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SEDIMENT MOVEMENT AT LTER SITES:
MECHANICS, MEASUREMENT, AND INTEGRATION WITH HYDROLOGY

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1. INTRODUCTION

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LTER Program

The Long-Term Ecological Research (LTER) program was designed by the National Science Foundation Division of Biotic Systems and Resources to support research which addresses the 10- to 100-year periods of ecological change, long-term trends in ecosystems, annual variability, and a wider scope of research than that of many previous ecological studies. Eleven project sites form the first LTER program which began in 1981 and 1982. All sites are required to address five core areas: 1) primary production; 2) populations describing trophic structure; 3) accumulation of organic matter in surface layers and sediment; 4) inorganic inputs and movement of nutrients through soils, ground water, and surface water; and 5) pattern 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 which span several habitats. In the hydrology and sediment components, the opportunity to extend results from small streams to the much larger Illinois and Upper Mississippi Rivers is one 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 erosion and sediment transport processes, A need for a workshop on sediment movement became apparent at a meeting of the LTER streams group and at an all-scientists meeting. The workshop and site reports presented here are the outcome of this desire for a meeting focused on sediment movement and its measurement.

Intersite Workshop on Sediment Movement and Measurement

An LTER intersite workshop on sediment movement and measurement was held on September 16-18, 1985, at Pere Marquette State Park near Grafton, Illinois. Investigators from all LTER sites were invited to prepare presentations on their sites' sediment component design, data collection, and current results. Representatives from six sites participated (see figure 1.1). Several experts from non-LTER sites and" agencies were also . invited to participate, though none accepted the invitation.

The first full day of the workshop included presentations by the keynote speaker and each investigator. The second day was devoted to discussions of measurements, intersite comparability, and future collaboration, and to an oral summary of the workshop. The workshop agenda and list of participants are included in the appendix.

Several questions were pertinent to this workshop. The impact of extreme events is important at all sites, but differs depending on the frequency of the extreme events and the relationship between extreme events and average conditions. The estimation of soil loss by methods such as the Universal Soil Loss Equation and its comparison with actual soil erosion is important at most sites. The ratio of instream sediment to watershed

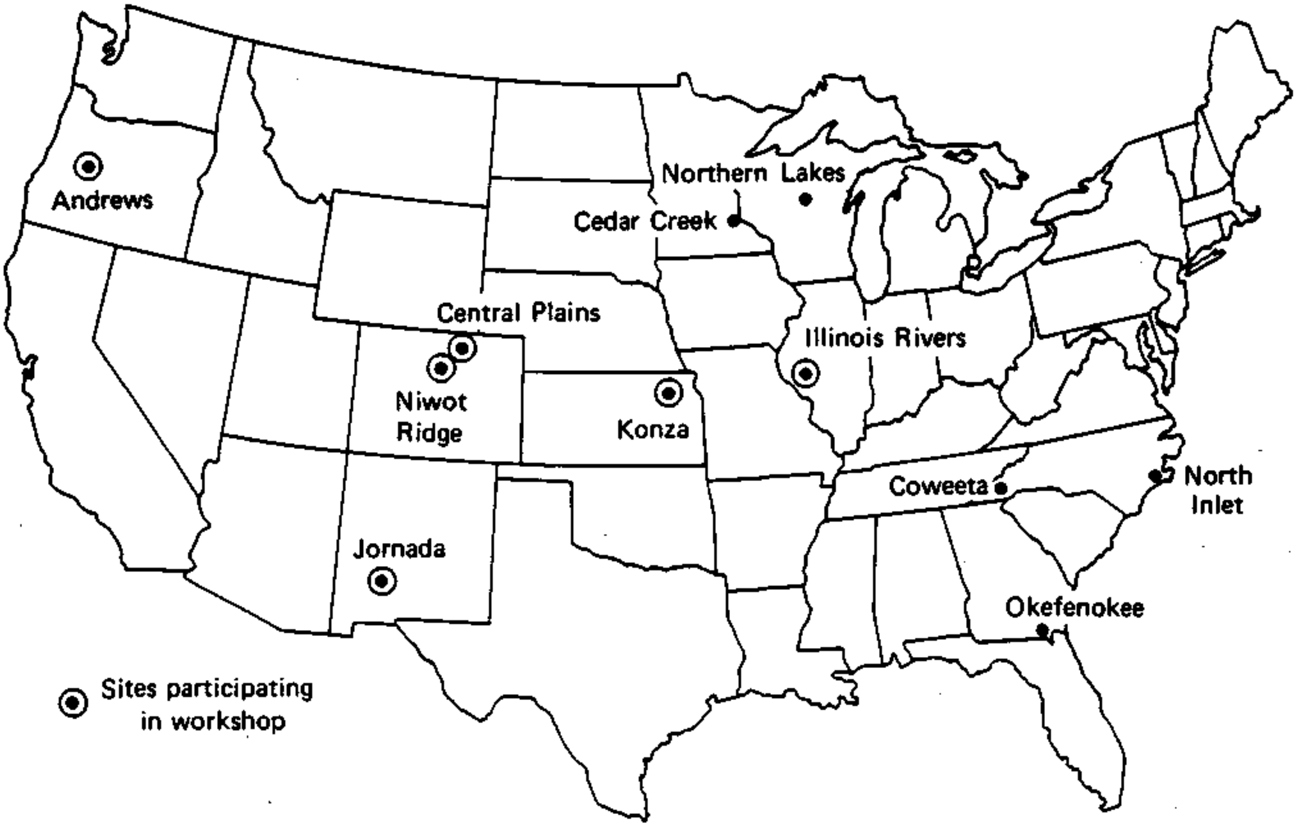

Figure 1.1. Long-Term Ecological Research sites

erosion is important to the geomorphology of a system. The accuracy of sediment measurement depends on sampling techniques and frequency and on the division of sediment transport between bed load and suspended load. Thus, agreement on methods is necessary for valid intersite comparisons. Other considerations such as water chemistry and mixing, annual flow regimes, water temperature during major transport periods, the characteristics of the material available for transport, and the relative importance of wind erosion make intersite comparisons difficult. Another consideration is organic debris, which is transported and deposited by aeolian and fluvial action and ranges in size from tiny particles to large tree trunks.

Workshop Objectives

The workshop was intended to achieve two objectives:

1. To develop coordination, cooperation, and exchange of information among the LTER sites.

2. To result in published proceedings that would include the site reports and a summary of the discussion of the presentations.

Outline of Report

This report includes the six site reports prepared by the workshop participants. It then presents a summary of the group discussions, a list of intersite hypotheses, and suggested goals for intersite cooperation and improved integration of hydrologic and erosion-sedimentation components into the LTER projects and program.

The site reports are presented in alphabetical order according to site: Andrews, Central Plains, Illinois Rivers, Jornada, Konza Prairie, and Niwot Ridge. These reports have been edited and retyped for uniformity of style.

Acknowledgments

The workshop was supported by the LTER Coordination Grant from NSF. Jerry Franklin of the Andrews Experimental Forest is chairman of the Coordinating Committee. Administrative matters were handled by Judy Brenneman, Department of Forestry, Oregon State University, Corvallis. Richard E. Sparks, Project Director for the Illinois and Mississippi Rivers site, encouraged us to plan and convene this intersite meeting. Kenneth S. Lubinski of the Illinois Natural History Survey Grafton Laboratory did an excellent job of making local arrangements. Douglas Blodgett and Frank Dillon helped with transportation between the St. Louis airport and Grafton, demonstrated the sediment sampling equipment used to measure suspended sediment transport, and assisted with other details. Nani Bhowmik spoke in place of Dr. Daryl Simons, who was unable to attend, and gave a commendable opening talk and assisted in the final summary and plan of action. The report was typed by Becky Howard and edited by Gail Taylor.

2. SEDIMENT MOVEMENT AT THE OREGON LTER SITE (H.J. ANDREWS SITE)

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The Oregon LTER site, located in the western Cascade Mountains in and around the H.J. Andrews Experimental Forest, is representative of a coniferous forest ecosystem developed in a steeply dissected landscape. Sediment movement within this site is complex, resulting from interactions between high relief, steep hillslope and channel gradients, annual precipitation of 2500 mm, very coarse (1 m+) bed material, and large accumulations of both living and dead trees. Natural and anthropogenic disturbances which affect the forest vegetation, such as wildfire or clearcutting, strongly influence sediment transport processes and rates. This site report presents a general overview of processes and rates of material transfer in this landscape as determined by monitoring of sediment fluxes on small forested watersheds. A more detailed analysis is reported by Swanson et al. (1982).

Processes and Rates of Material Transfer

A wide range of processes, with varying magnitudes, frequencies, and spatial distributions, contribute to the transfer of material down hillslopes and through the stream channel network (table 2.1). Magnitudes of specific processes can be measured in terms of the downslope velocity of individual particles or masses of soil. These range from millimeters per year in the case of creep to approximately 10 meters per second for debris flows. The frequency of individual events ranges from virtually continuous (solution transport and surface erosion) to those with a return period of several centuries (debris avalanches and flows).

The proportion of watershed area affected varies greatly from process to process, although the proportion of landscape affected can be difficult to assess in forested terrain with dense vegetative cover. Mapping of landforms interpreted as being susceptible to sediment movement by various mechanisms can be used to evaluate the percent of basin area over which locally measured transport rates should be applied. For example, the 5 to 8% of basin area interpreted as being influenced by slump/earthflow was determined from mapping of bench, scarp, and other landform elements associated with active slope movement. In general, high magnitude processes are restricted to a small part of the watershed, while lower magnitude processes occur over broader spatial scales.

An important distinction exists between a movement rate for a given process, which is the rate at which individual particles or parcels of soil are transported downslope, and a material transfer rate, which is the volume or mass of material transported per unit area per unit time. The former is expressed in terms of a velocity while the latter has units of

Table 2.1 Material Transfer Process Characteristics for an Old-Growth Watershed (Watershed 10), H.J. Andrews Experimental Forest, Oregon (Modified from Swanson et al., 1982)

Process	Downslope movement rate	Frequency	Area influenced	Appropriate measurement techniques
Hillslope processes				
Solution	$\frac{\text{cm to m}}{\text{yr}}$	Continuous	Watershed	Chemical analysis of soil and streamwater
Litterfall	$\frac{\text{cm to m}}{\text{yr}}$	Continuous, seasonal	Watershed	Litterfall traps
Surface erosion	$\frac{\text{cm to m}}{\text{yr}}$	Continuous	Watershed	Hillslope erosion boxes
Creep	$\frac{\text{mm}}{\text{yr}}$	Seasonal	Watershed	Inclinometer tubes
Root throw	$\frac{\text{m}}{\text{sec}}$	$\frac{-\ 1}{\text{yr}}$	0.10% of watershed*	Field mapping of individual sites, dendrochronology
Debris avalanche	$\frac{10\ \text{m}}{\text{sec}}$	$\frac{-\ 1}{370\ \text{yr}}$	1-2% of watershed*	Landslide inventory from sequential aerial photos
Slump/earthflow**	$\frac{\text{mm to cm}}{\text{yr}}$	Seasonal	5-8% of watershed	Inclinometer tubes, repetitive cross sections
Channel Processes				
Solution	$\frac{\text{m}}{\text{sec}}$	Continuous	1% of watershed	Chemical analysis of streamwater
Suspension	$\frac{\text{m}}{\text{sec}}$	Continuous, storm	- 1% of watershed	Continuous and storm suspended sediment sampling
Bed load	$\frac{\text{m}}{\text{sec}}$	Storm	- 1% of watershed	Bed load sampling during storms, sediment collection basis
Debris flow	$\frac{10\ \text{m}}{\text{sec}}$	$\frac{-\ 1}{580\ \text{yr}}$	- 1% of watershed	Inventory from sequential aerial photographs

* Area influenced by one event.

** Inactive in past century in Watershed 10.

discharge or yield. At the Oregon site, we have compared different sediment movement processes based on their transfer rates.

The most complete record of material transfer at our site has been compiled for a 10.2-ha old-growth watershed located in the H.J. Andrews Forest and clearcut in 1975 (Swanson et al., 1982) (table 2.2). Transfer of organic and inorganic material from hillslopes to the channel, and channel export by a variety of processes, were analyzed over a 5-year period; transfer rates for bed load, debris avalanche and debris flow processes were based, in part, on longer observations made on similar watersheds, since the short-term record from this watershed was inadequate for determining rates of infrequent events.

Results of the analysis indicate that episodic processes such as debris avalanches (on hillslopes) and flows (in channels) play a major role in delivering sediment to stream channels and exporting it from the basin. Volumes of material transported by these events, which may occur only once every several centuries, are sufficiently large that they dominate long-term sediment production. Solution transfer, a continuous process, ranks second in importance. The total volumes of inorganic material delivered annually to the channel and inorganic material exported by the channel are approximately balanced, within the margin of error of the measurements.

Measurement Techniques

The complex suite of material transfer processes in this landscape necessitates that a variety of techniques be used to monitor sediment movement (table 2.1). Transport rates for specific processes can often be measured in real time at a site, particularly where movement rates are high and frequency of movement is continuous. Where movement is episodic or slow, as in the case of earthflow or creep, long-term site monitoring may be required.

Determining rates for high magnitude/low frequency processes which occur over limited areas, such as debris avalanches and flows, may require use of landslide inventories over several thousand hectares since these events may not be adequately represented in a smaller area. Sequential aerial photographs can be used to compute a frequency of failure based on the number of events occurring over the time period spanned by the photos; the annual event frequency is then multiplied by an average volume of material moved per event, as determined from field measurements, to give an annual movement rate.

Long-term variations in water, suspended sediment, and bed load discharges associated with different intensities of timber harvest activities have been monitored continuously for over 30 years at several small watersheds within the Andrews Forest. Measurement techniques have included continuous stream discharge measurements, grab sampling of suspended sediment during low flow and storm periods, and annual resurveys of sediment collection basins. Sediment discharge measurements have been limited to small first- and second-order streams draining basins of 100 ha or less.

Table 2.2. Transfer of Organic and Inorganic Material to the Channel by Hillslope Processes (t/ha/yr) and Export from the Channel by Channel Processes (t/ha/yr) for Watershed 10 (Modified from Swanson et al., 1982)

Processes	Inorganic matter	Organic matter
	t/ha/yr	
Hillslope processes		
Solution transfer	.30	.03
Litterfall	0	.03
Surface erosion	.05	.03
Creep	.11	0
Root throw	.01	.01
Debris avalanche	.60	.04
Slump/earthflow	0	0
Total	1.07	.14
Total particulate		
Including debris avalanche	.77	.11
Excluding debris avalanche	.17	.07
Channel processes		
Solution transfer	.30	.03
Gross	.08	.01
Suspended sediment		
Net	.06	.01
Bed load	.06	.03
Debris torrent	.46	.03
Total	.88	.10
Total particulate		
Including debris torrent	.58	.07
Excluding debris torrent	.12	.04

Transport of coarse organic debris in streams is a subject of continuing investigation. Movement of woody debris has been measured by repeat mapping of channel wood deposits, tagging of wood pieces already in the channel which range in size and degree of decomposition, and introduction of marked wood pieces and monitoring of their movement following storms.

Site-Specific Factors

A number of factors distinguish sediment transport at the Oregon LTER site from that at other sites. One is the major role played by living and dead trees in affecting the flow of sediment both down hillslopes and through the stream network. The abundant organic matter ($^{-}$20 kg/m^2 in third-order channels in the Andrews [Lienkaemper and Swanson, Dynamics of large woody debris in streams in old-growth Douglas-fir forests, in review for publication in Ecology]) is sediment itself and forms storage sites for other sediment. Root systems associated with living trees play an important role in maintaining soil cohesion, reducing the probability of mass movement. When tree roots are killed by wildfire or clearcutting, debris avalanche erosion increases threefold (Swanson and Dyrness, 1975). Root throw, while not a major process for transporting sediment, results in a pit-and-mound topography which may increase the opportunities for hillslope storage of sediment, thereby reducing net hillslope transfer. Large organic debris accumulations in channels trap inorganic and fine organic sediment, reducing throughput. Entrainment of logs in debris avalanches and flows may increase the amount of sediment transported during these events as it entrains/scours alluvium and toe-slope colluvium. Logs themselves may be an appreciable proportion of the total mass transported. Site-to-site comparisons of wood accumulation and transport rates would be useful for evaluating the relative importance of this link between the terrestrial and aquatic ecosystems across a range of climatic and geographic conditions.

A second site-specific factor is that many of the deposits and landforms of the site appear to have developed under different climatic conditions. Large volumes of sediment are currently stored in relatively immobile positions within the landscape. For example, many stream channels are bordered by floodplains composed of glacially-derived large boulders and cobbles which are only rarely transported under the present flow regime. These relict features may help explain the importance of infrequent, episodic events in this landscape, since such events may more closely mimic the conditions under which certain deposits were originally emplaced.

References

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Swanson F.J., and C.T. Dyrness. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3:393-396.

3. HYDROLOGIC STUDIES OF SHORTGRASS PRAIRIE (CENTRAL PLAINS SITE)

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Introduction

The Shortgrass Prairie Long-Term Ecological Research Program is one of several long-term ecological programs covering the range of environments found in the United States. The research program is to be conducted at the Central Plains Experimental Range near Nunn, Colorado. The mission of the program is to describe a set of principles that govern the development and maintenance of ecosystems and that can be used to predict their response to environmental change. These principles or theories are to be described in a way that will enable them to be used to explain site-specific ecological phenomena for both scientific evaluation and management.

To accomplish the mission of the LTER, an organizational structure has been developed to encourage collaboration with several federal agencies and universities. It will also make maximum use of existing data and develop an efficient data information storage and retrieval system. An effective public relations program will also be needed. All of these support services are designed to make maximum use of the scientific results of the study.

Specific goals, defined within the scientific effort, have been identified. They consist of: 1) developing a series of ecological principles governing the structure and dynamics of semiarid ecosystems, 2) defining and testing hypotheses necessary to verify the ecological principles, 3) applying the principles to management problems, 4) using the results to evaluate succession theory necessary to evaluate trends, and 5) using the verified principles as a focal point for an ecological "think tank."

Obviously most of the research effort will be devoted to defining and testing hypotheses of the ecological principles. In very general terms the hypotheses test concepts such as: 1) the relationship among landscape pattern, catenas, and soil/plant associations, 2) the spatial distribution of organic matter, nutrients, and soil water along catenas, 3) the relationships between primary production and abiotic factors, 4) the relationships between production, abiotic factors, and the population of consumers, 5) the dispensation of inorganic substances, 6) the importance of drought in shaping semiarid ecosystems, 7) the effect of extreme rainfall events, and 8) the role of herbivores in shaping plant community structure.

A review of the specific hypotheses that support these general statements shows the importance that water plays in the entire ecosystem response. Water is responsible for the movement of sediment from upslope and for its deposition downslope. Its availability for plant growth is a function of the infiltration and water holding capacities of the soil and of the soil thickness. Water is responsible for the surface and subsurface movement of soluble chemicals and nutrients such as nitrate. It is necessary for microbial and bacterial activity. Collectively these factors indicate that a reliable knowledge of the status and movement of water is necessary.

We propose that an existing model of water, sediment, and nutrient movement be modified for application to the Central Plains Experimental Range and that its performance be verified by comparison with collected field data. The status and movement of water, sediment, and nutrients should be monitored along several transects representing different plant ecosystems and soils. The monitoring of water status and movement must be accompanied by complete records of plant species and their transpiration rates; by records of soil characteristics such as nutrient levels, horizonation, temperature, soil-moisture-tension relations, and soil-moisture-release curves; and by meteorological data such as data on solar energy, wind (speed and direction), relative humidity, temperature, and rainfall intensity or snow accumulation.

Computer Models of the System

The statements describing the ecological principles governing the structure and dynamics of semiarid ecosystems will very likely need to be accompanied by physical process models of the system. This will be necessary to study how the system responds to management or changes in various components over long periods of time. Since water is one of the important components of the ecosystem, it will be necessary to simulate its movement downslope both on the surface and in the soil mantle. On the surface its effect on the movement of soil particles should be considered. Both the surface and subsurface movement interact with dissolved materials, such as nutrients and salts, and the concentrations of these materials should be calculated. Since the soils change continuously from the ridge to the valley and from one side of a hill to another in nonuniform ways, it will be necessary to use a spatially variable model to simulate movement. It will be necessary for any such model to react to changes in its physical state brought about by changes in temperature, solar energy, plant transpiration, rainfall, etc.

At the present time, several of us in the Hydro-Ecosystems Research Unit at USDA Agricultural Research Service (ARS), Ft. Collins, Colorado, are involved in the development of models similar to that needed for the study of water movement along a soil catena. In the small watershed modeling effort we are using the more complete version of CREAMS2 to simulate the movement of water, sediment, and chemicals from field-size areas (Smith and Knisel, 1985). The model includes all of the physical characteristics described above; however, some of the individual components may need to be modified for particular situations at the LTER site. The model is capable of simulating the flow over irregular slopes, but it assumes that the soils are uniform. However, this component can be extended to spatially varying soils. The nutrient dynamics which were developed for agricultural crops may not be satisfactory for range land situations; a contract to investigate this is in effect with the Natural Resource Ecology Laboratory (NREL) of Colorado State University. We propose to work with other collaborators in modifying the model for application to the Central Plains Experimental Range.

Site Selection and Experimental Setup

Parameters of the model of water, sediment, and nutrient movement described previously must be estimated from field evaluation. Since the plant communities vary from point to point in the range in response to differences in soils and water availability, it will be necessary to sample this variability in some uniform or systematic way. We propose that this be done in conjunction with the transects used to describe or characterize the different catenas. Previous studies have shown that this area is extremely variable as a result of the interaction of selective erosion processes, climate, and geologic parent material. Thus, after all the transect sites on the Central Plains Experimental Range were studied, the site shown in figure 3.1 was selected for initial instrumentation. The site is on the east-west ridge of the northern half of section 21, in T10N, R66W.

This site in section 21 was selected for two main reasons. First, because these grasslands are so variable, we wanted to find two catenas as different as possible, but located close together, that could be used to represent relative extremes. If the model described on the previous pages can be shown to simulate response on these areas, then we should be able to use it to simulate other representative catenas. Second, the soils and their plant communities, which vary continuously from the ridge to the valley floor, must be representative of observed variability. On the ridge the soils are generally shallow and dry, whereas the soils near the valley floor are deeper and generally have a higher soil moisture level. The soils on the windward side of the hills (north and west) are also generally thinner and have a higher clay content than those on the opposite side of the hill. In some areas, dominant plant community-soil complexes have a definite pattern and may run in strips generally parallel to contour lines. In other areas there is no apparent pattern. The site selected in section 21 meets both criteria indicated above. The soils are quite variable from ridge to valley and are different on the two sides of the hill.

This region of the Central Plains experiences only about 11 to 12 inches of precipitation annually. About 40% is snow and the rest is distributed throughout the year in the form of light rain from upslope conditions, intense bursts from thunderstorm activity, and frontal showers. Since the soils are not uniform and the slopes are quite variable, runoff is also variable. It is likely that runoff might be produced near the

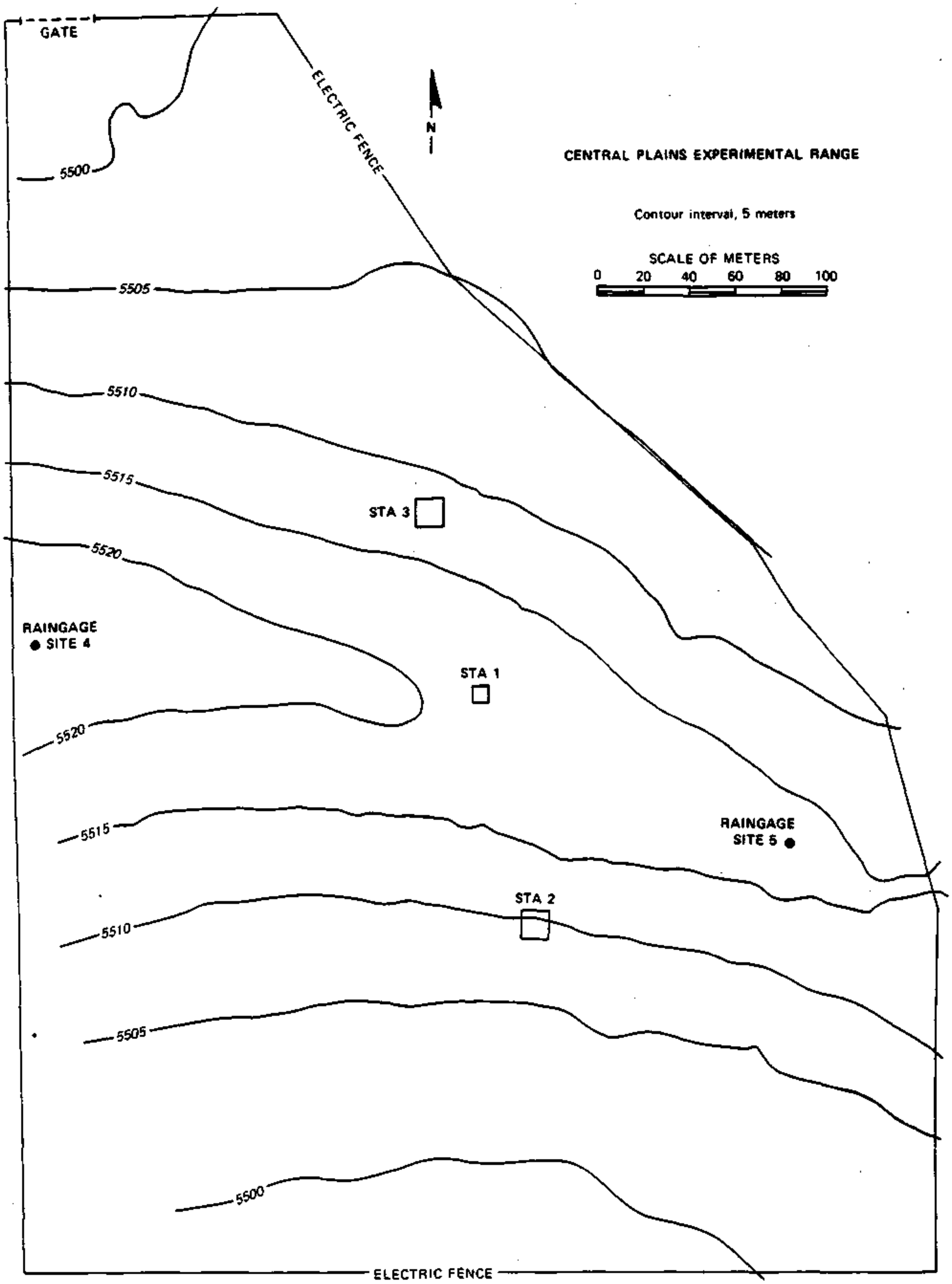

Figure 3.1. Site location for Central Plains LTER

crest of the hill but would not reach the bottom of the hill because of higher infiltration rates midslope. This nonuniformity also applies to soil moisture levels and their distribution downslope. As a result it is not possible to isolate midslope segments without significantly impacting the hydrology of the segment. The only way to document changes in the flow regime or soil moisture pattern is to study successively longer segments. Also, the natural runoff plots are separated from one another to provide access for reading instruments or taking measurements without imposing heavy traffic directly on the plot. The space between plots will provide a buffer to keep changes imposed in the flow regime by the measurement and sampling facilities from affecting the adjoining area. This space will also be used for rainulator studies. Plot borders will be 1/8" steel 12 inches wide.

The results from a series of eight natural runoff plots, varying in size from .02 to 0.25 ha, will be used to verify the model. However, because runoff events are very infrequent, the natural plots will be supplemented with a series of small plots that will be used for rainulator studies. These plots will provide data on infiltration, soil water redistribution, surface flow characteristics, erosion rates, evapotranspiration, and nutrient movement that can be used in initial model verification.

Instrumentation

Rainfall Simulator Studies

Pairs of rainulator plots will be placed between or below the natural plots on representative soil-plant communities. The number of locations will depend upon the results obtained in initial testing. Large variance in erosion, runoff, or evapotranspiration (ET) rates will require more measurements.

Water from local supplies, with characteristics as close to those of rainfall as possible, will be applied at rates representative of natural events. Runoff rates will be measured using 0.6' HS flumes equipped with FW-1 stage recorders. Time of travel and surface roughness estimates will be based on fluorimeter measurements of tracer dye injection. Samples of the runoff will be collected to measure sediment and nutrient concentrations, and particle and aggregate size and density. Climatological data will be collected at a central location. Additional net radiation will be provided at two sites. Soil moisture will be measured using a Troxler model neutron probe. Soil moisture levels at several locations and at several depths, at the beginning of the application period and every day for a period of at least 2 weeks after application of water, will be used to determine ET and soil moisture redistribution. The neutron measurements may be supplemented with data from a reflectometry instrument if initial tests show it to be satisfactory.

Natural Runoff Plots

Instrumentation for the natural runoff plots will be divided among four sites: 1) a meteorological station; 2) a site on the south side of the hill where runoff and related data will be collected; 3) a site on the north side of the hill also for collection of runoff and related data; and 4) two supplemental raingage sites. Following are descriptions of each of these sites.

The meteorological station, number 1, will be located as shown on figure 3.1, about in the center of the plots on top of the ridge. Data will be collected on a Campbell 21X Data Logger. Table 3.1 shows the data to be collected at this station. Net radiation will be measured at different sites to determine the variation in energy balance among plant species; between snow, wet, and dry surface conditions; and among seasons.

Data to be collected on the south and north sides of the hill, stations 2 and 3, respectively, will be used to monitor plot response. Two different recorders will be used at each of the two sites: a Campbell CR-21 and a Campbell CR-5. Table 3.2 shows the data to be collected at each of these stations. The snow gage will be located in the most likely spot for drifts; soil moisture and surface air temperature will be collected at the same location. Belfort FW-1 water level recorders with potentiometers will be used to record the flow depth in standard HS flumes. The flumes are 0.4, 0.6, 0.8, and 1.0 foot for the smallest to largest plots respectively. Four ISCO pumping samplers will be moved from site to site as necessary, to adequately sample nutrients and sediment concentrations in runoff from the plots.

Supporting instrumentation will consist of: 1) two standard raingages located as shown on figure 3.1 (standard strip charts will be used to record the data); 2) two hand-held net radiometers, one to be used for site-to-site comparison in the field and the other to be used to check calibration of all net radiometers; 3) a sling psychrometer to check the calibration of the relative humidity instrument; 4) a hook gage to check the pan evaporation record; and 5) a digital display to verify total wind run records at the evaporation pan.

All instruments that are read by the CR-5, CR-21, and 21X will have chart backup in case something goes wrong with the recorder. The CR-5 and CR-21 recorders will be housed in a small insulated and thermostatically controlled shelter with heat provided by solar panels and a battery system. Forty-watt solar panels will be used to power stations 2 and 3, and two 9-watt solar panels will be used to power the 21X.

Soil moisture and soil density will be measured using a dual gamma source at a few selected points in each plot. Spatial variability of soil moisture will be determined using the Troxler neutron probe. We will also investigate use of a reflectometry instrument to monitor soil moisture if tests show it to be accurate enough. Characteristic soil moisture, tension, and conductivity curves of the various soils will be developed. Small, non-weighing lysimeters will be installed to measure ET.

Table 3.1. Data to Be Collected at Station 1 with Campbell 21X Data Logger

Channel	Parameter*	Instrument	Manufacturer	Supplier
1	Rain and snow	Heated tilting bucket	Sierra Weather Inst. Corp.	Microchemical Specialties
2	Total wind run (E-pan.)	Digital readout anemometer	Weather Measure Corp.	Microchemical Specialties
3	Wind speed-4m	Photochopper anemometer	Met-One	Campbell
4	Wind speed-2m	Photochopper anemometer	Met-One	Campbell
5	Evaporation	Class A Pan and potentiometer	Belfort Inst. & Spectrol	Belfort & Nework Electronics
6	Wind direction-4m	Potentiometer	Met-One	Campbell
7	Incoming solar radiation	Pyranometer	Licor-Lambda	Campbell
8	Net all wave radiation	Net radiometer	Micro Met Inst.	Science Associates
9	Relative humidity	Linear voltage differential transformer	Texas Electronics	Science Associates
10	Soil moisture 2cm	Moisture block	Dalmhorst	Campbell
11	Soil moisture 12cm	Moisture block	Dalmhorst	Campbell
12	Air temperature 2m	Thermistor	Fenwal	Campbell
13	Air temperature .5m	Thermistor	Fenwal	Campbell
14	Air temperature surface	Thermistor	Fenwal	Campbell
15	Soil temperature 1cm	Thermistor	Fenwal	Campbell
16	Soil temperature 5cm	Thermistor	Fenwal	Campbell
17	Soil temperature 15cm	Thermistor	Fenwal	Campbell
18	Soil temperature 30cm	Termistor	Fenwal	Campbell
19	Evaporation pan meter temperature	Thermistor	Fenwal	Campbell
20	Open			

* Measurements will be taken at 2-hour intervals except wind speed and radiation, which will be integrated values over a 2-hour period; rainfall and runoff will be scanned at 5-minute intervals during events.

Table 3.2. Data to Be Collected at Stations 2 and 3 with Campbell CR-21 and CR-5

CR-21

Channel	Parameter*	Instrument	Manufacturer	Supplier
1	Air temperature 0.2m	Thermistor	Fenwal	Campbell
2	Air temperature .05m	Thermistor	Fenwal	Campbell
3	Air temperature surface	Thermistor	Fenwal	Campbell
4	Soil temperature 1cm	Thermistor	Fenwal	Campbell
5	Soil temperature 5cm	Thermistor	Fenwal	Campbell
6	Soil temperature 15cm	Thermistor	Fenwal	Campbell
7	Soil temperature 30cm	Thermistor	Fenwal	Campbell
8	Windspeed 2m	Contact anemometer (Sta. 2) Contact anemometer (Sta. 3)	Climet Instruments Cassella & Company Ltd.	Campbell Science Associates
9	Open			

CR-5

Channel	Parameter*	Instrument	Manufacturer	Supplier
1	Net radiation	Net radiometer	Micro Met Instruments	Science Associates
2	Soil moisture 2cm	Moisture block	Delmhorst	Campbell
3	Soil moisture 12cm	Moisture block	Delmhorst	Campbell
4	Snow water equiv.	Gama probe	Measurements Inc.	Campbell
5	Soil moisture .5m	Gama probe	Measurements Inc.	Campbell
6	Rainfall	Weighing rain gage Linear voltage differential transformer	Belform Schaevitz Eng.	Campbell Measurement Consultants
7	Wind direction	Potentiometer	Climet Inst.	Measurement Consultants
8	Runoff	FW-1 recorder (potentiometer)	Belfort Spectrol	Newark Electronics
9	Runoff	FW-1 recorder (potentiometer)	Belfort Spectrol	
10	Runoff	FW-1 recorder (potentiometer)	Belfort Spectrol	
11	Runoff	FW-1 recorder (potentiometer)	Belfort Spectrol	

* Measurements will be taken at 2-hour intervals except wind speed and radiation which will be integrated values over a 2-hour period; rainfall and runoff will be scanned at 5-minute intervals during events.

Cooperative Efforts

Several aspects of this study will require coordinated cooperative efforts because of the relation of the study to other ongoing projects.

Soil moisture sampling will be coordinated with the staff of the NREL, specifically Bill Parton. He is interested in testing a simple soil moisture probe used primarily for sampling in gardens and flower beds. Both he and the staff of the Hydro-Ecosystems Group are interested in the possible use of the reflectometer instrument. We will be setting up some experiments to test its usefulness in sampling soil moisture at various depths in the profile.

Evaluation of vegetative cover is very important in estimating evaporation and transpiration amounts. We need specific information on plant size and growth characteristics for use in the plant growth component of the model. There are specific ways of sampling plant cover that are used in other studies; and we need to be sure that these needs are merged. The ARS-Crops Laboratory has experience in sampling and is also interested in our study. Their recommendations will be used in sampling the plant cover on both the natural and rainulator sites.

Micrometeorological data are of interest to both the ARS study and other NREL studies. Both instrumentation and collection of the data will be coordinated to minimize the total effort expended.

Wind erosion may very well be as important or more important than water erosion of soil particles. The Department of Earth Resources staff at Colorado State University is very much interested in wind erosion. We will be coordinating instrumentation and data collection to provide information on wind erosion rates and the directions of wind responsible for the erosion.

Funding

All the data collection that has been described is supported by the Hydro-Ecosystems Research Unit. The cooperative efforts described in the previous section will be cooperative in that both parties are interested in the results. Specific discussions have not been conducted on who will provide what, but general discussions between all parties indicate that " there will be no problem in sharing in any additional expenses that may be incurred.

Conclusions

Hydrologic data will be collected from both natural plots and rainfall simulator sites on the Pawnee Grasslands near Nunn, Colorado. The study area is located in a region of the country which experiences only about 11 to 12 inches of rainfall a year. Thus, any downslope movement of water influences erosion and vegetative patterns and can have a significant impact on management. Collection of data is guided by applications of a specific process-oriented model, which will be used in future work, to simulate the movement of surface and subsurface water from the crest of a hill to the valley floor. Rainfall simulator plots will be used to get early information on basic parameter values for the model. Data from natural plots will provide final validation.

Reference

Smith, R.E., and W.G. Knisel. 1985. Summary of methodology in the CREAMS2 model. In Proceedings of the Natural Resources Modeling Symposium, Pingree Park, Colorado, pp. 33-36.

4. SEDIMENT TRANSPORT MEASUREMENTS IN THE MISSISSIPPI RIVER SYSTEM (ILLINOIS RIVERS SITE)

J. Rodger Adams

Suspended Sediment and Sediment Load

Suspended sediment is a key element of the aquatic and benthic environments of our three sites (figure 4.1). Each site has unique features. Pool 26 on the Mississippi River is typical of low-head (2- to 5-m) navigation pools and has a nearly balanced sediment budget. Its average annual sediment load is about 20(10)" tonnes, of which about 7.5(10)6 tonnes are contributed by the Illinois River. Pool 19 has the oldest (built in 1913) and second highest (11.6 m) structure in the Upper Mississippi River system. The average annual sediment load is about $10.7(10)^6$ tonnes with a net deposition of 3.2(10)6 tonnes. The pool is about halfway to a new condition of volumetric equilibrium. Peoria Lake on the Illinois River is a naturally broad area which had its water level raised about 1 m when the Peoria Lock and Dam was completed in 1938. Sediment deposition has reduced the water depth to less than 1 m in most of the upper lake outside the 100-m-wide by 4-m-deep navigation channel. The average annual sediment load upstream of Peoria Lake at Marseilles is 2.8(10)° tonnes, and the recent annual deposition in the lake is about $1.75(10)^6$ tonnes.

Sediment movement increases rapidly as the discharge increases, so most of the years's sediment load at a site is transported during floods. An extreme flood event may carry more than the average yearly sediment load. Despite the greater variability of sediment movement and the poor extrapolation of laboratory data to natural streams, measurements of suspended sediment are not as common and are for shorter periods than water discharge records. The available data near the LTER sites are summarized in table 4.1. Additional data for the Mississippi River in Pool 19 provide a good estimation of the sediment budget. The sediment yield per km^2 for the two tributaries is about 10 times that for the Mississippi River. Thus, tributary sediment loads are more significant than water volumes. The main river sediment transport into Pool 19 is 10,760,000 tonnes per year. The Skunk River and Henderson Creek, which drain 91% of the local area, transport 3,805,600 tonnes per year into the pool. Thus 26% of the sediment entering the pool comes from just 4% of the total basin area.

The sediment load is commonly assumed to be an exponential function of the water discharge. Regression analysis has been done for five stations, and the equations and correlation coefficients are given in table 4.2. The equations are of the form:

$$Q_S = A\ Q_W^{\ B}$$

in which Q_w is the water discharge in m^3/sec, Q_s is the suspended sediment load in tonnes/day, A is a coefficient, and B is an exponent.

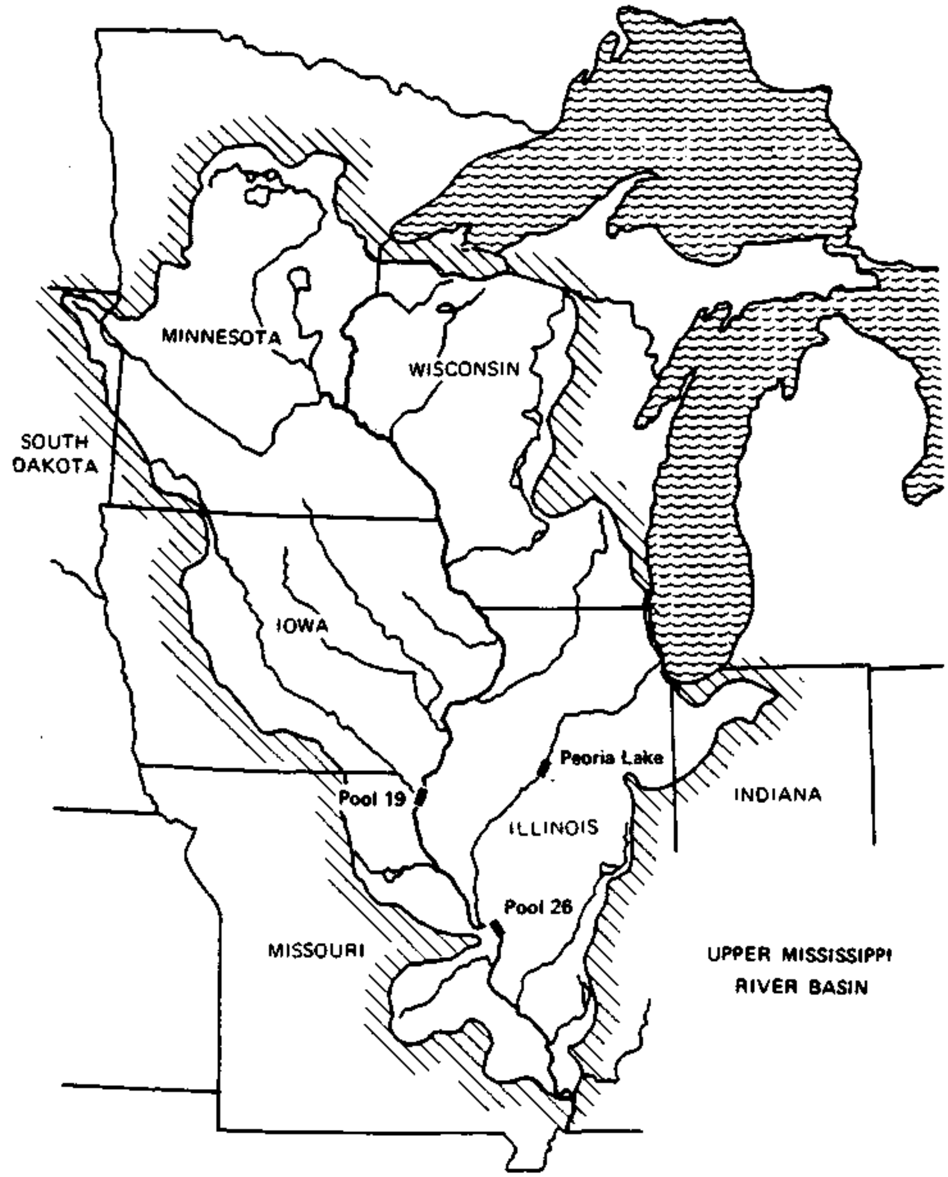

Figure 4.1. Illinois Rivers LTER sites

Table 4.1. Suspended Sediment Transport Data

River	Station	Pool	Length of record (years)	Drainage area (km^2)	Mean annual discharge, (m^3/sec)	Average annual sediment load (tonnes)
Henderson Cr.	Oquawka	19	3	1,120	8.10	312,600
Skunk R.	Augusta	19	7	11,140	67.3	3,493,000
Mississippi R.	Keokuk	19	14	308,200	1780	10,690,000
Illinois R.	Valley City (Meredosia)	26	3	68,000	615	6,819,000

Table 4.2. Suspended Sediment Equations

River	A	B
Henderson Cr. at Oquawka	2.3526	1.943
Skunk R. at Augusta	0.725	1.824
Illinois River at Marseilles	0.482	1.483
Illinois River at Valley City	13.588	1.029
Mississippi R. at Keokuk	0.0000992	2.400

An annual sediment budget can be calculated for Pool 19 with the available data and some regional equations relating sediment yield to drainage area. Both an average budget over the time of daily sediment sampling at Lock and Dam 19 and the budget for 1979 are given in table 4.3. Local sediment inflows are seen to be very important in the sediment budget.

The large amounts of deposition in Pool 19 and Peoria Lake are resulting in changes in the types of habitats available and may soon convert aquatic habitats to terrestrial ones in some areas.

Suspended Sediment Sample Collection

Two suspended sediment samplers are used: the US DH-59 and US P-72. These are standard samplers designed for the United States Geological Survey.

The DH-59 consists of a streamlined bronze casting 381 mm long and weighing 11 kg. A pint glass milk bottle is sealed against a gasket in the head cavity of the sampler by a hand-operated spring-tensioned pull-rod assembly at the tail of the sampler. The sample enters through the intake nozzle (three nozzles are available, calibrated to 1/8-, 3/16-, or 1/4-inch inside diameter) and is discharged into the bottle. The displaced air from

Table 4.3. Annual Sediment Budgets for Pool 19

	Sediment load - million kg/year	
	Average (1968-1979)	1979
Lock & Dam 18	10,763	10,268
Henderson Creek	310	344
Skunk River	2,551	2,986
Other tributaries	297	332
Total inflow	13,921	13,930
Lock & Dam 19	10,690	14,345
Net deposition (scour)	3,231	(414)

the bottle is ejected downstream through the air exhaust vent alongside the head of the sampler. Tail fins keep the sampler pointing into the current. The DH-59 is a depth-integrating sampler designed to accumulate a water-sediment sample from a stream vertical at such a rate that the velocity in the intake nozzle is almost identical with the immediate stream velocity, while traversing the vertical at a uniform speed. This sampler can be used in depths up to 5.5 m.

The P-72 consists of a 28-kg streamlined cast aluminum body which encloses an inner recess for a pint glass milk bottle or a quart-sized jar, a pressure-equalizing chamber, and a two-position rotary valve operated by a solenoid which controls the sample intake and air exhaust passages. The sampler is suspended on a cable using a winch (B-reel) and crane apparatus. The P-72 is capable of taking either a point-integrated or a depth-integrated sample at depths up to 55 m.

There are several variations in the way samples are collected. In all cases, the lid is removed from the sample bottle and labeled with the site code, sample number, date, and occasionally the gage height and temperature. The sample bottle is then placed in the sampler. Guy and Norman (1970) give the standard methods of using these samplers.

Depths Less than 6 m

The sampler is lowered to the water surface and held until the fin aligns the sampler with the flow direction. The sampler is lowered at a constant speed until it reaches the river bed. At the instant the sampler touches the river bed the direction of travel is reversed and the sampler is brought back to the surface at a constant speed. The up and down speeds need not be identical, but each must be constant. The sampler must not be allowed to rest on the river bed. In order to maintain approximately isokinetic sampling, the vertical traverse speed must be less than 40% of the mean water velocity. Also, in the pint sampler bottle, a valid sample volume is between 150 and 400 ml, and samples outside these limits are repeated with a different transit rate.

Depths between 6 and 12 m

The P-72 sampler is used to collect two samples per vertical, one taken from the river bed to the surface, and the second from the surface to the bed. For the first sample the valve is opened with the sampler resting on the river bed at the beginning of the traverse. The second sample is taken with the valve open at the surface, and the valve is closed when the sampler reaches the river bed.

The lid is replaced on each bottle after it is filled, and the sealed bottles are sent to the SGS Inter-Survey Geotechnical Laboratory in Champaign for analysis.

An analysis of errors is presented in Guy and Norman (1970). Consistent techniques including constant transit rates, immediate reversal of direction, using the slowest transit rate that obtains a valid sample volume, and use of the larger nozzles on the DH-59 improve the quality of the samples.

Reference

Guy, H.P., and V.W. Norman. 1970. Field methods for measurement of fluvial sediment. U.S. Government Printing Office, Washington, D.C.

5. PRELIMINARY ANALYSES AND COMPARISONS OF SEDIMENT YIELD DATA FROM THE NEW MEXICO LTER SITE (JORNADA SITE)

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Introduction

This is a report on the preliminary analyses of water and sediment yield data collected at the Jornada LTER site north of Las Cruces, New Mexico. The report is intended to serve two purposes: to supply LTER personnel a general overview of the data collected to date in order to facilitate future experimental plans, and to provide a summary of the data for those involved in water and sediment studies at other LTER sites. The analyses are limited in scope to those data provided by LTER experiments, both ongoing and as completed by two graduate students.

Numerous statistical tests and comparisons were conducted on the data sets in order to determine similarities, differences, and functional relationships where they existed. We used the Statistical Analysis System (SAS) on the New Mexico State University (NMSU) IBM 3081D mainframe computer to summarize and analyze the data. The three data sets we used were collected by Elkins (1983) for his Ph.D degree, by Bach (1984) for her M.S. degree, and by LTER personnel in an ongoing study (W.G. Whitford, Department of Biology, New Mexico State University, unpublished data). We analyzed 385 plot-events (number of times measurements were taken from a plot), with 272 of these supplied by LTER personnel. A detailed analysis is provided in the analysis section of this report.

Site Description

The Jornada site (see figure 5.1 for location) is principally a desert biome with distinct vegetation zones as one moves from the lower elevation playa grasslands upslope to the mountain shrubland. "Dry" is the best description for the weather: hot and dry in summer (June maximums in the mid-90°F range) and cool and dry in winter (January minimums in the high-30°F range). Annual precipitation is about 9 inches (with more than 50% of it falling in the July through September period), with pan evaporation about 10 times higher than precipitation. Localized, severe thunderstorms are a common phenomenon during the summer months. The entire LTER site covers a little over 1400 acres, which are excluded from grazing.

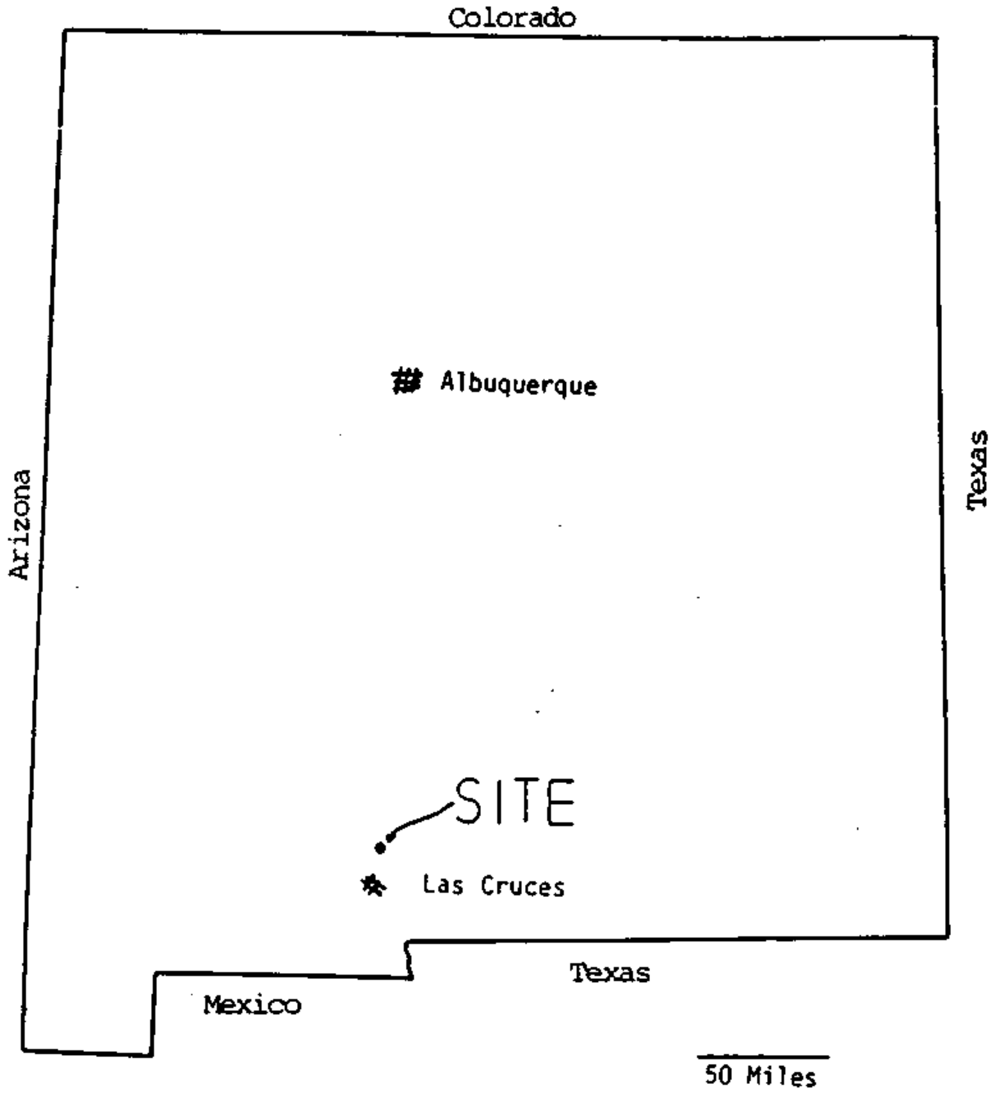

Figure 5.1. Location of Jornada ITER site in New Mexico

Erosional Setting

Erosion potential is high on the LTER site for several reasons: 1) the soils are fairly granular and lack the cohesion necessary to withstand erosion; 2) ground cover is sparse so that the soils are exposed to rainfall, overland flow, and wind; 3) slopes are sufficiently steep to permit overland flow; and 4) rainfall is typically from high intensity storms which exceed the soils' infiltration capacity and thus produce overland flow. All of these processes are active as evidenced by the numerous rills and arroyos in and around the site.

Analysis

Information on water and sediment yield from three different areas on the Jornada LTER site has been collected. The primary intent of the individual studies varied, but all provided data which can be compared. Two of the studies used portable rainfall simulators to measure yields. The other, ongoing study measured water and sediment yields from natural rainfall events. Conclusions from the individual studies and a comparison of the results from all the studies are presented below.

Elkins (1983) used a rainfall simulator to compare runoff and sediment yields from plots treated with chlordane in 1977 to remove termites, and plots where termites had not been eliminated (table 5.1). The treated and untreated plots were further divided into three cover types: less than 5% fluff-grass (*Erioneuron pulchellum*) cover, 10 to 15% fluff-grass cover, and creosote (*Larrea tridentata*) cover with a canopy greater than 1 meter in diameter. Slopes ranged from 2.0 to 3.5%. Runoff was higher on treated plots and on plots with less grass cover. Creosote cover decreased concentrations and yields for suspended and bed loads. In general, suspended sediment and bed load yields were related to runoff. Higher runoff resulted in greater sediment yields, and runoff was higher on plots with less vegetation. Note that in Elkins' simulations, and in those of Bach (1984) to be discussed subsequently, the plots were rained upon in a "dry" state, and 12 to 24 hours later in a "wet" state. Bach's simulations included a third state, "very wet," in which rainfall was repeated immediately (30-40 minutes) after the "wet" simulation.

Bach (1984) used a rainfall simulator on three vegetation zones to compare runoffs and yields (table 5.2). The upper zone, characterized by black grama grass (*Bouteloua eripoda*). had a mean plot slope of 4.2%. In the middle zone, with an average plot slope of 2.9%, the dominant vegetation was snakeweed (*Gutierrezia arothrae*). The lower zone cover was predominantly burro grass (*Scleropogon brevifolius*), and this zone had a mean plot slope of 2.4%. Total sediment yields from the upper and middle zones were significantly less than from the lower zone. This was probably caused by soil texture and vegetative cover differences. Total sediment yield was significantly greater from plots with less vegetation. In the lower zone, variation in total sediment yield was best explained by the amount of bare soil and by slope. For the middle zone, rainfall rate and slope explained the most variation. In the upper zone, average runoff rate

Table 5.1. Average Runoff and Sediment Yields from Rainfall Simulation Data (Elkins, 1983) (Standard deviations in parentheses)

Plot*	AMC**	N	Runoff (mm)	Bed load*** (kg/ha)	Suspended load*** kg/ha)	Total load (kg/ha)
Cl	D	5	15.54 (1.37)	564.4 (139.4)	1,029.2 (92.8)	1,593.6 (171.3)
	W	5	20.70 (1.36)	841.0 (151.1)	965.6 (68.6)	1,806.6 (148.2)
C2	D	5	12.24 (1.07)	329.2 (42.1)	802.9 (276.2)	1,132.1 (266.0)
	W	5	17.42 (1.03)	492.4 (63.1)	695.5 (177.7)	1,187.9 (196.2)
C3	D	4	6.60 (0.93)	101.0 (119.2)	229.6 (83.8)	330.6 (199.4)
	W	5	7.04 (1.39)	99.2 (86.2)	186.0 (71.9)	285.2 (54.4)
Tl	D	5	35.96 (3.12)	3,957.2 (686.3)	2,168.7 (527.6)	6,125.9 (745.4)
	W	5	37.64 (3.42)	3,352.6 (685.9)	1,746.7 (328.0)	5,099.3 (1,005.8)
T2	D	4	5.65 (0.42)	85.6 (33.5)	133.6 (29.6)	219.2 (49.9)
	W	5	6.86 (0.90)	215.4 (112.0)	167.3 (132.5)	382.7 (229.1)

* Plot names beginning with C are control plots. Plot names beginning with T have been treated with chlordane. Plots Cl and Tl have low cover, C2 has medium cover, and C3 and T2 have creosote cover.

** AMC stands for antecedent moisture conditions. Yields were measured under two soil moisture conditions: dry (D) and wet (W).

*** Bed load is that portion of the sediment which settled in the collection apparatus. Suspended load is that portion of the sediment which passed through the collection system in suspension. No size distinction was made between the two loads.

Table 5.2. Average Runoff and Sediment Yields from Rainfall Simulation (Bach, 1984) (Standard deviations in parentheses)

Plot*	AMC**		Runoff (mm)	Bed load*** (kg/ha)	Suspended load*** (kg/ha)	Total load (kg/ha)
UV	D	6	8.45	403.7	74.9	478.6
			(5.29)	(267.2)	(54.2)	(313.8)
	W	6	11.18	297.5	105.5	403.0
			(3.24)	(124.9)	(107.8)	(220.4)
	VW	4	11.27	285.3	93.9	379.2
			(5.20)	(273.6)	(65.1)	(333.4)
UN	D	4	14.52	481.0	132.3	613.3
			(15.41)	(253.5)	(131.3)	(283.4)
	W	4	25.6	739.0	158.7	897.7
			(5.02)	(501.6	(42.1)	(522.5)
	VW	2	20.95	42.80	99.9	527.9
			(6.29)	(404.5)	(32.4)	(436.9)
MV	D	6	2.72	374.7	23.4	398.1
			(2.59)	(233.0	(22.2)	(241.5)
	W	6	7.80	230.5	59.9	290.4
			(5.63)	(226.7)	(57.1)	(271.1)
	VW	4	9.57	216.0	32.3	248.3
			(9.52)	(90.0)	(24.9)	(101.4)
MN	D	1	18.2	436.0	195.5	631.5
	W	2	27.85	481.0	131.0	612.0
			(6.15)	(190.9)	(18.3)	(172.6)
	VW	2	29.95	872.0	325.7	1,197.7
			(14.21)	(571.3)	(249.8)	(821.1)
LW	D	6	26.38	681.5	1,682.7	2,364.2
			(5.62)	(438.1)	(515.5)	(609.8)
	W	6	23.32	631.0	788.7	1,419.7
			(5.64)	(640.3)	(244.9)	(645.6)
	VW	6	31.08	1,115.3	1,144.0	2,259.3
			(2.24)	(1,118.0)	(207.4)	(1,008.7)

* U,M,L stand for upper, middle, and lower zones. V and N represent plots with vegetation (V) and plots without vegetation (N).

** AMC stands for antecedent moisture condition. Yields were measured under three soil moisture conditions: dry (D), wet (W), and very wet (V).

*** Bed load is that portion of the sediment which settled in the collection apparatus. Suspended load is that portion of the sediment which passed through the collection system in suspension. No size distinction was made between the two loads.

explained most of the variation in total sediment yield. Overall, variation in total sediment yield was best explained by the amount of bare soil along with rainfall rate and average runoff rate.

Data from the natural rainfall plots (W.G. Whitford, unpublished data) were analyzed separately (table 5.3) and also compared to data from the two rainfall simulator studies. The natural rainfall plots were similar to Elkins' plots in that some had been treated for termites and some were untreated; there were two levels of cover (creosote bushes or no creosote bushes); and the slopes ranged from about 2 to 2.5%. The area of each plot is 4 square meters. Four plots were installed in summer 1982, and five more were added in fall 1983. In many instances, several rainfall events occurred before the collection tanks were emptied. Not all of the events created runoff, but all supplied energy input to the plots. Therefore the measured yields on the natural plots are a composite of events. All data were log-transformed before analysis.

No significant differences were found among natural plots for runoff and three measures of sediment yield (suspended load yield, bed load yield, and total yield). When yields were divided by runoff, the standardized values of bed load yield and total sediment yield were found to be significantly higher for plots with creosote than for plots without creosote. This contradicts the findings of the simulator studies which indicated that runoff and yield were lower on plots with more cover.

This may be explained by examining table 5.3. Yield values for plot Tl, which has creosote cover, are much higher than yields from the other plots. Plot Tl contains a small rill which contributes to the higher yields. If Tl is removed from the analyses, tests indicate that there are not significant differences between yields from plots with and without creosote. This finding is still puzzling, because the other studies found significant differences in yields on the basis of cover.

Several tests were conducted to compare the three data sets. Only dry runs from the rainfall simulator sites were used. Only the upper zone of Bach's study was used; although none of Bach's vegetation zones included creosote, the upper zone had the same soil type as Elkins'. Only those events from the natural rainfall site during which all nine plots had runoff (n = 14 events) were used in this comparison, and plot Tl was subsequently eliminated from the analyses. All of the values were log-transformed. Since the different sites had different rainfall amounts and rates, all yield values were divided by the measured runoff that occurred in order to standardize the values.

When the measured values for suspended, bed, and total yields are compared (table 5.4), it is seen that the three sites had significantly different amounts of suspended sediment yield. For bed load and total yield, the natural rainfall site had significantly lower values than the two sites where simulators were used.

Table 5.3. Average Runoff and Sediment Yields from Natural Rainfall Events (W.G. Whitford, unpublished data) (Standard deviations in parentheses)

Plot*	N	Runoff (mm)	Bed Load** (kg/ha)	Suspended load** (kg/ha)	Total load (kg/ha)
Cl	39	2.02 (4.44)	119.4 (332.8)	61.1 (256.6)	181.0 (510.1)
C2	37	1.64 (2.84)	86.5 (28.8)	30.4 (119.8)	116.9 (337.4)
C3	24	1.09 (1.58)	19.9 (48.1)	6.4 (11.7)	26.3 (59.1)
C4	24	2.15 (2.46)	92.6 (245.2)	65.3 (179.7)	157.9 (388.8)
Tl	37	4.12 (7.86)	150.9 (491.6)	343.3 (1,905.9)	494.2) (2,247.9)
T2	39	2.18 (4.26)	91.3 (269.2)	27.0 (77.7)	118.3 (304.5)
T3	24	1.72 (2.11)	43.4 (77.4)	15.9 (27.4)	59.3 (103,6)
T4	24	2.26 (3.82)	46.1 (91.7)	25.4 (48.4)	71.5 (128.4)
T5	24	0.54 (1.22)	5.4 (13.1)	4.7 (8.9)	10.1 (21.5)

* Plot names beginning with C are control plots. Plot names beginning with T are plots that have been treated with chlordane. Plots Cl, C2, Tl, T2, and T5 have creosote bushes. Plots C3, C4, T3, and T4 do not have creosote bushes.

** Bed load is that portion of the sediment which settled in the collection apparatus. Suspended load is that portion of the sediment which passed through the collection system in suspension. No size distinction was made between the two loads.

Table 5.4. Comparison of Mean Yields from the Three Study Sites*

	Measured yields			Standardized yields		
Data set	Suspended	Bed	Total	Suspended	Bed	Total
Elkins	A	A	A	A	A	A
Bach	B	A	A	AB	A	A
Whitford	C	B	B	B	B	B

* The same letter denotes no significant difference found between the means of the log-transformed variables using an LSD test in SAS.

For standardized suspended sediment yield, Elkins' site had significantly higher values than the natural rainfall site, while Bach's site was not significantly different from the other two. For the standardized bed load yield and total yield, the natural rainfall site values were significantly lower than those for the other two sites. We were not able to find any other types of differences among the plots using analysis-of-variance techniques except for the obvious ones such as differences between rainfall simulator yields for the dry and wet experiments.

The yield data were analyzed with respect to several rainfall-runoff energy variables. We found numerous statistically significant but "weak" relationships. One relationship which has interesting information is shown in figure 5.2. This is a plot of the log of the total sediment yield against the summation of the measured precipitation for each event times the log base 10 of the average rainfall intensity for that event or

$$E = \sum_{i=1}^{n} p_i \log I_i$$

where E = a measure of precipitation energy,
Pi = precipitation for event i, mm
Ii = average rainfall intensity for event i, mm/hr

Using this formulation accounts for the energy differences between storms of high and low intensities and of long and short durations. The scatter of data in figure 5.2 indicates that there is not a simple relationship between energy and sediment yield. The simulated rainfall data exceed the energy levels measured so far on the natural rainfall plots. Even though there are minor errors in the yields from the simulated rainfall experiments (the yields have not been scaled up to reflect the lower energy in the simulators versus natural rainfall), an order-of-magnitude analysis of these errors shows that on the log scale they would create only a minor shift in the yield values (approximately 0.3 log units). The general shape of the plotted data would not change.

The trend that the data show may be explained as follows. Rainfall energy striking a plot moves soil, and increasing the amount of energy tends to increase the soil yield. An analysis of the individual data sets on different scales confirms that observation. However, it appears that when viewed as a whole, sediment yields seem to have stabilized at a

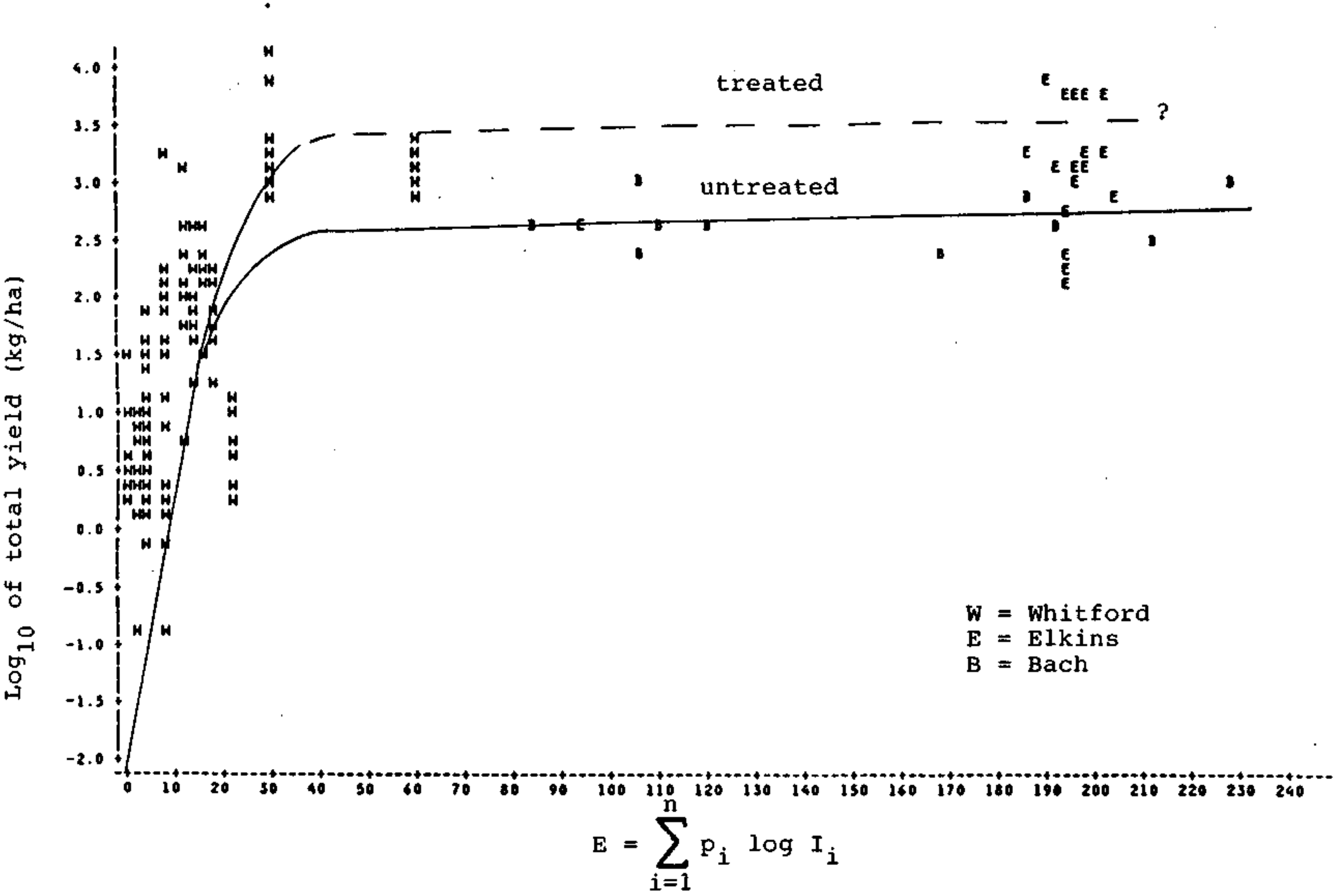

Figure 5.2. Relationship of total soil yield to precipitation energy input

certain level. To go beyond that level will require a higher input of energy than we have been supplying. We note a similar occurrence in the simulator experiments in that there appears to be a consistent and usually significant decrease in the sediment yield from a plot between the dry run and the wet run. We have a few data that show that increasing the energy input (higher intensity) for a wet run will generate substantially more sediment. The data shown in figure 5.2, when examined in more detail, indicate that there may be a higher level of yield for the treated plots than for the uncreated plots. The differences are not statistically significant in most cases.

Conclusions and Questions

We have conducted a preliminary analysis on the available sediment yield data from the Jornada LTER site. It appears, though, that we have generated more questions than we have answered. First, why does the sediment yield stabilize even though the energy is increasing? Second, are the natural events too noisy, or do we need a better measurement system? Third, what causes the discrepancies between Elkins' and Whitford's creosote plot data? Fourth, why don't we see a more pronounced effect from the cover when all the data are considered; and fifth, and most important, what are the overall implications for the entire ecosystem if the data are in fact presenting a reliable picture?

Acknowledgments

The authors thank the staff members of the LTER project for their time in explaining the data logs and providing additional information as needed.

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6. NOTES ABOUT SEDIMENT IN A TALLGRASS PRAIRIE (KONZA PRAIRIE SITE)

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Manhattan, Kansas 66506

Introduction

The Konza Prairie Research Natural Area (KPRNA) is an 8616-acre (3487-ha) tract of native tallgrass prairie set aside for ecological research purposes and administered by the Division of Biology at Kansas State University in Manhattan. It is one of the eleven Long-Term Ecological Research sites (LTER) funded by the National Science Foundation. It was acquired by The Nature Conservancy in 1971 and 1977. The research objectives of KPRNA are to evaluate the roles of fire and grazing by native ungulates (bison, elk, and pronghorn antelope) in maintaining the tallgrass prairie ecosystem, through a variety of short- and long-term research projects. The KPRNA management plan includes an array of watersheds upon which is imposed a schedule of prescribed burning at intervals of 1, 2, 4, and 10 years. There are other watersheds that are left unburned, some that are burned in an alternating cycle (3 years burned and 3 left unburned), and some areas that are burned only in years following years with precipitation greater than 1.2 times normal. Native ungulates will be introduced in the near future.

Site Description

KPRNA is representative of the geological region called the Flint Hills Upland. It is a dissected upland with hard chert- and flint-bearing limestone layers, resulting in steep-sided hills on which are exposed Permian limestone and shale layers. The ridges are characteristically flat with permeable topsoil and slowly permeable subsoils, and wider valleys have deep permeable soils. Vegetation is representative of unplowed native bluestem (tallgrass or true) prairie which once covered some 7% of the conterminous United States, nearly all of which has been converted into one of the worlds's most productive agricultural areas.

The U.S. Geological Survey included Konza in its Benchmark Network beginning in 1977. In Water Resources Data for Kansas (1984), the station is identified as Kings Creek near Manhattan, KS (06879650). The gaging site consists of a bubble gage in the natural channel along with an automatic recorder. Since the natural channel is unstable at the measured cross section, the rating curve is updated monthly by velocity-cross-sectipn techniques; more frequent measurements are made following major storm flows which may have altered the channel configuration at the gage. Samples are taken periodically for water quality analyses. Suspended sediment is measured about four times per year from grab samples. Concentrations reported range from 10 to 70 mg/1, with little correlation to discharge over the sampling range of 0.1-8.1 cfs (0.003-0.23 m^3/s). These data represent the only set available for the research site. Stream work at Konza has concentrated on organic matter processing and other biologically related phenomena. Several stream channel reference segments have been established to provide baseline data from which to evaluate geomorphological changes in stream channels. Figure 6.1 is an example of one of these segments.

In the past year, four watersheds [300-400 ac (120-160 ha)] within the Kings Creek drainage have been fitted with triangular-throated, reinforced concrete flumes with stilling wells and automatic stage recording and sampling devices. A 36-in. (0.9-m) Parshall flume with automatic stage recording and sampling device has also been installed on a 20-acre (8-ha) upland section. All flumes except the Parshall were sized to handle a peak discharge of 400 cfs (11.3 m^3/s), which is at least 1 cfs/acre (0.07 $m^3/s/ha$). This size was selected to pass the peak discharge expected from the 25-year storm on the largest watershed. Level berms on the ends of the flumes will allow extrapolation of the discharges in excess of 400 cfs. These sites will make sediment measurement more feasible; however, no plans have been made to routinely measure sediment movement.

Climate

The area has a temperate mid-continental climate with warm, moist summers and cool, dry winters. Annual precipitation averages 33 in. (835 mm) and has a 1% chance of being less than 18 in. (460 mm) or greater than 55 in. (1400 mm) (Henderson, 1971). Annual lake evaporation at nearby Milford Reservoir averages 53.56 in. (1360 mm), and it has a 1% chance of exceeding 62.95 in. (1599 mm) (Knapp et al., 1984). The annual moisture deficit (precipitation minus lake evaporation) averages -21 in. (-520 mm) but may vary from 11 to -45 in. (280 to -1140 mm). Such extreme variation can result in expected annual water yields from none to over 20 in. (0-510 mm), based on records from similar areas in Kansas. Exceptions to average conditions are frequent in the area and are important to the prairie ecosystem. Droughts are not uncommon in the area and may last several years. Floods may completely reset the stream ecosystem by scouring it clean, rearranging the bed and channel, and exposing or depositing new materials. No rare events (prolonged droughts or catastrophic floods) have occurred since watershed research began on KPRNA.

Sediment Production Mechanism

The steep topography and fine-grained surface soils at Konza would be conducive to high sediment production from the high-intensity thunderstorms which are common during the growing season (April-September) were it not for the permanent grass cover provided by the tallgrass prairie. As a result, very little sheet and rill erosion is observed. Erosion that occurs is mainly in the channels and on steep slopes where the soils are unstable through a combination of the steep slope and periodic saturation which renders the landform unstable. There is undoubtedly some natural creep of the hillsides toward the channels, which provides a renewable source of sediment. The meandering nature of the stream system in the

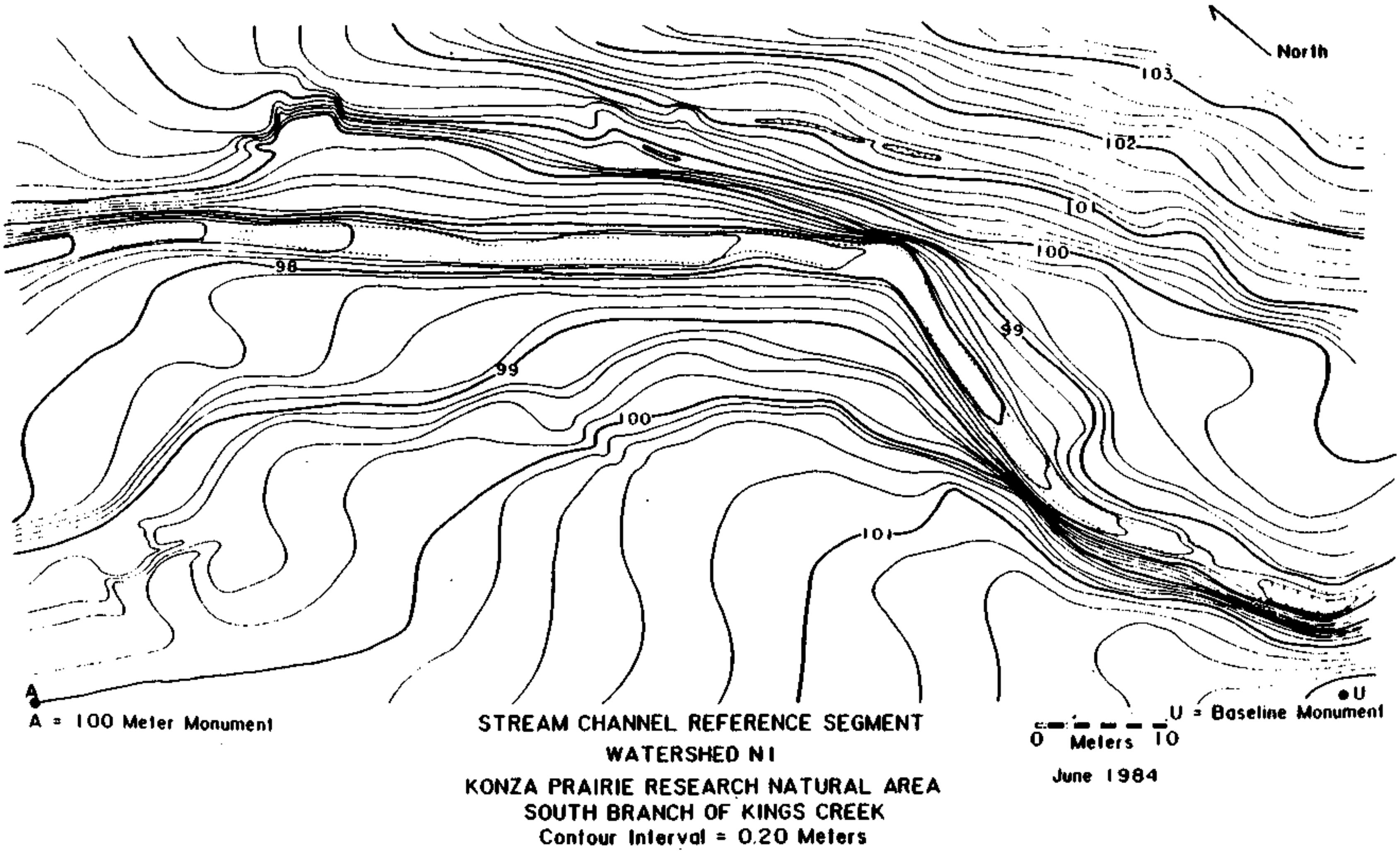

Figure 6.1. Sediment transport site at Konza Prairie

valleys results in most of the sediment movement by water. This movement, however, occurs mainly during runoff events exceeding 2- to 5-year frequencies, when discharge has sufficient hydraulic scour and transport capacity to move important amounts of sediment. Because surface soils are fine grained, once materials are suspended or begin movement the relatively steep gradient of the prairie streams assures that a large majority of the fine-grained sediment is exported from the site. The weathering process produces fragments of limestone and chert which are sorted during larger discharge events. Most stream bottoms are covered with varying amounts and sizes of these fragments. Wind erosion is not important at Konza.

Holland (1971) evaluated sediment yields from small drainage areas in Kansas. For the area of the Flint Hills near Konza, he estimated the sediment production to be 0.3 acre-feet per year per square mile (482 m^3 per year per km^2). The same report estimates sediment yields from cropland in the same area to be 4 times as much as from rangeland.

Discharge from Kings Creek at Konza has been quite variable from year to year and within years. As an example, in 1981 the stream was dry nearly nine months but flowed throughout the summer. In 1982 the stream was dry for nearly two months and flowed much of the winter. Based upon the record so far, it appears that "extremely variable" will be the typical description of stream discharges from the watershed. The largest instantaneous discharge of record of 400 cfs (11.3 m^3/s) occurred on July 1, 1982. The discharge increased nearly a hundredfold in less than 30 minutes. During the event the discharge changed the channel configuration sufficiently to require a revised rating curve after the storm peak. The reconfiguration of the channel cross section represents a major source of sediment loss during the storm. For the four years of record available, the average water yield has been 7.66 in. (185 mm), which is similar to the 31-year average of 7.4 in. (190 mm) for Mill Creek, a 316-mi^2 (830-km^2) gaged basin in the Flint Hills.

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7. SEDIMENT MOVEMENT AND STORAGE IN THE COLORADO ROCKY MOUNTAINS (NIWOT RIDGE SITE)

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Sediment Movement and Storage on Alpine Slopes

Contemporary rates of sediment movement on alpine slopes in three basins in the Colorado Rocky Mountains have been estimated for periods of up to 20 years. The upper Green Lakes Valley is a high alpine catchment of 2.1 km^2 which appears typical of the higher granitic terrain of the Colorado Front Range. The Williams Fork Lakes basin and the Eldorado Lake basin, both with areas of about 1 km^2, are in the alpine zone of the San Juan Mountains. The former is underlain by Tertiary volcanic bedrock and the latter by Paleozoic quartzite.

In the period of study, sediment transport in all three basins appears to have been less active than in other high mountain areas today. It is dominated by mass transfers within the cliff-talus system, especially by work done in infrequent rockfalls involving more than 5 m^3 of debris. Episodic debris flow activity also makes an important contribution to contemporary geomorphic work in this environment. In contrast, sediment movement by the quasi-continuously acting processes of solifluction, creep, and fluvial activity is relatively slight. Almost all transfers of sediment remain internal to the slopes which are thus effectively decoupled from the stream channels below them. One important exception to this involves silt and clay, imported to the alpine system through the atmosphere, which are transported via the streams to alpine lakes. A second exception, now receiving increased attention in Long-Term Ecological Research, is that of geochemical activity. Geomorphic work resulting from solute transport within the basins is equivalent to that of other processes and is the only process capable of exporting large volumes of material from the basins under present conditions.

Sedimentation records from the alpine lakes of all three basins suggest that the closure of their slope systems has been the case for most of the Holocene. Even on such a long time scale, hillslope processes have had little influence on landform generation. As a result, the Colorado alpine landscape remains a relict one, reflecting late Pleistocene glacial activity and increased rates of slope development immediately following deglaciation.

Sediment Transport in the Streams of Green Lakes Valley. Colorado Front Range

Green Lakes Valley is an alpine catchment about 2 km^2 in area above 3550 m elevation. In geomorphic terms, it represents a high energy, mountain environment, with a relative relief of 250 m/km^2, a mean slope of 25°, and an average channel slope of about 12°. More than 50% of the terrain in the basin consists of bedrock cliffs and their associated taluses. Peak discharges from the catchment may exceed 1 m^3/s, and rainfall intensities in excess of 30 mm/hr have been recorded within it.

Despite these indications of high potential energy, sediment movement on the hillslopes of the valley is less than that observed in other high alpine environments. As shown in table 7.1, it is dominated by rockfall and coarse debris transport, which involves more than 0.5 x 10^6 m^3 of debris and about 70 x 10^6 joules (J)/yr. In contrast, processes affecting fine sediment and soil on the hillslopes involve about 0.1 x 10^6 m^3 of material and less than 1 x 10^6 J/yr of geomorphic work (table 7.2). If the latter includes the only material likely to be transported by fluvial processes, this suggests a very low sediment delivery ratio.

Within the fluvial system, sediment yields have been estimated from water samples taken on weekly or shorter intervals at three sites for which discharge records are available. Bed load transport has not been estimated but appears to be negligible. The three sites represent catchment areas of contrasting sizes and characteristics. All three show a predictable pattern of sediment concentration which closely reflects the seasonal discharge hydrograph. Superimposed on this, especially at the site with the smallest catchment area, are short-term responses to summer rainstorms. All sediment concentrations are low (<0.5 mg/1) and include only very fine silt- and clay-size materials (mean size <10 μ). Thus, sediment fluxes through the fluvial system remain low, even at times of high water discharge: they involve less than 3 m^3 of material and 0.3 x 10^6 J/yr of work. The evidence of sediment records in the alpine lakes of the Front Range suggests that this low level of fluvial activity has been maintained through the late-Holocene.

Table 7.1. Coarse Sediment Budgets for Colorado Alpine Areas

	Green Lakes		Williams Fork		Eldorado Lake	
	Volume	Work	Volume	Work	Volume	Work
Rockfall	10	44.6	11.5	4.09	1	2.55
Talus accumulation	1.5	2.87	2.5	1.59	1	2.55
Talus shift	206,500	14.43	27,500	16.40	25,000	4.89
Debris flow	2.5	3.26	18.57	11.21		
Rock glacier flow	373,000	3.59				

Volumes are in cubic meters per year.
Work is in joules x 10^6 per year.

Table 7.2. Fine Sediment Budget for Colorado Alpine Areas

	Green Lakes		Williams Fork		Eldorado Lake	
	Volume	Work	Volume	Work	Volume	Work
Soil creep and solifluction	95,440	0.90	154,000	3.39	49,000	0.25
Surficial wasting	240	0.03	1,600	4.54	1,315	0.05
Lake sedimentation	13.5	1.00	N.D.		N.D.	
Suspended sediment transport	2.7	0.315				
Aolian transport	20.0	----				

Volume is in cubic meters per year.
Work is in joules x 10^6 per year.

The decoupling of the slope and channel systems suggested by this contrast in geomorphic activity may be explained by four factors that are characteristic of the alpine environments of the Colorado Front Range. First, at the time of highest stream discharge in early summer, more than 60% of the catchment area is snow-covered and any sediment on that area is effectively protected from remobilization. This is particularly true of the bare-soil zones which may become source areas for sediment release in the summer. Second, there are low-energy enclaves within the alpine environment (e.g., lakes and fens) which trap sediment moving through them. Even these are not accumulating large volumes of sediment, however. Third, only small volumes of sediment are available within the present stream channels, most of which are lagged by cobbles and boulders. Rarely is there any evidence of the lag materials being moved through the channels. Fourth, finer sediments transported to the valley floor (e.g., by debris flows) appear to be stabilized and removed from transport at that point. The concentration of the vegetative cover in the riparian zone seems an effective filter which passes little sediment.

8. SUMMARY

J. Rodger Adams

Discussion Topics at the Intersite Workshop

During the site reports at the LTER Intersite Workshop on Sediment Movement and Measurement, a considerable amount of questioning, comments, and interchange occurred. In this portion of the workshop we attempted to focus on data collection methods, means or measures of comparison, geomorphic or ecosystem reset or dominant events, and integration of the work of geomorphologists and biologists in LTER. The following accounts summarize the group discussions on energy and measurements.

Energy

Energy was proposed as a common measure of all sediment or soil moving events. Energy is measured in joules or newton-meters. One newton is the force required to accelerate 1 kg one m/sec^2, so $J = N\text{-}m = kg\ (m^2/sec^2)$. This is mass times speed squared. Frequently power, or the rate of energy per unit time, is measured in watts with 1 w = 1 J/sec. The energy input from an event (rainstorm, windstorm, etc.) is the integral over time and space of the power or rate of energy input. The area of interest may be a test plot, the area impacted by the event, an LTER site, or a larger area. The time is defined by the beginning and end of the event. There are still questions about measuring energy input during "major," "dominant," or "resetting" events or recording annual total energy input.

Some means of normalization will be necessary but there may be more than one basis for normalization. For example, Wischmeier's precipitation energy parameter may be a good norm for erosion potential, and stream power may be useful in channel flows, but how do we scale overland flow? Or how do we compare windstorms, thunderstorms, and frontal or cyclonic storms? What are the impacts of power levels and duration on erosion and transport?

This leads to another question: what do we want to compare? On one hand there is the event which can reform the landscape or reset an ecosystem. The frequency, energy input, and regional scale of these events are important. How does the total energy and maximum power of such events compare between sites? There is also a concern about effective energy and its measurement and the resultant movement or transport. In this case sediment yields, landform change, distance moved, and deposition need to be measured. Turbulence, sorting, and deposition are important and observable in transport by water. A complete energy budget, or first law of thermodynamics equation, may not be necessary, but determination of the effective or useful energy that moves material is necessary.

What measurements are necessary to compare energy of dominant events? A checklist of data might read: volume, rates, area affected, time, spatial and temporal variability, topography, precipitation, runoff, wind with/without rainfall, mass wastage, solar energy, elevation difference, and slope. Empiricism and observational approaches need to be avoided. We need to work in the context of quantitative geomorphology and related approaches such as climatic geomorphology and landscape ecology. Average annual values and seasonal cycles are important, as are dominant or resetting events.

Measurements

Much discussion of measurement techniques is included in the site reports which make up the largest part of this report. Following is a brief summary of measurements now being made or planned for future studies.

Andrews. Various methods including measuring sediment accumulation in pools above weirs, grab samples, pumped samples, and repeated cross-sectional measurements have been used for measuring stream sediment transport. Landslides have been detailed and movement estimated from aerial photographs and some ground surveys. This is done on the average of once in 5 years with no event identification in time. Erosion boxes are used to sample surface erosion. Stakes, inclinometers, and mapping have all been used to measure earthflow rates on steep slopes. Woody debris movement in channels is also important and is measured by mapping, tagging, and introduction of identifiable pieces. Woody debris which is similar in size to the channel also affects sediment and small organic matter transport and deposition.

Central Plains. The site report describes the plans for erosion measurements on steep topography. Because of the fragile plant communities on the site, wind erosion may be more important than rain or overland flow erosion. Several test plots are being delineated and instrumented. A major concern is the determination of the contributing area. This is affected by small scale topography, can be different for precipitation events of different intensities or durations, and can be changed by erosion during an event.

Illinois Rivers. Suspended sediment, bed load, and water velocity are measured using samplers and techniques agreed upon by the U.S. Interagency Committee. Suspended sediment samples for both concentration and particle size are collected with depth-integrating, isokinetic samplers. Data collection is being shifted from budget-oriented plans toward model validation, event-triggered sampling, and specific habitat analysis programs. In habitat studies other parameters such as wind speed, wave heights and energy spectra, and water velocities and lateral distributions are also measured. Weather, primarily wind and waves, limits sampling on large rivers. Dominant flood events add the hazards of large debris, high velocities, and submerged riparian areas. Regularly collected single vertical samples are calibrated by occasional full cross-sectional measurements of sediment load.

Jornada. Rainfall, runoff, overland flow, and erosion are measured. Except for rainfall, these all occur only when the precipitation rate exceeds the infiltration rate of the desert soils. Two sizes of rainfall simulators have been used to determine erosion and runoff rates. Drop size and land impact energy are measured for the simulation studies, but they are estimated with an empirical equation for actual storm events. The runoff-sediment collection system results in an arbitrary separation of sediment into suspended/ bed load or transported/settled fractions.

Several questions arise from this. One is the applicability to overland flow of the common instream bed-suspended load division or the measured-unmeasured load separation when using depth-integrating samplers. The other questions concern the yield and measurement of contributing areas. Sediment yields measured with two different rainfall simulators gave different delivery ratios for similar precipitation on different, but very small, areas.

Konza Prairie. Repeated cross-sectional measurements will be used to measure channel erosion and deposition in discharge weir pools. Bed load should be trapped in pools and may need to be removed occasionally. ISCO pumped samplers are being used for event suspended sediment sampling. The sampling tube inlet should be in or slightly downstream of the flume throat and pointing upstream, clear of the flume walls or bottom. It would be good to calibrate single point pumped samples with depth-integrated samples taken with a DH-48.

Niwot Ridge. The presenter of this site report (David Furbish) had to leave before this session, but the site report indicated little or no measurement of erosion or sediment. The annual snowmelt-runoff event accounts for most of the water and related movement in the project site.

Intersite Hypotheses

Many topics and concepts entered this discussion, but several were common to all of us and all of the sites. These concepts are: dominant or resetting events, mechanical energy inputs, rates, and scale effects. The following list is based on my own notes, Nani Bhowmik's suggested hypotheses, and a letter from Jim Koelliker.

A. Sediment and organic matter transport is important on two time scales:

   1. Annual and seasonal variations
   2. Dominant or extreme events with low probability of occurrence in any one year

B. The impact of extreme events decreases with increasing drainage area. This is similar to the steering committee hypothesis which proposed increases in complexity and stability with increasing drainage area.

C. Dominant events impact both the landscape and the ecosystem.

    1. The near future geomorphic regime may be reset.
    2. The ecosystem is reset.
    3. Human intervention may change the impact process, system response, and the magnitude of the event which can cause resetting.

D. The result of extreme events depends on potential energy (elevation or gradient) and total energy and peak power of the event (rainfall impact, wind). Land surface conditions (soil, rock type, vegetative cover, orographic protection, and prior disturbance) alter the effectiveness of energy inputs in moving material.

E. Total energy, peak power, precipitation volume or mass, and frequency of occurrence can be used to characterize and compare extreme events of different types on different sites.

F. Movement of organic material (woody and leafy debris, etc.) by water involves transport, storage, and mechanical size reduction. This is a key link between hydrology and biology.

    1. Frequency of movement depends on size of debris in relation to the flow geometry (depth, channel size and shape).

    2. The degree of mechanical processing depends on the amount of similar-sized material, speed of transport, bed roughness and material, and duration of the event.

<u>Suggested Goals</u>

There was a general feeling of satisfaction with the workshop. However, several sites did not participate, and a future workshop which might be focused on landscape ecology should be planned to include these sites. All participants are engineers or geologists and have a common concern about being integrated into their site research team. Thus several specific goals seem practical and vital to LTER. These are:

1. Develop inter-group cooperation between the water and sediment group and the streams biologists, especially by involvement in nutrient transport by overland flow and streams.

2. Cooperate with the intersite climate group on antecedent conditions, spatial and temporal variability, and regional comparisons.

3. Attempt to characterize extreme events on an energy input or effective energy basis.

4. Refine hydrologic and geomorphic hypotheses to better explain impacts on the ecosystem.

5. Address the scale problem between sites : from 1 m to 1000 km linear and 1 m^2 to 1,000,000 km^2. This range is large, but at least a 1 to 100,000 km^2 comparison appears necessary.

6. Begin integration of hydrologic models into the overall modeling framework at each of the sites.

7. Consider a future intersite workshop on landscape ecology or landscape and ecology.

8. Rework this report into an article, probably for EOS, the AGU weekly newspaper.

APPENDIX

Agenda and Participants,

Long-Term Ecological Research Intersite Workshop on Sediment Movement and Measurement,
Pere Marquette State Park, Grafton, Illinois,
September 16-18, 1985

Agenda

Monday, September 16, 1985

Afternoon:	Arrival at park, pickup of people at St. Louis airport
5:30 - 7:30	Picnic dinner at NHS River Research Lab
7:30 - 10:00	Social at Lab

Tuesday, September 17, 1985

8:00 - 9:00 a.m.	Breakfast, on your own at lodge
9:00 - 9:30 a.m.	Introductions, overview of workshop
9:30 - 10:30 a.m.	Keynote talk by Dr. Nani Bhowmik
10:45 - 12:45 p.m.	Site presentations
12:45 - 1:45 p.m.	Lunch
2:00 - 5:30 p.m.	Site presentations
6:00 - 7:00 p.m.	Dinner
7:30 - 9:00 p.m.	Group discussions

Wednesday, September 18, 1985

8:00 - 9:00 a.m.	Breakfast, on your own at lodge
9:00 - 10:30 a.m.	Group discussions
11:00 - 12:00 p.m.	Group summary reports
12:30 - 1:30 p.m.	Lunch
1:45 - 2:30 p.m.	Summary by Dr. J.R. Adams and Dr. Bhowmik
3:00 - 5:00 p.m.	Tour of Replacement Lock and Dam 26 construction site; take people to airport

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