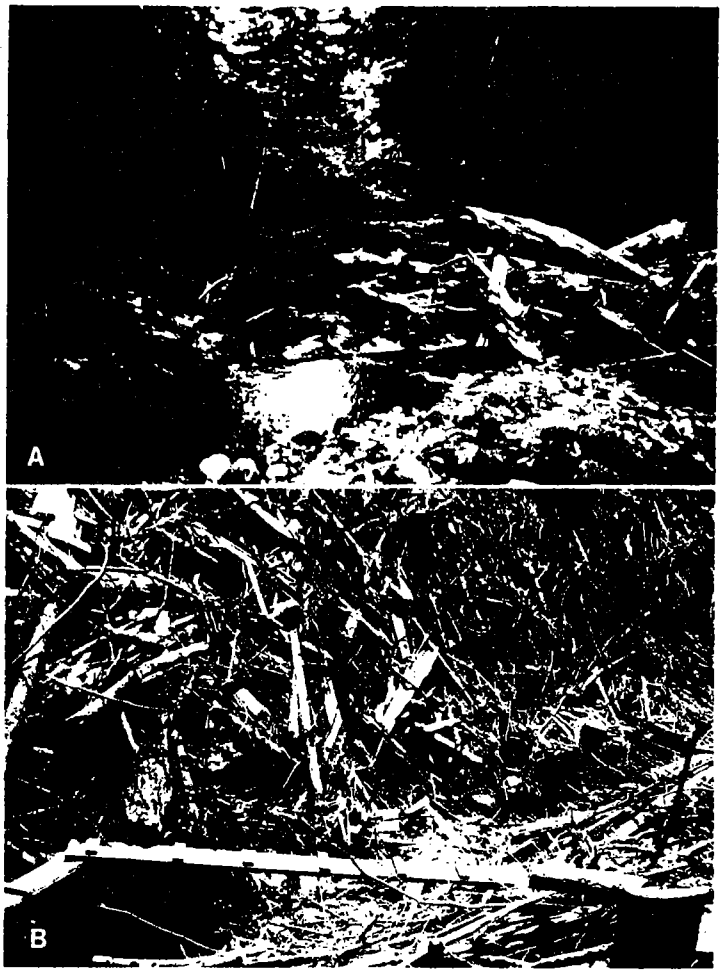

FIG. 1. (A) A log debris dam in Mack Creek at H. J. Andrews Experimental Forest, and (B) logging debris on the forest floor and in the small stream draining Watershed 10.

streams, Mack Creek and Hagen Creek. Aquatic investigators at the Andrews LTER site include Stan Gregory, Norm Anderson, Fred Swanson, Art McKee, George Lienkaemper, and Jim Sedell. The LTER stream studies are tightly integrated with additional programs of terrestrial and aquatic research at Oregon State University.

Third-order Mack Creek (Fig. 1) drains a 600-ha forest of old-growth (>400 yr) Douglas-fir and western hemlock. Downstream of the old-growth portion of the watershed is a 20-yr-old clearcut. LTER research at Mack Creek has characterized the physical, chemical, and biological features of both the old-growth and the regrowth regions. Permanent channel cross sections have been established and all logs in a 900-m reach have been tagged and are inventoried annually. Detrital, algal, invertebrate, and fish components are being monitored in both sections of Mack Creek.

The Hagen Creek site includes the 450-ha drainage of the North Fork and the adjacent 590-ha South Fork drainage. The lower region of the South Fork drainage will be logged in summer 1985 to create sections with all riparian vegetation and wood debris removed, only wood debris removed, and only riparian vegetation removed. These regions will be compared to the unharvested upstream reaches and to the adjacent control watershed of the North Fork. Permanent channel cross sections have been estab-

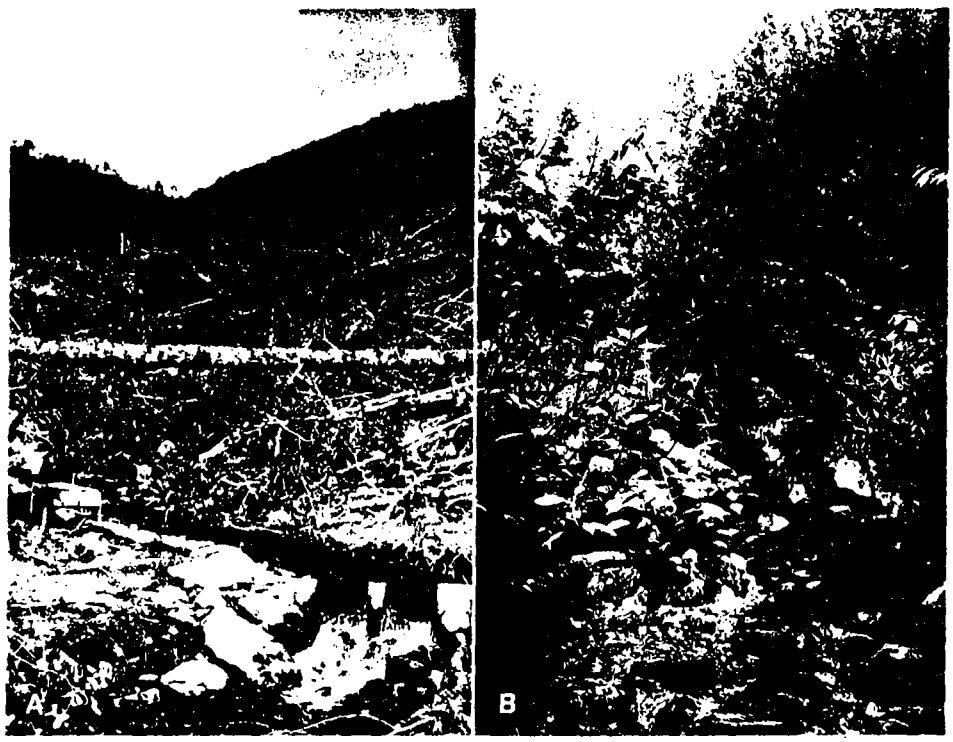

FIG. 2. (A) Big Hurricane Branch in 1977, shortly after the watershed was logged, and (B) the same site in 1983, 6 yr after logging. Big Hurricane Branch drains Watershed 7 at Coweeta Hydrologic Laboratory.

lished and 800 m of channel have been mapped. Detrital, algal, invertebrate, and fish components of both forks are being compared and are quite similar. LTER studies will evaluate both physical and biological responses to alteration of riparian vegetation and large wood debris.

Future aquatic LTER studies at the Andrews Reserve include a long-term terrestrial-aquatic investigation of log decomposition and a year-long time-lapse movie of a stream.

Coweeta Hydrologic Laboratory

Coweeta Hydrologic Laboratory was established as a site for U.S.D.A. Forest Service research in 1934 and is one of the oldest continuously operating projects of its type in the world. Located 17 km south of Franklin, North Carolina, in the deciduous forest of the southern Appalachian Mountains, Coweeta has been the site of multi-institutional ecological research since 1968. The major focus of ecological research has been on the effects of forest management practices on watershed nutrient cycles. The objectives of LTER-sponsored studies concern long-term forest dynamics, the nature of forest ecosystem response to anthropogenic influences, and the accumulation of potentially toxic substances.

The 50-yr history of watershed hydrological and meteorological data, the wide variety of manipulated ecosystems, the framework of terrestrial ecological studies, and the accessibility of numerous different-order streams make this an ideal site for research on stream ecology. Investigators involved in LTER-sponsored stream research include Judy Meyer, Bruce Wallace, and Jack Webster. The focus of their research is the effect of watershed disturbances on streams (Fig. 2), specifically on stream particulate organic matter dynamics, dissolved organic carbon, and invertebrates.

Streams at Coweeta range from first- to fourth-order, 675 m to 1350 m elevation, and from relatively undisturbed (selective logging prior to 1925) to recently disturbed (clearcut logging in 1976–1977). Stream studies other

FIG. 3. The confluence of the Illinois and Mississippi Rivers, ≈22 km north of St. Louis. Side channels, islands, and backwaters are typical of both rivers.

than those sponsored by LTER include in-stream nutrient dynamics, the role of invertebrates in streams, invertebrate-microbial interactions, detritus feeding studies, microfauna studies, fish community interactions, salamander studies, effects of low pH on crayfish and insects, and seston dynamics.

Illinois River and Upper Mississippi River

The Illinois Natural History Survey began ecological research on the Illinois River and its backwaters and floodplain in 1876, and the Illinois Water Survey began collecting chemical data in 1898. In addition to these two groups, other institutions participating in the LTER are the State Geological Survey, the State Museum, and Western Illinois University. Large, undisturbed rivers no longer exist in the United States, and the major research objective at the Illinois River and Upper Mississippi River LTER site is to document large rivers as they are now (Fig. 3).

Research objectives at this site are: (1) to explain the basis of productivity, and controls on productivity, in large floodplain rivers, (2) to determine temporal and spatial patterns of nutrient inputs, losses, and utilization, (3) to examine effects of natural and man-made perturbations, including droughts, floods, navigation dams, barges, and contaminants, on key species and processes, and (4) to define relationships between community structure and the hydrologic regime and geomorphic structure. Specific research approaches include reconstruction of historical and prehistorical disturbances using cores from sediments and old trees, sampling and modeling of populations of key producers and consumers, sampling and modeling of water, sediment, and carbon flows in habitat compartments, and analyses of successional patterns in both natural floodplain lakes and navigation pools.

Three sites have been selected for long-term study. Keokuk Pool is the oldest impoundment on the Mississippi (dammed in 1913) and has extensive beds of aquatic vegetation and dense populations of burrowing mayflies and fingernail clams. It attracts one of the largest inland concentrations of diving ducks in North America and supports a commercial fishery. Although the Keokuk Rapids were flooded by the dam, torrent-loving species, such as net-spinning caddisflies, occur in dense numbers on the dam itself and the rock and rubble below the dam. In contrast, the second study reach will include the newest impounded reach on the Mississippi when dam number 26 is completed in 1987, just upstream from St. Louis. The third site is the middle reach of the Illinois, including a natural mainstem lake at Peoria.

Investigators at the Large Rivers LTER site are J. Roger Adams, Richard V. Anderson, Nani G. Bhowmik, Richard A. Cahill, Misganaw Demissie, Robert W. Gorden, David Gross, James King, Kenneth S. Lubinski, Paul G. Risser, Richard E. Sparks, Wayne Wendland, and Michael J. Wiley.

Konza Prairie Research Natural Area

Tallgrass prairie once covered nearly 7% of the conterminous United States, but undisturbed prairie ecosystems are now rare because of extensive conversion to grain crop agriculture. The Konza Prairie Research Natural Area (≈3500 ha), located in the Flint Hills, 10 km south of Manhattan, Kansas, was purchased by The Nature Conservancy in the 1970's. Prior to acquisition, this area had

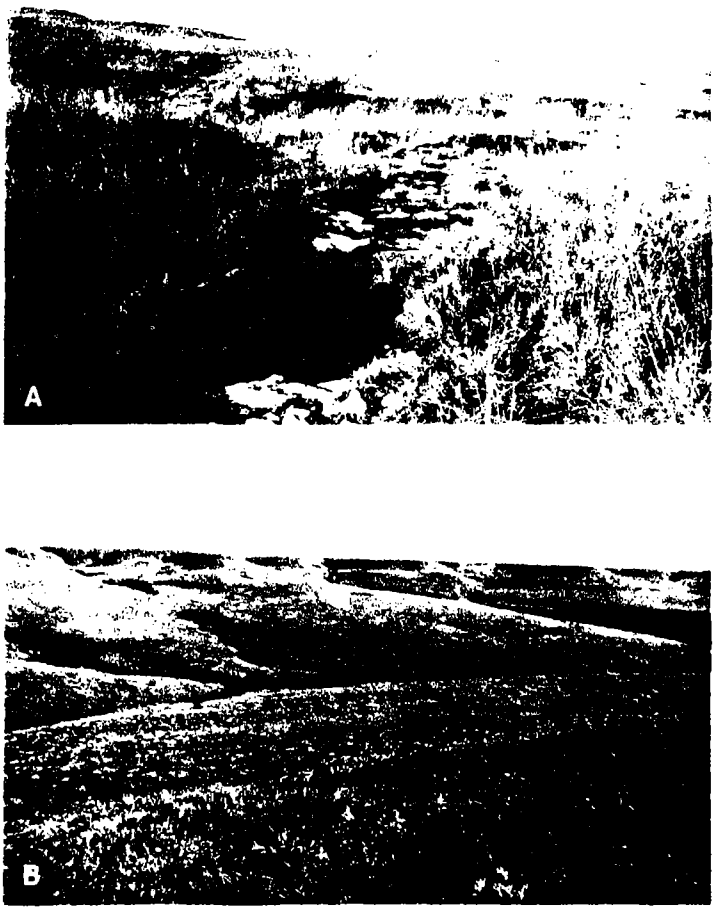

FIG. 4. (A) A headwater stream in the tallgrass prairie uplands at the Konza Prairie Research Natural Area, and (B) an overview of the South Branch drainage of Kings Creek showing the tallgrass prairie uplands and the gallery forest along the downstream reaches of the stream.

been used for grazing for ≈125 yr. When acquired it was in good to excellent condition and dominated by native prairie plants.

Streams at the Konza Prairie site contrast with running-water systems at other LTER sites. Headwater channels in the bluestem prairie uplands are dominated by grasses in both channel and streamside vegetation; there is little or no tree canopy (Fig. 4). Midreach riparian vegetation includes shrubs (smooth sumac and buckbrush) and small trees (elm and locust) as well as grasses and sedges. There is a relatively abrupt transition to a gallery forest (Fig. 4) of oaks (chinquapin and bur), hackberry, and elm along lower stream regions. The hydrologic regime is characterized by high temporal and spatial variability. Headwater channels are ephemeral and most other channels have only intermittent flow, but a few perennial pools and flowing regions occur in the drainage. Spatial variability results from geologic influences on groundwater movements and channel permeability. The seasonal hydrologic pattern includes a flow period, which varies considerably in duration from year to year, as well as major storms which vary in frequency, magnitude, and timing. Most of the precipitation occurs in late spring and early summer thunderstorms. High evapotranspiration in the summer often leads to a dry (no flow) period in the late summer and autumn. Recharge

occurs during autumn, winter, and spring precipitation when evapotranspiration is low. The timing and intensity of storms influence organic matter storage in stream channels and the metabolic characteristics of prairie streams. The variable duration of flow periods also influences life history strategies of the biota.

LTER stream research at Konza Prairie is focused primarily on questions relating to hydrology and nutrient export from managed catchments where fire occurs annually, at 4-yr intervals, or where fire is excluded. Some of these catchments are to be grazed by native ungulates (bison, elk, and antelope) and others will be left ungrazed. LTER stream research is directed by Dick Marzolf. Non-LTER stream research at Konza Prairie has included analysis of instream primary production patterns, microbial utilization of dissolved organic matter and nutrients, instream nitrogen dynamics, organic matter import, storage, and transport, and the role of hydrologic disturbances (flooding and drought) in ecosystem phenomena.

Niwot Ridge and Green Lakes Valley

The Niwot Ridge/Green Lakes Valley LTER site is located 45 km northwest of Boulder, Colorado. The site is surrounded by protected lands including the Indian Peaks Wilderness Area, City of Boulder Watershed, and Roosevelt National Forest. Within the area are a variety of landforms including glaciers, glacial lakes, patterned ground, talus slopes, and mountain streams. The main vegetation types are alpine tundra and subalpine forest. LTER-sponsored research is integrated with a perspective of the past provided by paleoenvironmental studies. LTER researchers hypothesize that current communities are not in equilibrium with the climate but lag behind. They propose that moderate disturbance will hasten community development. Historical and baseline data are being collected to determine the time frame for changes in the alpine region.

For the past 2½ yr there has been monthly sampling of dissolved inorganic and organic stream water chemistry. The hydrologic pattern consists of spring (May–June) snow melt with a peak in the hydrograph. The majority of dissolved material transport occurs during this time. Although concentrations of dissolved inorganic constituents decrease during this peak in the hydrograph, dissolved organic carbon increases 3 to 5 fold, indicating that there is a flush of organic carbon from soil and interstitial waters during snow melt.

Soil interstitial water contains nearly equal amounts of dissolved inorganic and organic compounds. Dissolved organic carbon concentrations are 30 to 60 mg/L, which is 10–50 times greater than the stream water concentration. This suggests that soil waters contribute little to the dissolved constituents of the stream. Studies are continuing on the organic chemistry of soil and stream waters in order to characterize the nature and role of organic carbon in the stream. The overall plan is an organic carbon budget for the soils, plants, and water of Green Lakes Valley. Stream research at the Niwot Ridge/Green Lakes Valley site is being directed by Nel Caine, Mike Thurman, Dale Toetz, and Jay Windell.

North Inlet Marsh and Estuary

The North Inlet LTER site, known as Hobcaw Barony, is a 7085-ha tract of forest and coastline located 1.6 km north of Georgetown, South Carolina. The primary research area is a 2630-ha high-salinity marsh, one of the most pristine coastal areas on the east coast. Most of the LTER-sponsored research concerns the biological, chemical, and physical components of the marsh-estuary ecosystem.

Streams at the North Inlet site drain forested, low-topography, sandy soils. The flow period varies considerably from year to year, but generally streamflow only occurs from January to June. The frequency, timing, and magnitude of major storms also vary greatly. Hydrologic studies at North Inlet began in 1975 with measurement of groundwater levels. In 1978 five streams were gauged, and two of the streams have been monitored continuously since that time. Precipitation and weather information have been collected since 1971. Water chemistry studies were initiated in 1982. Since 1983 stream studies have expanded to include detritus processing, evaluation of macroinvertebrate communities, and the role of terrestrial nutrient cycling in regulating nutrients transported into the streams. Stream studies at the North Inlet site are being directed by Liz Blood and Len Smock.

Other Sites

At two of the LTER sites, Jornada and Central Plains Experimental Range, surface water is ephemeral, and there are no plans for stream research. At the Okefenokee Swamp site there has been research on hydrologic and nutrient budgets of the swamp watershed, but there is no current stream research. However, the preliminary baseline research opens numerous opportunities for productive research on swamp streams. Though there are numerous streams on the Cedar Creek Natural History Area site, there is currently no stream research, but there is interest in initiating collaborative stream studies. Aside from sporadic monitoring of several streams, little stream research has been done in the Northern Lakes area, but visiting scientists or collaborative stream research would be welcome. The seasonal stability of flow and the fact that streams at the Northern Lakes site are short segments between lakes makes for interesting comparisons with other LTER streams.

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