Hydrologic Research at LTER Sites

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The Long-Term Ecological Research (LTER) program of the National Science Foundation was formulated and initiated by the Division of Biotic Systems and Resources to support research that addresses ecological variabilities that may last or be detectable only over a period of 10 to 100 years. Eleven sites have been selected at which research in various ecological areas is being conducted by interdisciplinary groups of scientists with backgrounds in hydrology, biology, geology, forestry, geography, chemistry, and other disciplines. At all the sites, data collection and analyses are being performed on various biological processes that represent the total environment of these sites. Research on hydrological processes and their interactions with biology is a vital part of the long-term ecological research projects. This article summarizes various topical hydrological research and data collection projects that are being performed at these sites.

Introduction

The Long-Term Ecological Research (LTER) program was designed to support research that addresses 10–100-year periods of ecological changes, long-term trends in ecosystems, and annual variability and to cover a wider scope of research than that of many previous ecological studies. Research on 11 sites is being conducted within a LTER program that began in 1981–1982. All the sites are required to address five core areas:

- primary production,
- populations that describe trophic structure,
- accumulation of organic matter in surface layers and sediment,
- inorganic inputs and movement of nutrients through soils, groundwater, and surface water, and
- patterns of disturbance.

One of the key concepts in the LTER program is the integration of data and results from the various sites to produce research results that span several habitats. In the hydrology and sediment components, the opportunity to expand results from small streams to the much larger Illinois and upper Mississippi rivers holds the chance for substantial development in our understanding of the hydrology of complete river systems. Other LTER sites range from estuarine to alpine to desert, with associated differences in hydrology, erosion, and sediment transport processes.

Figure 1 shows the 11 LTER sites. An evaluation of logging methods on reforestation, erosion, and water quality. Since 1977, the National Science Foundation (NSF) has supported a baseline monitoring program that includes climatic variables, streamflow, stream water, chemistry, atmospheric deposition, litter fall, and successional changes in the composition and structure of vegetation. The site receives about 2500 mm of precipitation annually, most of which falls from October to March (R. Dennis Harr, Pacific Northwest Forest and Range Experimental Station, personal communication, 1984). Slopes are very steep and the surface soil is extremely porous with high permeability. Rapid melting of snow provides most of the streamflow, and high flows can be as much as 1000 times the low summer flows.

Basic hydrologic data on precipitation, climatic variables, stream discharges, suspended and bed load, sediment transport, and water quality parameters are being collected at this site. Some of this data collection began in 1949.

Research on hillside transport of sediment particles is being conducted, and an identification of the various processes has been made [*Grant*, 1986]. Processes such as these related to dissolved state, litter fall, surface erosion, creep, root throw, debris avalanche, and slump/earth flow have been identified on the hillslopes, while within the stream environment, materials can move either in dissolved

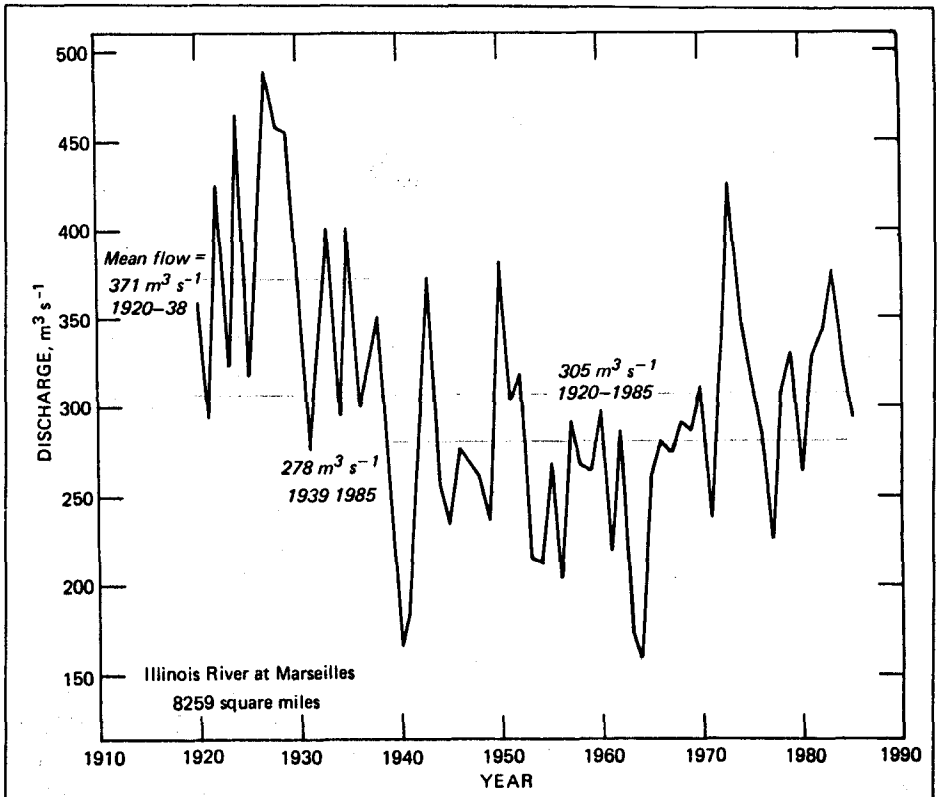

Fig. 2. Annual flows of the Illinois River at Marseilles.

Cedar Creek Natural History Area Site

The Cedar Creek site is a 2185-ha experimental ecological reserve located 50 km north of Minneapolis-St. Paul on a large glacial outwash sand plain. The average elevation of the site is about 175 to 288 m above mean sea level. The site has a continental climate, with cold winters, hot summers, and average annual precipitation of about 660 mm, which is scattered throughout the year. Mean temperatures are 22.2°C in July and −10°C in January [*Halfpenny and Ingraham*, 1984].

The site has an extensive data base, including information on climate variability, plants and vertebrates, land use patterns, primary productivity, effects of N and Mg on early succession, biotic disturbance patterns, and effects of nitrogen fertilization on herbivore dynamics and on vegetation. Research is centered on the "mechanisms whereby soil processes, interspecific plan competition, and herbivores influence the diversity and species

Forest Service since 1934. This is an upland area covering approximately 2185 ha with an average slope of 30°. Climate varies from a cool summer to a mild winter, with an average annual precipitation of 1800 mm that is distributed uniformly throughout the year. Lowest flows in the streams occur in September and October, and highest flows are in February and March. Soils have high infiltration rates, and no overland flow occurs on undisturbed sites.

Early research was designed to document the effects of mountain farming, woodland grazing, and unrestricted logging on soil and water resources [*Webster and Swank*, 1985]. Even though the initial research was concerned with hydrologic processes, since the 1970s research has been expanded to include other areas, including forest nutrient cycles.

Long-term climatic and hydrologic data on, for example, precipitation, wind velocity and direction, temperature, solar radiation, evaporation, atmospheric deposition, soil erosion rate, runoff, and water discharge are avail-

sites has shown that the major hypotheses or questions can be classified as follows [*Callahan*, 1985]:

- the influence of the physical environment on the structure and the changes in structure of the biota,
- the processes that regulate the accumulation and movement of organic matter,
- the processes that regulate the dynamics of inorganic nutrients,
- the distribution and regulation of populations of herbivores, and
- the role of disturbance in maintaining or changing the character of ecosystems.

Even though these 11 sites were never meant to be a statistically valid sample of the ecosystems of the United States [*Callahan*, 1985], they do represent a sample of diverse ecosystems. At all sites the hydrological processes, including surface runoff, soil erosion, frequencies of water movement, and transport, deposition, distribution of sediment, carbon, and other nutrients, play a significant role. I will now present a brief description of the hydrological data collection at various sites (in alphabetical order by site name). Some information on sediment data collection and analyses has been compiled by *Adams* [1986]. Other specific information on these sites is given by *Halfpenny and Ingraham* [1984].

H. J. Andrews Experimental Forest Site

This site was initially established by the U.S. Forest Service in 1948 to examine the

bris flow. Analyses have shown that episodic processes such as debris avalanches (on hillslopes) and flows (in channels) play a major role in transporting sediment particles. Even though these extreme events may occur only once in several centuries, they dominate the long-term sediment movement within the site. Movement of materials in the dissolved state occurs continuously and has been ranked second in amount of material transported. No long-term accumulation of inorganic materials within the subwatershed channel has been observed.

Research on the transfer of inorganic coarse debris within the site is continuing. Living and dead trees in both the watershed and the stream channel play an important role in the movement, deposition, scour, and resuspension and transport of organic and inorganic materials. Glacially formed large boulders and cobbles on the floodplains of many streams indicate the importance of infrequent but large episodic events that were responsible for the transport and deposition of these large particles.

The major research emphases include composition, structure, and process changes during succession, nature of forest stream interactions, population dynamics of forest stands, effects of nitrogen fixers on soils, and log decomposition patterns. Oregon State University (Corvallis), the Pacific Northwest Forest and Range Experimental Station, and Willamette National Forest have shared the administrative responsibility for the Andrews Forest site since 1977.

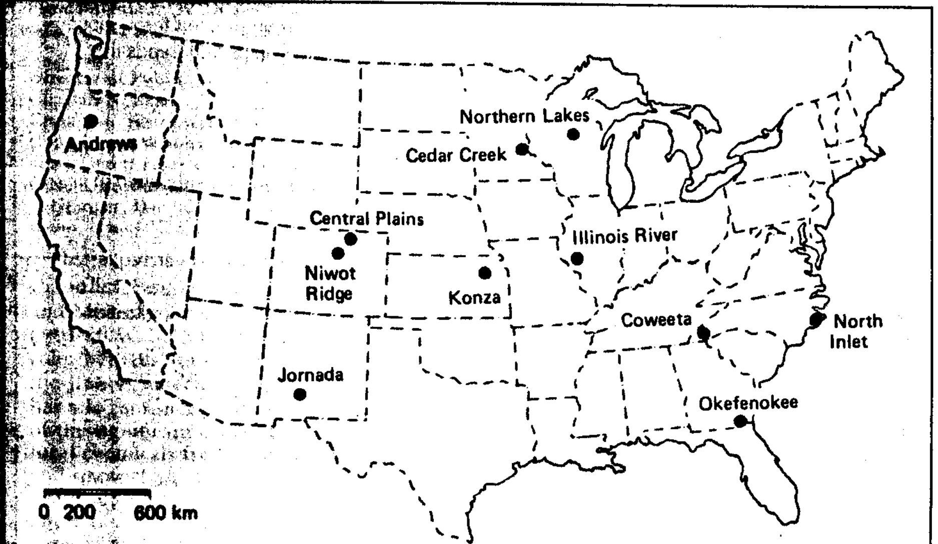

Fig. 1. NSF Long-Term Ecological Research (LTER) sites.

[*Halfpenny and Ingraham*, 1974]. Relationships between primary productivity, nutrient budgets, soil chemistry, climatic variation, and plant and herbivore dynamics on the secondary succession of oak savannah forests are being investigated through long-term observational and experimental studies. The research at this site is managed by the University of Minnesota.

Central Plains Experimental Range Site

This site consists of a 6280-ha tract of land with shortgrass rangeland, administered by the U.S. Department of Agriculture (USDA) Agricultural Research Service. A significant amount of grassland research was conducted at this site during the Grassland Biome portion of the International Biological Program. The site is dominated by shortgrasses (64%), succulents (21%), and half-shrubs (8%). Climatic fluctuation is extreme, with mean monthly temperatures ranging from −4°C to 22°C. Average annual precipitation is about 311 mm, with 70% of the precipitation occurring during the growing season, April to September.

Water plays an important role at this site, moving sediment from the upslope area, depositing it on downslopes, transporting soluble materials, and providing nourishment to plants. The hydrologic research at the site is aimed at the modification, verification, and use of the Chemicals, Runoff, and Erosion From Agricultural Management Systems 2 (CREAMS2) model [*De Coursey and Doehring*, 1986] to simulate the movement of water, sediment, and chemicals from field-sized areas. Eight natural runoff plots, varying in size from 0.02 to 0.25 ha, are to be used to verify the model. Data for both natural precipitation and simulated rainfalls will be collected. Meteorological and hydrological data are to be incorporated in the model verification.

Core research at this site emphasizes the relationship between hydrologic cycle and primary production, key microbial response, plant succession, plant and animal population dynamics, and organic matter aggradation and degradation; erosion and its impact on matter, nutrients, and pedogenic processes; and the influence of atmospheric deposition on primary production and nutrient cycles. The research here is conducted by Colorado State University (Fort Collins) and the USDA Agricultural Research Service.

Coweeta Hydrologic Laboratory Site

The Coweeta site is located in North Carolina and has been operated by the USDA

water quality parameters, including nitrogen, phosphorus, sulfur, trace metals, and carbon in the water column are also being collected (W. T. Swank, Southeastern Forest Experimental Station, personal communication, 1984).

Clearcutting of forests with carefully located and designated roads has produced an increase of about 15% in peak flows and storm flow volumes [*Webster and Swank*, 1985]. Research is being conducted on the effect of logging on summer temperature (maximum increase of 7°C); changes in vegetation (significant) and increase in stream sediment load (measurable and significant), changes in allochthonous inputs (an initial decrease occurs after logging but there is a return to the prelogging rate after about 7 years), instream primary productivity (about tenfold increase after logging), and other parameters such as dissolved organic carbon concentration, leaf breakdown rates, benthic organic matter, and benthic invertebrates.

The core research at this site addresses the areas of long-term trends in ecosystem responses, responses to anthropogenic influences, long-term changes in input-output nutrient dynamics, and process-level changes during ecological succession. Researchers from the University of Georgia (Athens), U.S. Forest Service, and southeastern Forest Experiment Station are working at this site.

Illinois and Mississippi Rivers Site

The Illinois and Mississippi Rivers site consists of three river reaches along the Mississippi and Illinois rivers within the Upper Mississippi River System (UMRS). These three locations include Pool 26 along the Mississippi River near Alton, Ill.; Pool 19 along the Missisippi River near Keokuk, Iowa, and Hamilton, Ill.; and Peoria Lake along the Illinois River near Peoria, Ill. The extreme tem-

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...perature ranging from −23°C to +38°C, annual precipitation ranging from 880 to 1220 mm, and more than half of the annual precipitation occurs during the growing season, with 20–80% from thunderstorms. Annual snowfall averages 640 mm. The long-term average annual discharges at Pool 26, Pool 19, and Peoria Lake are 2900, 1774, and 385 m³/s, respectively [*Bhowmik and Adams*, 1986; *Demissie and Bhowmik*, 1987]. The drainage areas at these sites are 444,900, 308,200, and 36,687 km², respectively. Pool 26 extends about 62 km along the Mississippi River, and along the Illinois River, it extends about 129 km. Pool 19 extends about 43 km along the Mississippi River. Peoria Lake extends about 39 km along the Illinois River. The research area for this site is the largest among all the LTER sites.

Extensive hydrometeorologic, hydrologic, water quality, and biological data are available for this site [1985]. Hydrologic ing constructions, such as dikes and closure structures, were also constructed to control the navigation channels. Flows from Lake Michigan have been diverted through the Illinois Waterway, increasing its long-term average flows since 1900. All of these human interventions have a profound impact on the hydrology, hydraulics, sediment transport, and sedimentation patterns of these large rivers [*Bhowmik et al.*, 1986]. The flows at Marseilles on the Illinois River (Figure 2) clearly show the impact of Lake Michigan diversion, which has been limited to 90.6 m³/s since 1939.

Construction of locks and dams has accelerated sediment deposition at these research sites. Pool 19 has lost about 58% of its capacity since 1913, and this pool may reach a dynamic equilibrium by the year 2030 or 2050, when it will have lost about 68% of its capacity [*Bhowmik et al.*, 1986]. Approximately 2.4 billion kg of sediment per year is deposited within this pool. Peoria Lake has lost about 68% of its 1903 volume, and the average depth is about 0.6 m, compared to an aver- searchers from Western Illinois University at this site.

Jornada Site

The Jornada site, which is a "desert biome with distinct vegetation zones as one moves from the lower elevation playa grasslands upslope to the mountain shrubland" [*Bolin and Ward*, 1986], is located near Las Cruces, N.Mex. The weather is hot and dry in the summer and cool and dry in the winter. Annual precipitation is about 229 mm, of which more than 50% falls between July and September, and the evaporation rate is about 10 times higher than the precipitation. The entire LTER site covers about a 570-ha area and is excluded from grazing.

The erosional potential at this site is very high because of the granular soil, sparse ground cover, steep slope, and intense storm events, which produce disproportionately high runoff rates. Some climatic data, on precipitation, wind velocity and direction, temperature, solar radiation, evaporation, atmospheric deposition, soil erosion, and runoff

The main research topics at this site include factors limiting primary production, impact of experimental application of nitrogen, lysimeter studies, and vertebrate and invertebrate populations. Researchers from New Mexico State University are working at this site.

Konza Prairie Research Natural Area Site

The Konza Prairie Research Natural Area consists of 3487 ha of native tall grass prairie that has been set aside for ecological research purposes [*Koelliker*, 1986]. This site is representative of the geological region called the Flint Hills Upland. The area is dissected with flat ridges that have permeable topsoil and slowly permeable subsoil and with wider valleys that have deep, permeable soil. Vegetation is representative of unplowed native bluestem (tall grass) prairie. The area has a temperate midcontinental climate, with warm, moist summers and cool, dry winters. Annual

water discharge, sediment movement, and sedimentation rates; sediment quality; and aquatic resource quality parameters, including sand, temperature, precipitation, atmospheric deposition, solar radiation, and evaporation. Benchmark data on fishes, plankton, and benthos from the Illinois River since [illegible] and biological information on waterfowl, aquatic and floodplain vegetation, and commercial fishing are also available. Long-term extensive research on all aspects of hydrological cycles and on biological cycles, including those in aquatic and terrestrial environments, has been conducted at this site. All the locations at this site have been extensively disturbed by human intervention. Locks and dams have been constructed along both rivers since 1913 [*Bhowmik and Adams*, 1986; *Demissie and Bhowmik*, 1987], which transformed the original natural free-flowing rivers into a series of pools with a minimum water depth of 3–4 m to allow commercial navigation. Extensive levees and river-training century [*Demissie and Bhowmik*, 1987].

The broad objectives of the research conducted at this site are to explain the basis and controls of productivity in large floodplain rivers; to determine temporal and spatial patterns of nutrient inputs, losses, and utilization; to examine effects of natural and human perturbations in key species and processes; and to define relationships between community structures and the hydrologic regime and geomorphic structure. Hydrological research in these areas addresses succession and perturbation; the hydrological environment, including mathematical modeling of water, sediment, carbon, and nutrients; and long-term sedimentation patterns [*Bhowmik and Adams*, 1986; *Demissie and Bhowmik*, 1987]. Research on the interrelationships between hydrological and biological processes is also being conducted at this site. Researchers from the Illinois State Water Survey, Natural History Survey, and Geological Survey, located at the campus of the University of Illinois, Urbana-Champaign, are working with re-

some have been collected since 1982 (W. G. Whitford, New Mexico State University, Las Cruces, personal communication, 1984). Some climatic data have been available since 1915 [*Halfpenny and Ingraham*, 1984]. Water level and water quality data from ephemeral lakes have been collected since 1984.

Hydrologic research includes the measurement and evaluation of water and sediment yields from three different areas within the site. At two areas, portable rainfall simulators have been utilized, and at a third area, data are collected only for natural rainfall events. In the areas where rainfall simulators are utilized, various plots were treated with chemicals to remove insects or were given various grass covers or vegetation zones. In general, runoff rates were higher from treated plots and from plots with less grass cover, a result similar to the observation of increased sediment yield from plots with less vegetation [*Bolin and Ward*, 1986]. Data from natural plots did not show any significant variations from those of the controlled plots.

average lake evaporation is about 1360 mm, indicating an average annual moisture deficit of 525 mm. Droughts are not uncommon and may last for several years. Floods can rearrange the morphology of the stream completely [*Koelliker et al.*, 1985].

Hydrologic research at this site addresses stream hydraulics, surface and groundwater movement, altered water quality parameters caused by prescribed burning of the prairie at 1-, 2-, 4-, and 10-year intervals, and sediment yield and transport within the watershed. Because of the permanent grass cover, very little sheet and rill erosion exists at the site. Erosion is caused mainly by streambank instability. However, because of the fine-grained soil characteristics, most of the sediment is transported away from the site when suspended. Emphasis at this site has been on organic matter and other biologically related phenomena.

This site is managed to approximate the condition of the presettlement ecosystem to provide a comparison of natural and manipulated systems in similar hydrologic and climatic settings. The main emphasis is on determination of the role of fire, grazing, precipitation, and drought in a tall grass prairie ecosystem [*Halfpenny and Ingraham*, 1984]. The research is being conducted by researchers from Kansas State University (Manhattan).

Niwot Ridge/Green Lakes Valley Site

The Niwot Ridge research site is located in Roosevelt National Forest near Boulder, Colo. The Green Lakes site is close to Niwot Ridge but is under the administration of the City of Boulder. The site has a high elevation with midcontinental climate: cold, wet winters and cool, dry summers. The extreme temperature variations range between −37°C and 19°C. At this site, 80% of the 1020-mm annual precipitation falls as snow from September to May. Lakes are frozen from October to May. Streams in Green Lakes Valley have steep gradients, with average slopes of 12°, and the basin has a mean slope of 25°.

Transport of sediment occurs primarily as mass transfer, with infrequent rockfalls involving more than 5 m^3 of debris [*Cain*, 1986]. Transport of sediment by fluvial activity is relatively minor even during high runoff events, probably because of the snow cover on about 50% of the watershed during the highest stream discharges. Concentration of vegetative cover in the riparian zone also acts as an effective filter barrier for sediment. At-

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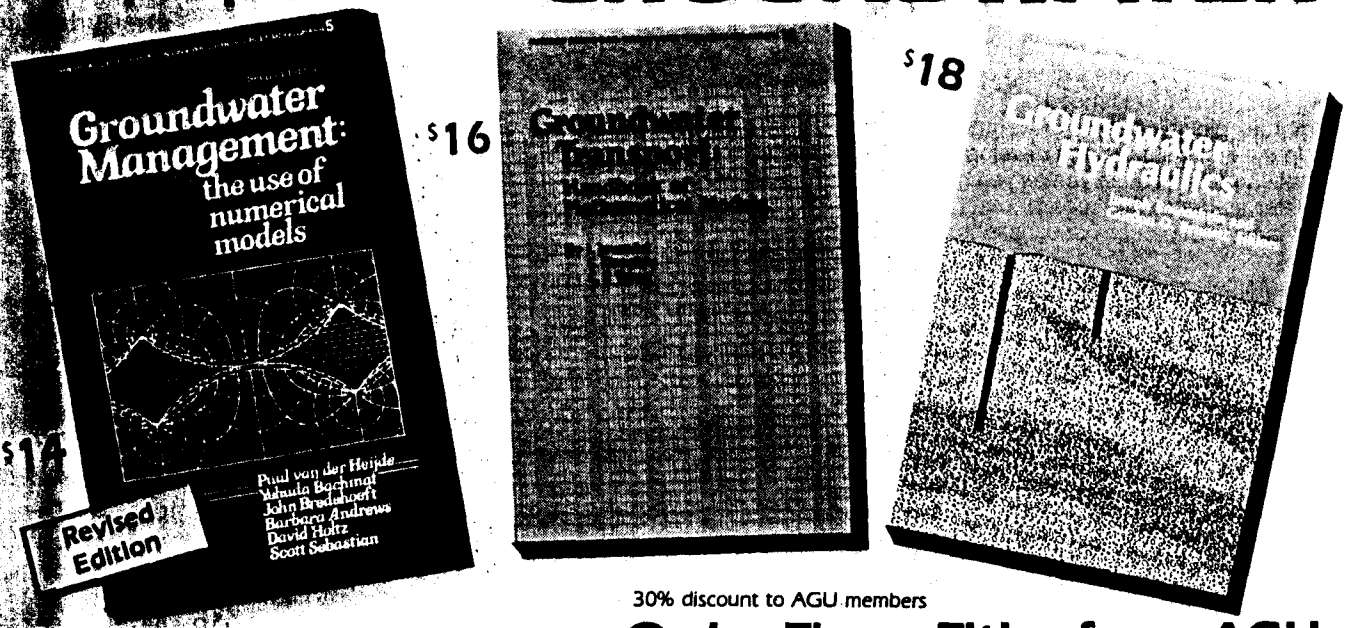

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atmospheric transport and deposition of silt and clay are important for this site.

The main research areas at this site include climate, water, and soil; paleoecology and geology; communities, ecophysiology, and ecology; mammals, aquatic communities, and aquatic invertebrates; and lake productivity. Research is also being conducted on the premise that current plant and animal communities are not in equilibrium with the climate but lag behind due to directional changes in the climate since the end of glaciation [*Halfpenny and Ingraham*, 1984]. Research at this site is being done by researchers from the University of Colorado, Boul-

North Inlet Marsh-Estuarine System Site

The LTER research site is located near Georgetown, S.C., on North Inlet along the coast. The site is within a 2-m elevation of mean sea level and has about 7085 ha available for conducting studies of marine biology, forestry, and wildlife. The primary research area is a 2630-ha high-salinity marsh that is separated from the Atlantic Ocean by sand barrier islands and is bordered on the land by loblolly and longleaf pine forests [*Halfpenny and Ingraham*, 1984]. This site is one of the few pristine marsh estuaries on the East Coast.

The maritime climate influences the area, with air temperatures varying from −4°C to 36°C and water temperature ranging from 3°C to 32°C. Average annual rainfall is 1150 mm, with very little ice or snow. Approximately 5–10 years of data are available on climatic variables, subtidal biological population, and primary production and meiofauna. Wetland habitats include exposed and sheltered sandy beaches; intertidal mudflats and oyster beds; submerged algae beds; sand, shell, and mud benthic habitat; rock jetties; and bird rookery islands.

The major research topics include patterns and control of primary production, dynamics of selected populations, organic accumulation, patterns of inorganic contributions, and site disturbances. The research at this site is conducted by researchers from the University of South Carolina, Columbia.

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Northern Lakes Site

The Northern Lakes site is located about 320 km north of Madison, Wisc., south of Ironwood, Mich., and north of Rhinelander, Wisc., near the Wisconsin-Michigan border. This area encompasses 10,000 km² and contains thousands of lakes. The biological station is located at Trout Lake. This area has the largest concentration of lakes in the world. The average elevation of the site is 500 m above mean sea level. The site has a continental climate with an average annual temperature of less than 5°C. Mean monthly temperatures range from −17°C to −6° in January to 26°C to 13°C in August. Average precipitation equals 760 mm, and about 230 mm of this falls in the spring. Snowcover averages 1270–1520 mm for about 120 days each year [*Halfpenny and Ingraham*, 1984].

Extensive long-term data are available at this site on the chemistry, flora, fauna, fish populations, and limnology of the lakes; climatic parameters at five sites within 45 km of the site; and primary productivity of some lakes. Land use and land cover photographs and maps for four periods since 1931 are available for this site. Data on hydrology, climate, and water quality are also collected at varying intervals.

The major goals at this site are to collect, evaluate, and analyze data to detect long-term changes in physical, chemical, and biotic features of the lakes; understand the linkage among climate, hydrology, biology, and water and soil chemistry; and detect lake features that enhance stability and resiliency to natural and anthropogenic disturbances. Researchers from the University of Wisconsin, Madison, are working at this site.

Okefenokee National Wildlife Refuge Site

The Okefenokee National Wildlife Refuge Site is located in southeastern Georgia and northern Florida and is one of the largest wetlands in the country. It occupies a 382,500 ha area, of which 177,500 ha (44%) is swamp proper. Because of impermeable deposits inhibiting vertical seepage, the swamp can be considered a perched watershed. The climate at this site is warm temperature subtropical, with mild, wet winters, hot, wet summers, and dry autumns. Average precipitation ranges from 1000 to 1500 mm per year with mean temperatures ranging from 11.7°C in January to 27.1°C in July. Long-term data bases at this site include those on climatic and water level fluctuations, river discharges, land use and vegetation histories, nutrient balance, nutrient contribution from birds, invertebrate

1) Okefenokee Swamp is a detritus-based ecosystem in which most of the primary production enters a detrital reservoir composed principally of refractory organic matter, such as lignocellulose, which degrade slowly; 2) water level is a major factor controlling patterns and rates of productivity, nutrient cycling, trophic dynamics, organic accumulations, succession, and life cycle dynamics within the swamp; and 3) fire is a controlling factor in the dynamics of the above mentioned processes.

As of 1987, LTER research at this site has been discontinued. Researchers from the University of Georgia and the U.S. Fish and Wildlife Service have conducted research at this site.

Summary

I have summarized the hydrological research that is being conducted at 11 Long-Term Ecological Research (LTER) Sites around the country. These research projects are supported by the National Science Foundation. At all the sites, hydrological processes (such as soil erosion, sediment transport and sedimentation); climatic parameters (including precipitation chemistry and deposition); water chemistry, water level fluctuations, and interactions between surface and groundwater have been shown to play a significant role in numerous biological processes. Among these processes are primary production; nutrient cycling and uptake; successional dynamics; accumulation utilization, distribution, processing, and movement of organic matter; population dynamics; microbial responses; growth, development, and dynamics of vertebrate and invertebrate populations; and other related processes. Research at all these sites is conducted by teams of scientists who are using an interdisciplinary approach in which hydrological and biological processes are studied and evaluated simultaneously. Specific research projects on hydrological processes at all these sites have not been outlined here. The importance of the interdependence of the environmental sciences and hydrological/hydraulic engineering is amply demonstrated at all 11 LTER sites.

Acknowledgments

This research was supported in part by the Illinois and Mississipi Rivers Project in the Long-Term Ecological Research Program of the Division of Biotic Systems and Resources, National Science Foundation, through grant BSR81–14563. Many researchers from all 11 LTER sites contributed significant amounts of materials that were utilized liberally in the preparation of this article. Special thanks are

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Nani G. Bhowmik *received his B.S. in civil en-*

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populations, other biological parameters, and water chemistry of the swamp.

Okefenokee is a spatially and temporally heterogeneous system that fluctuates in response to variability in water balance, hydroperiod, and catastrophic disturbances. The main research emphasis at this site addresses three basic hypothesis [*Halfpenny and Ingraham*, 1984]:

Rodger Adams, Mike Demissie, and Rip Sparks of the Illinois LTER project for their contributions.

References

Adams, J. R. (Ed.), Sediment movement at LTER sites: Mechanics, measurement, and integration with hydrology, *Ill. State Water Surv. Contract Rep. 387*, April 1986.

Bhowmik, N. G., and J. R. Adams, The hydrologic environment of Pool 19 of the Mississippi River, in *Ecological Perspectives of the Upper Mississippi River*, edited by M. M.

gineering from Dacca University in Bangladesh. He received his M.S. (1965) and Ph.D. (1968) from Colorado State University. Since 1968, he has been working with the Illinois State Water Survey at the University of Illinois, Urbana-Champaign. His major research area encompasses river mechanics, sediment transport, interactions between sediment and aquatic environments, and erosion and sedimentation. He is presently employed as principal scientist and assistant head of the Surface Water Section.

Plan to Attend
the 1987 Medalists and Awardees
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to be held at the AGU Fall Meeting

Wednesday, December 9
Cathedral Hill Hotel
5:45 to 9:30 P.M.

Join President Eagleson and the AGU Officers in paying tribute to the 1987 Medalists and Fellows at the banquet following the Honors Ceremony on Wednesday, December 9, at the Cathedral Hill Hotel. The recipients of the Medals are:

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Macelwane Medalist

Mary Lou Zoback
Macelwane Medalist

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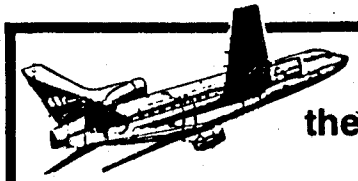

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