Open-File Report 95-156

COLLECTION OF SHORT PAPERS ON THE BEAVER CREEK WATERSHED STUDY IN WEST TENNESSEE, 1989-94

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U.S. Department of Agriculture, Natural Resources Conservation Service (formerly known as Soil Conservation Service)

U.S. Department of the Interior, U.S. Geological Survey

Tennessee Department of Agriculture

Tennessee Department of Environment and Conservation

Shelby County Conservation District

University of Tennessee, Agricultural Extension Service

Clemson University

The University of Memphis

Cover photograph. Loosahatchie River looking upstream at Highway 205 in the Beaver Creek watershed.

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Compiled by W. Harry Doyle, Jr., and Eva G. Baker

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Open-File Report 95-156

Memphis, Tennessee
1995

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PREFACE

In 1989, the U.S. Geological Survey began a scientific investigation to evaluate the effect of agricultural activities on water quality and the effectiveness of agricultural best management practices in the Beaver Creek watershed, West Tennessee. The project is being conducted jointly with other Federal, State, County agencies, the farming community, and academic institutions, in support of the U.S. Department of Agriculture's Hydrologic Unit Area program.

The Beaver Creek project has evolved into a long-term watershed assessment and monitoring program. In 1991, a grant was received to develop and evaluate sampling strategies for higher order streams. During the summer of 1992, a reconnaissance of water-quality conditions for the shallow aquifers in Shelby, Tipton, Fayette, and Haywood Counties was conducted and included 89 domestic wells in the Beaver Creek watershed. Results from this effort lead to the development of a 1-year program to evaluate cause-and-effect relations that can explain the observed water-quality conditions for the shallow aquifers in the watershed. In 1992 the USGS, in cooperation with the Soil Conservation Service and the Shelby County Soil Conservation District, began an evaluation of in-stream processes and in-stream resource-management systems. In 1993, a biomonitoring program was established in the watershed.

This collection of articles and abstracts was originally published in the American Water Resources Association National Symposium on Water Quality Proceedings for the National conference held in Chicago in 1994. These articles address the optimimum sampling strategy for obtaining water-quality data in nonpoint-source pollution studies; provide an understanding of the fate and transport of agrichemicals in the surface runoff and the soil profile; demonstrate that the most significant water-quality problem in the watershed is the transport of sediment; support qualitative and quantitative statements of the effects agriculture has on water quality in the Beaver Creek watershed. The purpose of this report is to present the current (1994) results of these investigations in one document related to the Beaver Creek watershed.

CONTENTS

ASSESSMENT OF AGRICULTURAL NONPOINT-SOURCE POLLUTION AND BEST MANAGEMENT PRACTICES FOR THE BEAVER CREEK WATERSHED, WEST TENNESSEE: AN OVERVIEW

Angel Roman-Mas[1], Robert W. Stogner, Sr.[1],
W. Harry Doyle Jr.[1], and Stephen J. Klaine[2]

ABSTRACT: In 1989, the U.S. Geological Survey began a long-term research project to evaluate the effect of agricultural activities on water quality and the effectiveness of agricultural best management practices in the Beaver Creek watershed, West Tennessee. The project is being conducted jointly with other Federal, State, and county agencies, the farming community, and academic institutions, in support of the U.S. Department of Agriculture Hydrologic Unit Area program. This paper presents a historical account of the project, a general description of the study area and the methods used for data collection and analyses, and a synopsis of the most significant project findings.
KEY TERMS: Agriculture, nonpoint-source pollution; best management practices; water quality; ground water; surface water; soils.

INTRODUCTION

In 1989, efforts by the farming community in Tennessee facilitated a cooperative agreement between the U.S. Geological Survey (USGS) and the Tennessee Department of Agriculture (TDA) to evaluate agricultural nonpoint-source pollution and best management practices (BMP's) in the Beaver Creek watershed, West Tennessee. An assessment conducted by the Tennessee Department of Environment and Conservation (TDEC) (formerly the Tennessee Department of Health and Environment, 1988) indicated that agricultural activities were the principal cause for water-quality degradation in this watershed. This paper presents a historical account of the project, a general description of the study area and the methods used for data collection and analyses, and a synopsis of the most significant project findings.

For this study, a multidisciplinary, multiagency team of scientists from the USGS, Clemson University, University of Memphis, and the University of Tennessee Agricultural Extension Service (UTAES) was assembled. The team selected four small basins (less than 50 hectares each) to conduct deterministic (cause-and-effect relation) and mechanistic (processes and factors) evaluations of agricultural nonpoint-source pollution and BMP's. A major component of this study was the evaluation of existing sampling methods for runoff and soils and the development of new methods as needed.

In 1990, the Beaver Creek watershed was selected for the U.S. Department of Agriculture (USDA) Hydrologic Unit Area (HUA) program. The HUA program provides technical, financial, and educational assistance to farmers for the implementation of BMP's. The following BMP's were identified: (1) conservation tillage systems, (2) terrace systems, (3) conservation reserve program, (4) contour stripcropping, (5) diversions, (6) critical area treatment, (7) grass waterways, and (8) water and sediment control basins.

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The Beaver Creek project has evolved into a long-term watershed research and monitoring program. In 1991, a grant was received from the Water Environment Federation to develop and evaluate sampling strategies for higher order streams. During the summer of 1992, a reconnaissance of water-quality conditions for the shallow aquifers in Shelby, Tipton, Fayette, and Haywood Counties was conducted (Fielder and others, 1994). The reconnaissance, which was undertaken in cooperation with the TDA and the UTAES, included 89 domestic wells in the Beaver Creek watershed. Results from this effort lead to the development of a 1-year program to evaluate cause-and-effect relations that can explain the observed water-quality conditions for the shallow aquifers in the watershed. The evaluation is being funded by the TDA, the TDEC, and the Shelby County Conservation District (SCCD). In 1992 the USGS, in cooperation with the Soil Conservation Service and the SCCD, began an evaluation of in-stream processes and in-stream resource-management systems. In 1993, a biomonitoring program was established in the watershed.

Current project objectives include the: (1) evaluation of the extent that agricultural activities affect water quality and threaten environmental integrity in the Beaver Creek watershed, (2) evaluation of in-field and in-stream BMP's, (3) development and evaluation of chemical and biological sampling strategies, (4) identification and quantification of processes and factors that control the degradation and transport of agricultural pollutants, and (5) evaluation of mathematical-mechanistic models. Results from the Beaver Creek watershed project can assist resource management agencies in developing strategies for use in their conservation programs.

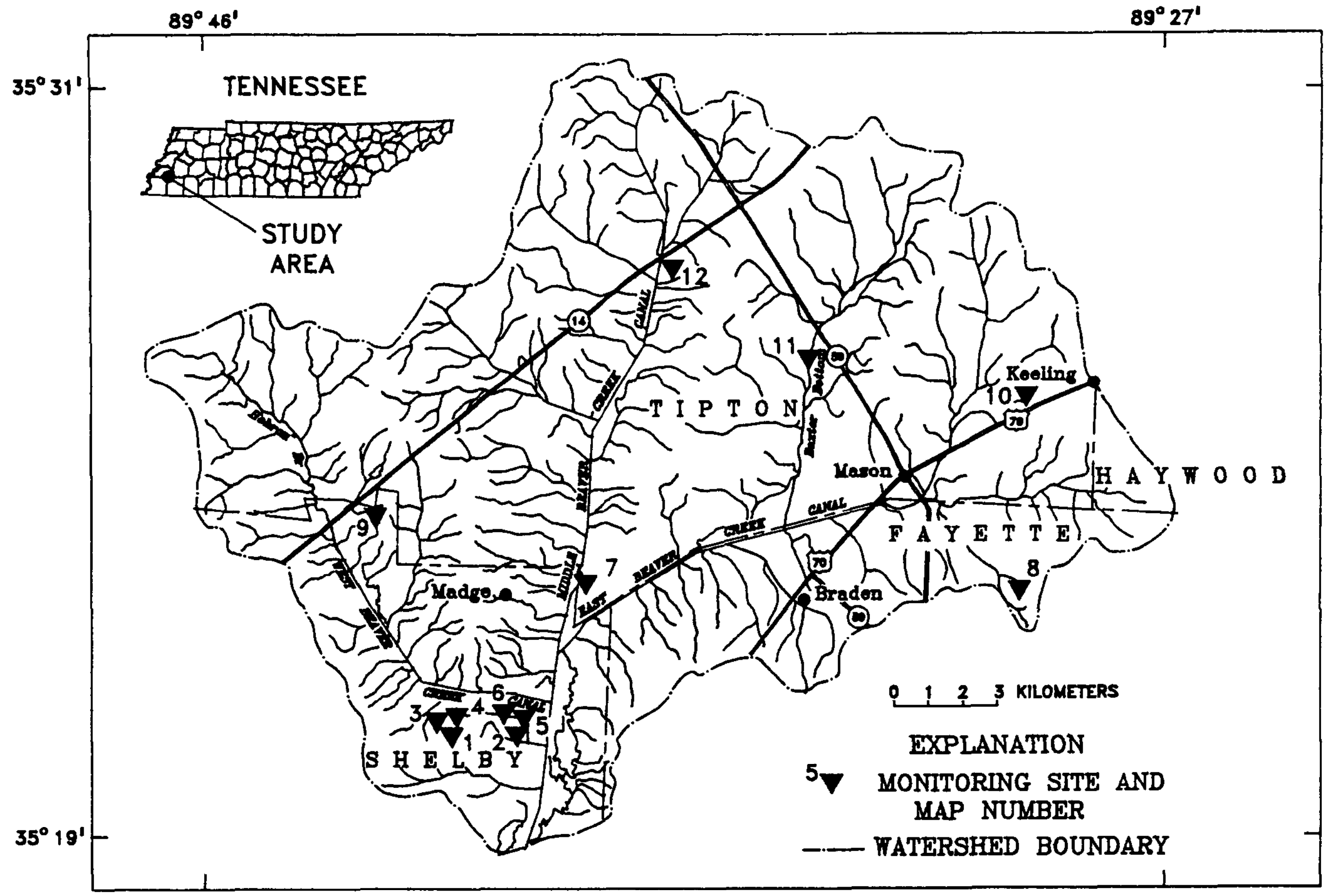
DESCRIPTION OF STUDY AREA

The Beaver Creek watershed, located in Shelby, Tipton, Haywood, and Fayette Counties in southwest Tennessee (see Figure 1), encompasses about 40,000 hectares (ha). The watershed lies within the Southern Mississippi Valley Silty Uplands major land resource area (U.S. Department of Agriculture, Soil Conservation Service, 1988). Two major physiographic regions, upland and bottomland, can be distinguished in the watershed. Agriculture is vital to the local economy. Cropland covers about 70 percent of the watershed; cotton, soybeans, and corn are the principal crops. Forests and range land occupy 10 and 20 percent of the watershed, respectively. Forest stands are primarily pole and small saw timber, reflecting extensive harvesting 40 to 60 years ago. All major tributaries in the Beaver Creek watershed were channelized in the early to mid-1900's to facilitate drainage.

The mean annual rainfall is about 130 centimeters (cm); about 25 cm fall during the 180-day growing season of April through September. The wettest month is April, with a mean rainfall of 14 cm, and the driest month is October, with a mean of 6 cm. Mean monthly temperatures range from 1 °C (January) to 27 °C (July) and the mean annual temperature is 16 °C.

Geologically, the watershed is in the Mississippi embayment of the Gulf Coastal Plain physiographic province. Alluvium and fluvial deposits of Quaternary and Tertiary(?) age make up the shallow aquifer in the watershed (Parks, 1990; Parks and Carmichael, 1990a, 1990b). Alluvium, consisting of sand, gravel, silt, and clay, is present beneath the bottomland areas; fluvial deposits of sand, gravel, minor clay, and ferruginous sandstone are present beneath the loess in the uplands and valley slope areas (Parks, 1990; Parks and Carmichael, 1990a, 1990b). Locally, the alluvium and fluvial deposits are underlain by the Cockfield Formation, Cook Mountain Formation, or the Memphis Sand of Tertiary age. The Cockfield Formation and the Memphis Sand consist of sand, silt, clay, and lignite and make up the Cockfield and Memphis aquifers (Parks, 1990; Parks and Carmichael, 1990a, 1990b). The Cook Mountain Formation, which consists primarily of clays, makes up the confining unit overlaying the Memphis aquifer.

Soils in the watershed consist of well to poorly drained silt loam (U.S. Department of Agriculture, Soil Conservation Service, 1988). Three principal soil associations are present: Memphis-Loring, Granada-Loring-Memphis, and Falaya-Waverly-Collins. The Falaya-Waverly-Collins soil association occurs in the bottomland areas whereas the other two soil associations are typically in upland areas. The soils are acidic with pH ranging from 5.1 to 5.5 units.



Digital data from the 1;100,000 National Mapping Division Universal Transverse Mercator projection. Projected in State Plane 1927 North American datum

Figure 1. Location of the Beaver Creek watershed study area and surface-water monitoring sites.

RESEARCH AND MONITORING ACTIVITIES

For the Beaver Creek watershed project, a watershed-based risk assessment approach was adopted to design the research and monitoring activities. The following steps were taken as part of this approach:

(1) *Identification of the natural resources and their specific functions:* For the Beaver Creek project, this task was conducted by the SCS in support of the HUA program. Soils and water quality were the identified resources. Specific functions of these resources are production agriculture, fish and wildlife, aquatic recreation activities, irrigation, and livestock.

(2) *Identification of stressors:* This step refers to anthropogenic activities that can degrade the resources or impair specific functions identified in step 1. Row-crop production (cotton, soybean, corn), cattle (range land), and channelization were identified as potential stressors.

(3) *Assessment of physiographic variations:* The watershed-based risk assessment approach requires identification of the range of physiographic settings that can produce different resource-stressor or function-stressor responses. For instance, in the Beaver Creek watershed, cotton and soybeans are cultivated in upland and bottomland areas. Therefore, the evaluation of cotton and soybean crops as a potential stressor must include experimental fields located in both these areas.

(4) *Evaluation of BMP's:* The evaluation of BMP's adds another dimension to the monitoring program. Paired-basins analysis, which is the preferred technique to evaluate BMP's, required two monitoring sites for every resource-stressor response identified in a given physiographic setting. The upstream-downstream approach also requires two monitoring sites for every resource-stressor response to be studied. In this approach, data from a site downstream from the area where the BMP's have been implemented are compared to data collected at a site upstream from the BMP area. Trend analysis is the third and most common approach for evaluating BMP's. In this approach, pre- and post-BMP's implementation data are collected and compared. This approach typically includes one monitoring site at the downstream end of the area where the BMP's are implemented. In some instances, monitoring sites upstream and downstream of the BMP implementation area are needed to isolate the area's contribution to water-quality conditions.

(5) *Selection of monitoring sites:* The number of sites to be monitored is based on the number of resource-stressors identified in the watershed and the BMP's to be evaluated. In the Beaver Creek watershed, row-crop agriculture and channelization were determined to be the most important stressors to soils and water resources in the watershed, and non-tillage and riparian zone restoration were the most important BMP's. The scale of the monitoring sites is dictated by the type of investigation being conducted. Whereas occurrence and distribution studies can be conducted in relatively large-scale systems, mechanistic and deterministic evaluations typically require small-scale systems. Both types of evaluation are required to fulfill the Beaver Creek project objectives.

(6) *Data collection:* Any biases imposed by the data-collection methods must be recognized and quantified. Sensitivity analyses, in which the magnitude of response of a parameter is evaluated relative to changes in other parameters, are necessary to develop, evaluate, and modify data-collection methods.

(7) *Modeling:* Modeling efforts should provide resource managers with tools (1) to simulate field- and watershed-level processes related to specific stressor-resource response and (2) to extend information gained in bench-mark studies to other areas. Models can range in approach from synoptic, which provide a broad overview of the resource-stressor response with minimum data, to mathematical-mechanistic, which attempt a full differentiation of the processes and factors controlling the resource-stressor response.

Surface Water

Twelve surface-water monitoring sites have been established in the watershed (see Figure 1). Climatic, hydrologic, chemical, biological, and geomorphological (channel evolution) data collected at these sites are being used in paired-basin analyses, upstream-downstream comparisons, and trend analyses (see Table 1).

Streamflow Stations and Measurements

Each surface-water monitoring site includes a stream-gaging station to measure discharge. The stations were constructed and are being operated according to standard USGS procedures. Drainage boundaries for each station were determined and the drainage areas computed. Topographic maps for each basin were developed from 7.5-minute quadrangle topographic maps or from field surveys. A detailed inventory of farm activities is being maintained.

Each station was outfitted with a pressure sensor or a stilling well and an automated recorder programmed to record stream elevation (stage) at variable time intervals according to the rate of change in stage. Continuous discharge records were developed from the stage data following standard USGS methods (Kennedy, 1983). At selected monitoring sites (see Figure 1, sites 1, 8, 9, and 10) automated rain gages were installed.

Unit hydrograph analysis and water budgets are being used to evaluate the hydrologic response of the basins. It is reasonable to expect that changes in the hydrologic response of the basins would be observed if the implementation of BMP's are effective. Increases in infiltration rates and evapotranspiration and associated decreases in runoff to rainfall ratio, basin response time, and peak discharge are expected to result from the implementation of BMP's.

Table 1. Location, data collection, physiographic and agricultural information for surface-water monitoring stations in the Beaver Creek watershed, Tennessee

[hyd, hydrological; cli, climatic; chm, chemical; bio, biological; geo, gemorphological; *, estimated from topographic maps]

Map Number	Data Being Collected	Type of Evaluation Being Conducted	Drainage Areas (hectares)	Area Under Cultivation (percent)	Crop(s)	Physiography
1-2	hyd, cli, chm, bio, and geo	1. Up-stream/down-stream, in-stream processes, and resources management 2. Sampling protocols	171-258	95-95	Cotton soybean	Bottomland
3-4	hyd, cli, chm, and geo	1. Paired-basins, conventionally tilled versus non-tilled cotton	6.88-6.93	100-100	Cotton	Bottomland
5-6	hyd, cli, chm, and bio	1. Up-stream/down-stream, constructed wetland	0.4 (wetland)-28 (cropland)	0-100	Soybean corn	Bottomland
7	hyd, cli, chm, and geo	1. Trend analyses 2. Sampling protocols	12,000*	65	Cotton	Upland and bottomland
8	hyd, cli, chm, and geo	1. Trend analyses 2. Sampling protocols	44	100	Soybeans	Upland
9	hyd, cli, chm, and geo	1. Trend analyses 2. Sampling protocols	26	80	Soybeans	Upland
10	hyd, cli, chm, and geo	1. Trend analyses 2. Sampling protocols	11	100	Cotton	Upland
11-12	hyd, cli, chm, bio, and geo	1. Paired basin, channelized versus non-channelized 2. Sampling protocols	1,215-1,135*	70-70	Cotton soybeans	Upland

Water Quality

Surface-water samples for the determination of nitrogen and phosphorous species, organic carbon, suspended sediment, and selected pesticides and their metabolites are being collected during stormflow and base-flow conditions. Two automated samplers were installed at each station to aid in the sample collection. Approximately 20 rainfall-runoff events are monitored annually. During stormflow, water samples are collected at an interval equal to 5 percent of the total stormflow duration. During base-flow, water samples are collected every 15 minutes for the first 3 hours after stormflow and every hour thereafter until the end of the event or the beginning of a new event.

Annual and seasonal concentration-frequency curves (percent of the time that a particular concentration is exceeded during a given period of time) are being developed for each basin. Loads for annual, seasonal, and individual rainfall-runoff events are being computed. Statistical analyses will be used to determine if the variance in concentration-frequency curves and loads could be attributed to the implementation of BMP's. In addition, changes in chemical speciation and the phase (suspended or dissolved) in which the constituents occur are being evaluated.

Coarse particulate organic matter (CPOM) in surface water is being sampled by diverting approximately 8 percent of the total flow into a collection net. Trapped CPOM is collected, placed in a labeled plastic bag, and transported to the laboratory after each storm event. CPOM samples are being analyzed for particle size and for nitrogen, phosphorous, and pesticide content. Differences in the physical, chemical, and biological characteristics of the CPOM that determine its suitability as a food source for organisms downstream are also being evaluated.

Mathematical models that can simulate runoff and constituent transport at the field and watershed levels [for example, AGNPS (Young and others, 1991) and HSPF (Donigian, 1991)] will be calibrated and applied to the basin being monitored. A detailed evaluation of the mathematical algorithms used in these models will be conducted and modified as needed. Only those models that attempt a full differentiation of the processes and factors controlling the degradation and transport of agricultural chemicals are being considered.

Benthic macroinvertebrate data are being collected at selected sites in the Beaver Creek watershed (see Figure 1 and Table 1). The primary goal of the biomonitoring program is to evaluate and develop, as needed, biological sampling methods for streams in the watershed. Various methods are currently being studied. In addition, structural and functional indices are being used to evaluate water-quality conditions and environmental integrity.

In-Stream Processes

Modifications to the drainage network to improve drainage and control floods have altered the hydrologic regime of streams and marginal ecosystems (such as wetlands) in the Beaver Creek watershed. The preservation of biological and non-biological functions (for example, habitat and water quality, respectively) performed by streams and marginal ecosystems is central to the development of environmentally sound agriculture in the watershed. Quantitative understanding of these functions and the extent to which they have been impaired by drainage modifications is needed before in-stream resource-management systems can be developed and implemented.

Although little information is available on the natural drainage system in the bottomlands of the Beaver Creek watershed, the system was likely dominated by forested riverine wetlands. Flooding conditions of the bottomlands hampered their exploitation for timber and agriculture and lead local landowners to seek engineering solutions to drainage problems (Ashley, 1910). Channelization has been the most common engineering practice used in the watershed.

The Upper Middle Beaver Creek Canal subwatershed (see Figure 1, monitoring site 12) represented a typical example of a channelized condition. In contrast, the Baxter Bottom subwatershed at monitoring site 11 (see Figure 1) has not been channelized. A 250-ha forested riverine wetland is part of the Baxter Bottom subwatershed drainage network. This condition likely resembles natural drainage conditions for bottomlands in the Beaver Creek watershed. The two subwatersheds are of comparable size, slope, and land use. In 1993, a paired-basin study was started to document differences in water quality between the two subwatersheds and to identify and quantify biological, geochemical, and geomorphological processes responsible for the observed differences in water quality.

Constructed Wetlands

Wetlands can immobilize and metabolize chemical constituents through a complex network of physical, chemical, and biological processes and thereby improve water quality at their downstream ends. Constructed wetlands have been proposed as an off-site BMP for the treatment of cropland runoff because in many instances the transport of agricultural chemicals in runoff cannot be controlled in the field. Constructed wetlands have been successfully used to treat domestic and animal wastewater (Watson and others, 1989).

The design parameters used in constructed wetlands for the treatment of wastewater are typically determined by reaction kinetics (Kadlec, 1989; Watson and others, 1989). These parameters are unsuitable for designing wetlands to be used for treating cropland runoff because of the extreme temporal variations in flow and constituent concentrations, the chemical speciation of the constituents, and the unknown reaction mechanisms and rates for these chemical species in wetland environments.

In 1993, a 0.4-ha single-cell herbaceous wetland was constructed in the Beaver Creek watershed. Its purposes are to (1) evaluate the effectiveness of the wetland in assimilating or modifying the nutrient and pesticide content in cropland runoff; (2) identify and quantify the relevant processes responsible for the immobilization and metabolization of selected constituents within the wetland; and (3) develop design criteria for constructed wetlands to be used for treating cropland runoff.

Stream-gaging and water-quality monitoring stations were established upstream and downstream of the wetland (see Figure 1, monitoring sites 5 and 6). Water samples are being collected and analyzed for the determination of total and dissolved nitrogen and phosphorous species, organic carbon, selected pesticides and their metabolites, and suspended-sediment concentration. Changes with time in the concentration of these constituents, chemical speciation, and loads at the upstream and downstream sampling stations are being compared. Biological samples are being collected within the wetland for the determination of succession patterns in the benthic macroinvertebrate and the plant communities.

Soils

Non-tillage has been effectively used to reduce soil erosion. However, researchers have suggested that non-tillage can enhance chemical transport through the soil zone and increase the potential for ground-water contamination (Dick and others, 1989; Hall and others, 1989). Resource management agencies in the Beaver Creek watershed, which has soils that are highly susceptible to erosion, have recommended non-tillage as a BMP. The potential for ground-water contamination associated with the implementation of non-tillage in the watershed needs to be addressed before non-tillage is widely adopted.

Since 1990, a series of experiments have been conducted to (1) develop a sampling strategy that accurately characterizes the spatial and temporal distribution of agricultural chemicals in the soil profile, (2) evaluate the transport and degradation of agricultural chemicals in the soil profile, (3) compare the behavior of agricultural chemicals in conventionally tilled and non-tilled cotton fields, and (4) evaluate solute transport models such as CMLS (Nofziger and Hornsby, 1987), MOUSE (Steenhuis and others, 1987), PRZM (Carsel and others, 1985), GLEAMS (Leonard and others, 1987), and LEACHMP (Wagenet and Hutson, 1987).

Ground-Water Quality

As in many rural areas in the United States, residents in the Beaver Creek watershed rely on domestic wells for their primary source of water. Residents share a growing concern that agricultural activities could be affecting the quality of ground water in the watershed.

Water-quality, well-construction, and land-use data for 89 domestic wells (See Figure 2) completed within the shallow aquifers in the Beaver Creek watershed were used to statistically relate water-quality conditions to land-use activities. The data are part of a ground-water-quality reconnaissance conducted during the summer of 1992 for the shallow aquifers in Shelby, Tipton, Fayette, and Haywood Counties (Fielder and others, 1994). Non-parametric statistical methods were used to determine the extent to which land use affects the occurrence and distribution of nitrate within the water-table aquifer in the Beaver Creek watershed.

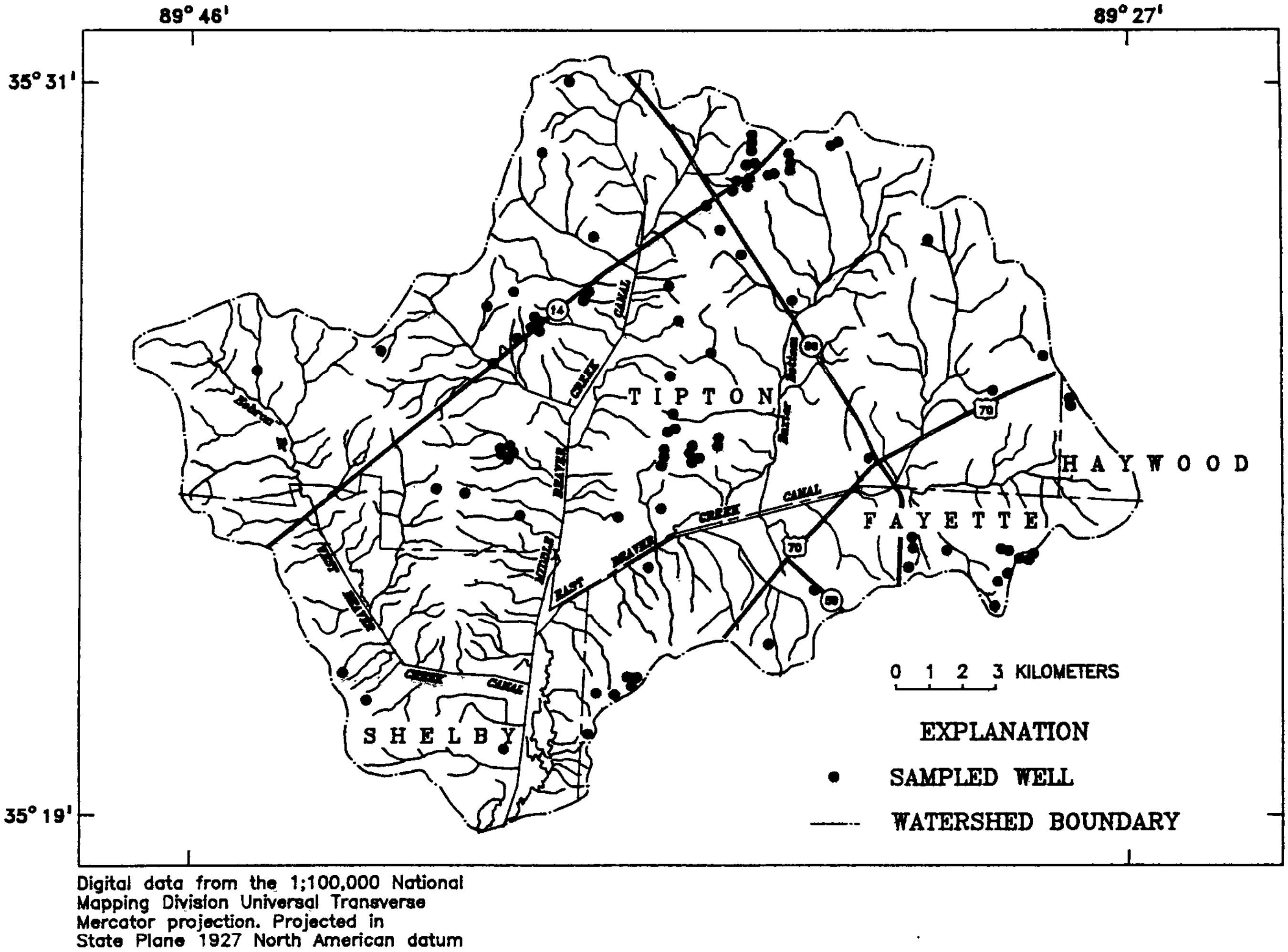


Figure 2. Location of sampled wells in the Beaver Creek watershed, 1992.

In 1993, a ground-water-quality network was established in the watershed. The network includes about 100 shallow wells that are sampled 5 times a year. Water samples are being analyzed for major constituents, nutrients, fecal bacteria, and selected pesticides. The water-quality data being collected will allow further investigation of cause-and-effect relations controlling the occurrence of pollutants in the shallow aquifers.

SIGNIFICANT FINDINGS

The following is a synopsis of the project's most significant findings.

(1) An optimal sampling strategy for the temporal characterization of chemicals and suspended sediment in agricultural runoff includes frequent sampling during stormflow and less frequent sampling during recession or base flow. Sensitivity analyses showed that a sampling interval equal to 5 percent of the stormflow duration is required during stormflow. For recession or base flow, a calibrated regression can supplement a limited number of concentration measurements.

(2) Soil-sampling transects perpendicular to the orientation of the rows provided adequate spatial representation to conduct statistical analyses and compute reliable field averages for the concentration of agricultural chemicals in soils.

(3) Surface-catalyzed reactions appear to be an important mechanism for the degradation of aldicarb metabolites in the soil profile. The calculated half-lives of aldicarb metabolites were an order of magnitude shorter than those computed from laboratory experiments in which surface-catalyzed reactions were absent.

(4) Horizontal transport within the soil profile was negligible for the conventionally tilled and the non-tilled fields.

(5) Observed patterns in the concentration of aldicarb and its metabolites in runoff are consistent with the convective-diffusion limited transfer concept and inconsistent with the instantaneous-equilibrium concept used in lumped-parameter models.

(6) Sediment transport resulting from soil erosion was identified as the major water-quality problem in the watershed. Computed suspended-sediment loads for these basins exceeded 30 metric tons per ha.

(7) Crop residue at different stages of decomposition accounted for about 80 percent of the total nitrogen exported from crop fields. The chemical speciation and the temporal distribution of nitrogen exported from these basins could not be directly related to fertilizer application.

(8) Background nitrate concentrations in water from the shallow aquifers have increased as a result of fertilizer application in the watershed. Significantly higher nitrate concentrations were measured in water from wells near septic tanks and confined animal facilities.

(9) Community structure indices for benthic macroinvertebrates varied greatly depending on the sampling techniques used. Potential biases resulting from the sampling technique can be reduced by using multiple sampling techniques.

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EVALUATION OF BIOMONITORING TECHNIQUES USED IN ASSESSING AGRICULTURAL NONPOINT SOURCE POLLUTION

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ABSTRACT: A biomonitoring program was established in the Beaver Creek Hydrologic Unit Area, West Tennessee in 1993, as part of an ongoing comprehensive water quality assessment program. A primary goal of the biomonitoring project was to evaluate and develop biomonitoring protocols appropriate for first- and second-order streams in the Beaver Creek watershed. The biomonitoring techniques examined included benthic community structure, colonization of multiplate samplers and plant debris packs, and decomposition of the plant material. Results varied greatly between biomonitoring techniques at the same sites. The multiplate samplers generally had the lowest number of organisms and the smallest values for diversity. The plant debris packs and the benthic community structure techniques both provided high numbers for abundance and diversity, but under different conditions. The plant debris packs had a greater total number for abundance in the open streams than the shaded streams, whereas the benthic community structure-technique had higher numbers for abundance in the shaded streams than the open streams. These trends demonstrate a bias in the sampling techniques that should be considered when designing a biomonitoring project. Biases could be minimized by applying more than one biological collection technique to the same site.

KEY TERMS: Biomonitoring; channelized streams; macroinvertebrate; agriculture.

INTRODUCTION

Increased concern for water quality has resulted in the escalated use of biomonitoring to determine the impact of non-point pollution derived from agricultural activities, a major contributor of pollution in the USA (USEPA, 1989; USEPA, 1992). Biomonitoring is a technique that utilizes the natural biological community in the ecosystem to assess the impact of environmental stress. If a pollution problem exists, one expects to find a corresponding adverse effect on the aquatic biological community. The ecosystem can also be modified by human-induced channelization of streams, as has been done in many of the riverine systems in the southeast and southwest. The hydrologic and geomorphic modifications resulting from channelization can affect the biological community as much as pollution can (Cooper, 1993). Thus, aquatic biomonitoring techniques that were developed for study of natural settings must be validated and adapted before they are applied to these modified aquatic systems. Several biomonitoring techniques were evaluated to determine their effectiveness for assessing water quality in a modified stream of West Tennessee.

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The site selected for study was the Beaver Creek Watershed (BCW), located in the West Tennessee section of the Mississippi embayment. It is an area intensively farmed with row crops of cotton, soybean, winter wheat and corn. Soils in the BCW are predominately alluvial silt deposits in the bottomlands and loess deposits in the uplands. Recently, (1989-present) conservation practices have been initiated by the farming community, in connection with the US Department of Agriculture, to reduce the impact of agricultural activities on water quality.

The main Beaver Creek channel and most of the tributaries were channelized in the early to mid-1900's to facilitate the drainage of land. Channelization has resulted in increased hydrologic responses such as rapidly rising water levels and increased stream velocity during rain events. In 1990, the U.S. Geological Survey initiated a water-quality monitoring research program. The program included collection and evaluation of water chemistry, stream hydrology and geomorphology data. Biomonitoring was added as a fourth parameter in early 1993 as part of this comprehensive project.

The modified hydrology and geomorphology of the BCW brought the applicability of established toxicity bioassessment protocols under question. It was unclear how the modified geomorphology and hydrology would affect the collection and interpretation of biomonitoring data with regard to chemical disturbance. Other ecological factors had to be considered as well, such as species distribution patterns in the different stream orders, geographic location of the watershed, seasonality and natural habitat. Thus, study were: (1) to evaluate and develop biomonitoring protocols appropriate for modified streams such as those in the BCW, (2) determine if the effects of chemical perturbation could be distinguished from hydrologic and geomorphic disturbances, and (3) characterize the general structure and function of a first-second order channelized stream in the BCW. This paper presents the results to the first objective and preliminary results of objective number 3.

METHODS AND MATERIALS

Macroinvertebrates ("organisms that are retained by a Standard #30 sieve [600 um mesh]") were selected as the indicator organisms because considerable research has demonstrated that they are excellent biological indicators of water quality (Klemm, *et. al.*, 1990; Plafkin, *et. al.*, 1989; Rosenberg and Resh, 1993). Benthic macroinvertebrates were collected with scoops and sieves during two reconnaissance trips through the basin. This was done to obtain a general census of the species distribution pattern in the basin. The difference in biological community structure between upstream and downstream sites indicated that if any correlation was to be made between macroinvertebrate response and chemical exposure, initial efforts should focus on a first and second order tributary. Therefore, the main monitoring sites were selected in a well characterized, channelized, first-second order tributary, draining a 300 hectare cotton and soybean field. The stream had intermittent riffles with perennial pools.

Sampling sites were chosen in this tributary to reflect unique riparian conditions. The riparian features represented were herbaceous bank vegetation and woody bank vegetation. The herbaceous and woody reaches of stream were each approximately 1 kilometer long and straight due to channelization. All the data reported herein were collected in the pools of the tributary because flow in the riffle sections reduced to a trickle during the dry season. General site characteristics of the herbaceous and woody riparian stream segments are shown in Table 1.

TABLE 1. Site characteristics observed during June through September. [HRV, herbaceous riparian vegetation; WRV, woody riparian vegetation; FFB, forest flood basin; WR, wetland reference site.

	Site			
Characteristics	HRV	WRV	FFB	WR
Lentic (ponded) water	perennial	perennial	perennial	perennial
Lotic (flowing) water	seasonal	seasonal	no	perennial
Temperature (°C) range	27-34	24-30	24-32	25-30
pH range	7.5-9.2	7.0-8.1	7.0-9.0	7.5-8.2
Width (meters) range	0.8-2.0	1.2-2.0	0.5-4.0	1.3-2.5
Depth (meters) range	0.1-0.5	0.1-0.7	.05-0.3	0.2-0.7
Periphyton (% coverage)	95	35	45	70
Woody debris in water	no	intermittent	yes	yes
Emergent aquatic plants	yes	no	no	yes

We were unsusccessful at locating a nonchannelized reference site with a similar hydrologic regime (flowing water during the wet season, and ponded water during the dry season) in the same watershed, so two reference sites were selected to represent these hydrologic conditions. The first reference site was in a flooded forest basin adjacent to the cotton field. This non-channelized site was annually inundated with 5 to 30 cm of ponded (lentic) water. The second reference site was located in another branch of Beaver Creek just downstream from a natural, hardwood, bottomland wetland and series of beaver ponds. This site was in a small third order stream with perennial flowing (lotic) water. The characteristics of the two non-channelized reference sites also are listed in Table 1.

Standard U.S. Environmental Protection Agency (EPA) biomonitoring protocols were reviewed and procedures were selected based on adaptability to the BCW system. Two conventional biomonitoring techniques, colonization of multiplate samplers and composition of the benthic macroinvertebrate community, were chosen from the EPA standard protocols (Klemm, *et. al.*, 1990; Plafkin, *et. al.*, 1989). The first procedure surveys the macroinvertebrates that colonize a Masonite, multiplate sampler placed in the water column and harvested after a set incubation time. This method has been standardized and comparisons are often made between studies in the literature (Rosenberg and Resh, 1993). The second method quantifies the macroinvertebrates that inhabit the top few inches of the stream bottom (LaPoint and Fairchild, 1992). Both methods are considered semi-quantitative because the number of organisms within a sampling area are counted. Three replicate samples per location (*e.g.*, three multiplate samplers) were collected on each sampling date.

A less conventional biomonitoring method was also examined. The technique used natural material, such as leaf and cotton plant debris, as a substrate for colonization. The application of leaf packs as an indicator of biological integrity has been explored by other investigators (Elder and Cairns, 1982; Paul *et al.*, 1978). The data gathered in those studies provided information on the function (*i.e.*, biogeochemical processes) of the waterway. The present study modified and adapted the leaf-pack methods to include structure (*e.g.*, quantify macroinvertebrate colonization) and function (*e.g.*, rate of plant debris decomposition). It was assumed leaf or cotton packs provided a better replication of substrates occurring in these streams for macroinvertebrate colonization than the artificial substrate-multiplate samplers. The leaf materials were collected in early winter from an adjacent bottomland forest, dried and sorted by genus. The composition of the leaves, dry weight (in grams), and percent of sample per bag were: oak 7.5 (50%), willow 2 (13%), hickory 1.5 (10%), sweet gum 1 (6.6%), silver maple 1 (6.6%), cottonwood 1 (6.6%) and dogwood 1 (6.6%). Cotton stems and bolls ("cotton debris") were also collected, dried, weighed, and placed in similar mesh bags. Cotton was selected because it is a primary crop in the Beaver Creek basin and large quantities of debris have been reported to wash into receiving streams after harvest during intense rain events.

The plant material was dried in an oven at 70°C until the decrease in dry weight stopped (about 1 week). Predetermined dry weights of plant material (15.0 g leaves, 35 g cotton) were placed in labelled 1.6 mm mesh bags of 10 by 10 cm size. The bags were closed and tied off to 2-ft stakes with nylon string. They were installed in late April 1993 at the same time as the multiplate samplers. Replicate samples were retrieved in early June, early July and early September. The contents of the bags were emptied into plastic tubs and the macroinvertebrates were sorted out, identified, quantified and preserved for identity confirmation. The plant material was gently cleaned with deionized water and dried in an oven at 70°C until dry. The resulting weight was recorded and the change in weight was calculated for each bag of plant material.

Biological samples were collected 6, 12 and 18 weeks after the substrates were placed in the field. The substrate samplers were enclosed with zip-lock plastic bags and placed on ice until the organisms could be harvested, taken to the laboratory, and preserved in 70% alcohol. The benthic sediment samples were collected using a long handled shovel with a special steel scoop, 8 inches across, 10 inches long and having 2 inch sides. The collected sediment was sifted in the field and the macroinvertebrates were preserved in 70% alcohol, brought to the laboratory and identified to Family. Surface-water samples were collected every 5 minutes during storm flow at the water-chemistry sampling station separating the herbaceous and woody riparian zones. These samples were analyzed for pesticides, nitrogen and sediment load. Preliminary results of the chemical analyses indicate that pesticides were not a problem during this study period. Additional field measurements were made every 2 to 3 weeks during the study period to monitor low-flow conditions of water depth, pH, temperature, and dissolved oxygen. Aquatic plant and animal species observations were also recorded at this time. Many of these organisms represent sentinel indicator species analogous to macroinvertebrates (Table 1).

Data observed or calculated for this study included abundance (total number of organisms), taxonomic richness (number of Families), mean diversity of taxon (Shannon-Weaver mean diversity, Klemm, *et al.*, 1990) and Beck's biotic index (Beck, 1955; Terrell and Perfetti, 1989; Resh and Jackson, 1993). The data are reported on a temporal and spatial comparison, and the average change in dry weight of replicate leaf and cotton debris packs are reported as a function of time. Standard deviations for the Beck biotic index are reported.

RESULTS

Community structure estimated by the abundance of macroinvertebrates at each location and sampling date is depicted by the height of the bars in Figure 1a-1c. Abundance is the total number of organisms counted per 3 replicate samples at each site. The overall abundance of organisms collected increased over the duration of the study (from 1259 in June, to 1498 in July and 1651 in September). The multiplate samplers generally had the lowest abundance of the four sampling methods tested. The cotton packs located in the herbaceous riparian vegetation streams always provided the greatest abundance on each sampling date. However, cotton packs located at the other sampling locations did not have the same trend. Benthic community sampling appeared to be the most consistent sampling technique with regard to abundance at each location or time.

TABLE 2. Richness, abundance, and mean diversity of sampling method. [HRV, herbaceous riparian vegetation; WRV, woody riparian vegetation; FFB, forest flood basin; WR, wetland reference site; MPS, multiplate sampler; BCC, benthic community composition; LP, leaf pack; CP, cotton pack; R, richness, number of Families; Ab, abundance, sum total; MD, mean diversity; ---, no data collected]

	MPS			BCC			LP			CP		
Site	R	Ab	MD	R	Ab	MD	R	Ab	MD	R	Ab	MD
June												
HRV	3	8	1.36	7	144	2.49	8	151	1.36	7	329	0.87
WRV	4	39	1.52	6	192	1.95	6	35	2.10	5	39	2.55
FFB		------			------		7	56	2.09	9	161	1.77
WR		------		5	105	1.73		------			------	
July												
HRV	5	195	1.75	10	145	3.73	9	194	2.50	9	258	2.57
WRV	5	45	1.92	8	216	2.46	5	116	1.58	6	100	2.34
FFB		------			------		8	50	2.35	8	57	2.41
WR		------		7	126	2.18		------			------	
Sept												
HRV	5	108	1.85	10	144	2.11	9	265	2.20	9	475	1.26
WRV	4	25	1.38	9	98	2.09	7	132	1.93	8	209	2.01
FFB		------			------		9	77	2.73	5	46	1.99
WR		------		8	108	2.69		------			------	
Avg*	4.5	70	1.63	8.3	151	2.47	7.3	149	1.95	7.3	235	1.93

**Averages calculated using HRV and WRV values only from all three sampling dates*

Richness is a measure of the number of different taxa (Families) found at each location and sampling date. The richness of each sampling technique during each sampling date is depicted in Figure 1 and tabulated in Table 2. The patterns shown in the bars of Figure 1 represent different taxa (Families) collected from each site. The height of each pattern represents the number of organisms within that taxon. In general, the benthic community sampling provided the greatest measure of richness compared to the three substrate-sampling techniques (multiplate samplers, leaf packs and cotton packs). Multiplate samplers consistently gathered the poorest taxon-richness of the 4 techniques at any particular site.

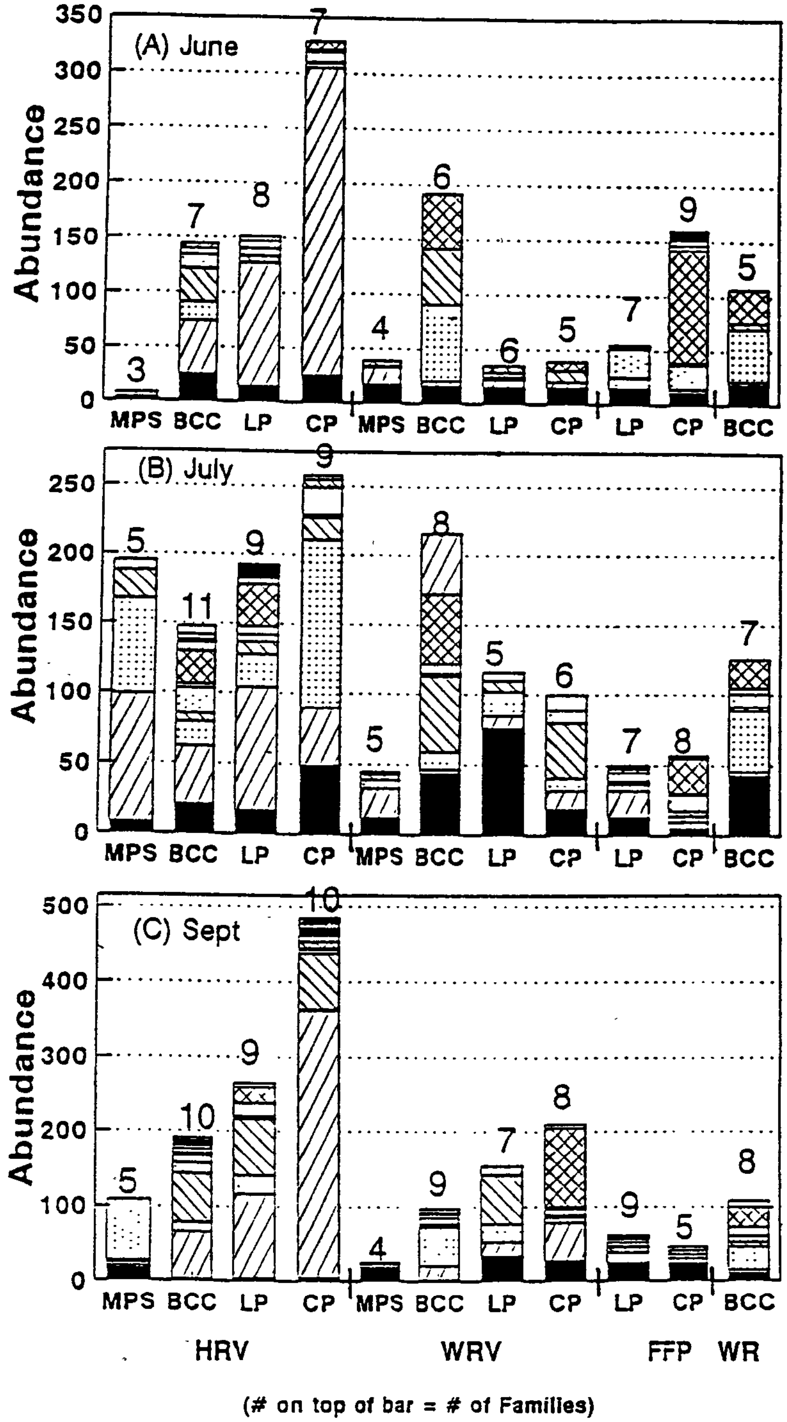

Figure 1. Richness and diversity as measured by sampling technique collected in (a) June (b) July and (c) September 1993. Patterns in the bars indicate abundance of different taxa. [HRV, herbaceous riparian vegetation; WRV, woody riparian vegetation; FFB, forest flood basin; WR, wetland reference site; MPS, multiplate sampler; BCC, benthic community composition; LP, leaf pack; CP, cotton pack]

Mean diversity is a measure of taxonomic diversity and distribution. The scale increases with increasing diversity and distribution of organisms between the taxa. The rationale behind this measure is that species diversity decreases with decreasing water quality. Quite frequently a particular Family dominated the percentage of organisms collected using a particular sampling technique or date.

For example, a high density of organisms was observed in the cotton packs collected from the herbaceous riparian stream in June (Fig. 1). Yet, only one species of snail represented almost 90% of the total number of organisms. This resulted in a low mean diversity (Table 2). Of the four sampling techniques tested, the benthic community grab samples provided the highest value for average mean diversity. Smaller values were associated with leaf packs and cotton packs, and the smallest values were provided by multiplate samplers (Table 2).

Beck's biotic index is a score that weighs the taxonomic richness of the sample and the tolerance of the taxa to pollution. Organisms are classified by three categories: sensitive, moderately sensitive and tolerant of pollution. The categories for Beck's biotic index were established from ecological surveys in Florida (Resh and Jackson, 1993). Points are given for sensitive and moderately sensitive taxa. A score of 10 or less is considered polluted water and warrants further attention to determine and remediate the problem (Terrell and Perfetti, 1989). With one exception, the multiplate samplers always had a very low biotic index score that indicated a polluted stream (Table 3). The benthic community grab samples consistently resulted in healthy scores. Thus, one could reach completely opposite conclusions from the same location in the BCW depending on the sampling technique used. The leaf pack and cotton packs each averaged moderately healthy biotic index scores over time and location. These data suggest that streams where physical habitat is lacking or constantly changing, or where predation is highly selective, biotic indices scores are tremendously influenced by the sampling technique used.

Table 3. Beck's biotic index for the four sampling techniques. [HRV, herbaceous riparian vegetation; WRV, woody riparian vegetation; FFB, forest flood basin; WR, wetland reference site; MPS, multiplate sampler; BCC, benthic community composition; LP, leaf pack; CP, cotton pack; ---, no data;] The bottom line [CV] is the coefficient of variation of Beck's biotic index for the four sampling techniques at the HRV and WRV sites.

Site	MPS	BCC	LP	CP
June				
HRV	0	71	25	18
WRV	2	122	14	11
FFB	---	---	40	37
WR	---	54	---	---
July				
HRV	89	59	78	44
WRV	10	75	35	57
FFB	---	---	32	24
WR	---	59	---	---
Sept				
HRV	10	45	104	94
WRV	8	64	67	123
FFB	---	---	47	18
WR	---	50	---	---
CV	1.6	0.31	0.54	0.76

A basic stream function was evaltuated by measuring the change in leaf weight over time at three of the sites. This was done to determine how rapidly plant material would decompose under stream conditions in the BCW. The results are shown in Figure 2. Both the leaf material and the cotton debris lost approximately 35% of their initial dry weight over the course of the study. The material in the forest flood basin location was slowest to lose weight. In fact, the leaves gained weight due to sediment embedding in the material. Sediment embedded in leaf material at the other sites as well, but the amount on the leaves in the forest flood basin was greatest. Forest flood plains have been noted for their ability to retain sediment (Mattraw and Elder, 1984). It has also been demonstrated that plant material will usually decompose faster under permanently inundated conditions (Elder and Cairns, 1982). The cotton debris was less vulnerable to embedding sediment material and lost much of its weight in the first 6 weeks. This quick weight loss could be explained by a quick loss in easily consumable food, followed by a slow decay in the less energy efficient fibers and waxes. Microscopic examination of the plant material revealed that fungal hyphae were more prominent on the cotton stalks than leaf material. The leaf material sustained macroinvertebrates classified as shredders (Cummins, 1973) more frequently than the cotton material. However, leaf material that was heavily embedded with sediment particles had noticeably fewer shredders than particle-free material.

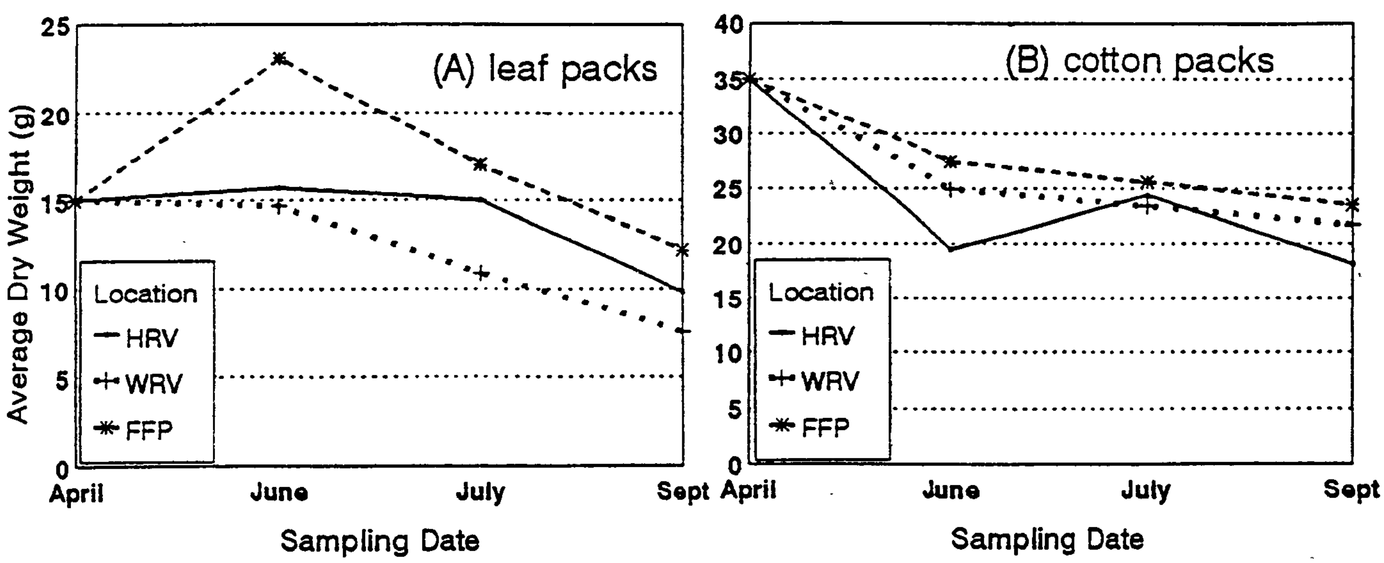

Figure 2. Average weight of the (A) forest leaves and (B) cotton debris as a function of time at three sites.

DISCUSSION AND CONCLUSION

There were distinct differences between the sampling methods used and the results of the biological assesment. The benthic community grab sampling technique provided the best scores for mean diversity and Beck's biotic index compared to the use of plant-material packs or artificial substrates. In fact, the results for multiplate samplers and benthic community grab samples were completely opposite. The multiplate samplers failed to attract many species even after an 18 weeks incubation period. Multiplate samplers did not provide a true picture of the taxonomic richness or abundance in this particular tributary.

The results support the assertion by LaPoint and Fairchild (1992) that benthic grab sampling provides the best representation of the benthic community composition and ecological health of the system. The consistent scores and low coefficient of variation (Table 3) resulting from the use of this method supports this hypothesis. Proper sampling of the benthos precludes many of the sampling biases associated with substrate colonization studies. Benthic grab sampling requires more time than artificial substrates, but the data appear to be more accurate.

The assumption behind substrate sampling is that it removes habitat as a variable and provides standardized surface between sites. The plant material packs, which served as more natural substrates, had greater macroinvertebrate taxonomic richness and biotic index scores than the multiplate substrates. Some of this could be explained by the fact that the leaf and cotton material served as a primary or secondary food source as well as a shelter for the organisms. The low mean diversity in several of the cotton- and leaf-pack samplers could be explained by the removal of predation pressure. For example, 329 macroinvertebrates were counted in the cotton packs collected in June from the herbaceous riparian location. Eighty-eight percent of these organisms were snails that could move about freely without fear of predation. Snail-eating beetles, common in that reach of the tributary, were excluded from the sample because they were unable to get through the mesh. Therefore, the leaf and cotton debris packs biased the outcome of the stream survey.

Channelizing a stream results in increased water velocity and a reduction in the debris retention-time, producing a flushing effect (Petersen and Petersen, 1991). Inspection of the tributary revealed that most of the plant debris moved a significant distance with each rain event. Thus, very little information about the rate of decomposition or the ability of the system to recycle this material has been determined. Retaining plant debris in packs provided some information on the function of the stream. Results confirm that many of the leaves in the forest leaf packs would decompose at a steady rate after an initial weight gain (Figure 2). The cotton debris however, appeared to be resistent to decomposition after the initial weight loss. This indicates that the stream could process and transform forest leaf-material faster than cotton crop debris.

In summary, based on the results of the different sampling strategies tested, multiplate samplers were found inadequate for biomonitoring a channelized stream with conditions similar to the BCW. The data derived from multiplate samplers were misleading. The plant material packs were valuable in determining the functions of the stream. However, they had some drawbacks when used to characterize stream community structure. Benthic grab sampling was the most effective sampling method tested in this study. Plant material packs and benthic grab sampling each have their advantage. They should be considered jointly when designing a biomonitoring project for channelized streams such as in the Beaver Creek Watershed.

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