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Stream Community Response to Road Construction Sediments

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PREFACE

Non-point sources of pollution are gaining increased attention throughout the United States. Many forms of pollution exist which do not fit the standard definition of point-source pollution, and thus they escaped the early thrust of research and abatement attempts in this country. Only recently have attempts intensified to define and study non-point sources of pollution. One such source is silt and sediment from the many types of earth-distributing activities, which include floods, construction, and land clearing.

This study of the effects of silt and sediment produced by road construction on aquatic biota was undertaken because road construction is widespread and frequent in the United States, and often is adjacent to natural or man-made waterways. Unlike many prior studies on siltation which focused upon physical or chemical effects, this one centers on biological effects and attempts to utilize the results in assessing the impact of road construction on aquatic faunal communities.

This publication summarizes a two-year study in the effectiveness of erosion-control measures, the effect of silt on macrobenthic and fish populations, and the ability of these populations to recover from stream degradation.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This study investigated how aquatic macrobenthic and fish communities responded to the effects of siltation from highway construction. Community response was evaluated on the basis of community diversity and changes in the numbers of organisms and/or species. An innovative computer program was used to calculate the diversity indices, using the sequential comparison technique.

The primary response observed among the macrobenthic and fish communities was a reduction both in numbers of species and in organisms downstream from the construction. Responses of the macrobenthic community ranged from a reduction of 23 percent in numbers of species and 66 percent in numbers of organisms (based upon single comparisons) to a 40 percent reduction of species and an 85 percent reduction of organisms (based upon several observations of the same population). Single comparisons of fish communities showed reductions of approximately 20 percent in numbers of species and 40 percent in numbers of organisms. The diversity index also demonstrated a statistically significant long-term change in aquatic community structure, but was less meaningful for indicating initial effects or making single comparisons.

Findings suggest that drift is a major physical response of macrobenthos to increased siltation, and may be a primary mechanism for repopulating stressed habitats. This is contrary to the commonly held hypothesis that smothering is a major effect, and should be tested in further investigations. Fishes apparently vacated areas of increased siltation, but were able to repopulate such areas within 12 months after construction activities stopped, depending upon the stream's cleansing ability. In this connection, stream flow rate and gradient are significant factors.

In general, this study found that erosion-control measures as they commonly are applied in highway construction are of limited value in preventing damages to stream communities, especially in the early construction stages. This indicates a need for more comprehensive and particularly more timely application of appropriate erosion-control techniques.

Key Words: non-point sources, pollution, road construction effects, macrobenthos and fishes, population response.

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INTRODUCTION

Earlier in this century, sedimentation was a concern because of the desire to preserve productive soils. Today, a new wave of concern is focused on the effects of waterborne sediment and its subsequent deposition in aquatic environments.

Highway and road construction, with its attendant erosion and siltation, represents one of the major sources of non-point water pollution in this country today. However, to date, there is little factual data available to evaluate the effects of such construction on the aquatic community or the effectiveness of methods currently used to control erosion.

The products of erosion of primary concern to the aquatic community are silts, sands, and clays. Silts and clays stay suspended in the water column for long periods and may, in many cases, reach estuaries before being deposited. Suspended in water, these products are non-poisonous. However, they are noxious to the aquatic environment by:

1. destroying bottom habitat through the blanketing or smothering action of sedimentation;
2. reducing food supply by limiting light penetration, thereby reducing the depth to which green plants can grow;
3. clogging the gills of higher aquatic organisms such as fish.

The James River, which drains approximately 10,000 square miles of Virginia, would have a soil loss of 200,000 tons per year if all its watershed lands were forested. Considering all other sources, including man's activities, 2 million tons per year would be a fair estimate of this loss [Brehmer and Biggs, unpublished].

In Scott Run, a tributary of the Potomac River, highway construction covered approximately 11 percent of the watershed from 1961 to 1964. Gross erosion from construction areas in that watershed was found to average 151 tons per acre per year. This is about 10 times the expected normal from cultivated land, 200 times that expected from grassland, and 2,000 times that expected from forest land in the Potomac River Basin [Guy and Ferguson, 1970]. A number of other researchers have identified or commented on these problems [King and Ball, 1964; Reed, 1971; Shirley, 1970; and Gammon, 1970] or have proposed methods for protecting aquatic environments [Cairns, 1968 and Gammon, 1970].

The first objective of this study was to delineate the effects of siltation on the aquatic macrobenthic and fish communities by evaluating their response to accelerated siltation from highway construction. Community response was projected on the basis of numbers and diversity of organisms in clean stream areas above the source of siltation as compared to the affected downstream areas. Baseline data (control data) were collected prior to land disturbance. Data collecting continued throughout the construction (land disturbing) phase until some degree of recovery in the community occurred.

Collecting timing was of critical importance. Not all sites afforded the proper starting times with regard to construction or showed recovery in the time frame of this study. Faunal drift and repopulation of downstream habitats cleansed of sediment by storm events were investigated as types of responses exhibited by the macrobenthic community.

A second objective of the study was to provide a suggested method for evaluating the long-term effects of siltation on aquatic communities through the use of bottom organisms as indicators of pollution levels. The study is intended as a numerical system to be centered on living organisms, with their responses recorded in number values.

Cairns and Dickson [1971], in establishing the use of aquatic bottom-dwelling organisms as a water-quality monitoring system for waste discharges, proposed to demonstrate:

1. That biological data are as easily assessed as chemical and physical data;
2. That biological data can be presented numerically;
3. That existing biological concepts, properly applied, can furnish information not now provided by other systems of pollution detection;
4. That the collection and evaluation of biological data are within the capabilities of industrial pollution control groups.

The methods employed in this study to evaluate the responses of the macrobenthic and fish communities meet all of the criteria established by Cairns and Dickson [1971]. A review of the literature showed this study to be the first to utilize diversity and numbers of organisms to evaluate the effects of siltation from highway and road construction.

MATERIALS AND METHODS

I. Benthic Data

Macrobenthic fauna were collected in four streams ranging in size from 1 to 15 meters in width and 0.2 to 3 meters in depth. Adjacent construction was in varying stages, ranging from early phases to late phases or completion.

Upstream and downstream collection sites were carefully selected to insure comparable benthic communities. The upstream sites were selected above any possible effect of siltation from the construction activities or other possible sources. The downstream collection sites were chosen immediately below the introduction of construction sediment and within a habitat comparable to the upstream site. In one stream, an additional site was placed some five miles downstream to give some indication of the length of stream affected by increased silt loads.

Each sampling station consisted of a stream reach approximately 35 meters in length. The selected segment represented a broad range of habitats, including typical riffle-run-pool complexes and a variety of substrates such as sand, rubble, gravel, rock, and mud. Each site included some bank cover and overhanging vegetation.

The samples were collected with a D-frame dip net with a bag 46 cm long, 20 cm wide, and 25 cm deep. Pools were sampled by collecting the organic detritus and bottom muck with the frame net. Riffles were sampled by placing the net downstream and dislodging the organisms by kicking the rocks and stirring the bottom sediment.

Thirty minutes were spent at each sampling station with approximately equal effort spent on each type of habitat represented. Samples were fixed in formalin in the field and transferred to the laboratory, where they were sorted and preserved in 70 percent isopropanol.

Artificial substrates consisting of round, wire mesh baskets, 15.2 cm high by 25.5 cm in diameter, were placed in Wilderness Run located in Orange and Spotsylvania Counties. The artificial substrates were filled with natural substrates (rocks, leaves, etc.) from the stream bed and anchored to steel rods driven into the streambed. Five baskets were placed in comparable habitats both upstream and downstream from the construction site. Separation and preservation of the organisms from the artificial substrates was similar to that described for the D-frame dip net samples.

The aquatic macrobenthic fauna collected was classified to genus and, where possible, to species, using keys to Pennak [1953], Usinger [1956], and Ward and Whipple [1959]. The United States Environmental Protection Agency's identification manuals 1 through 11 on the "Biota of Freshwater Ecosystems" were consulted for specialized problems, particularly the *Astacidae* [Burch, 1973; Ferris et al., 1973; Williams, 1972; Klem, 1972; Hobbs, 1972; Kenk, 1972; Cressy, 1972; Burch, 1972; Foster, 1972, and Holsinger, 1972]. Often distinct differences were evident among several individuals, but these could not be positively identified as to species. The sequential comparison technique requires separation only to such a level, and thus it was felt that valid comparisons could be made.

II. Fish Data

Fish collections were made in similar habitats to those described for benthic organisms. Electrofishing using a 230-volt portable alternator and hand-held electrodes was done on an equal-time (30 minutes), equal-effort basis at each site. Block nets prevented fish from escaping the sampling area. Fishes were fixed in 10 percent formalin in the field and preserved in 40 percent isopropanol in the laboratory. Identifications were verified with the aid of Blair et al. [1971].

III. Data Treatment

The sequential comparison technique [Cairns and Dickson, 1971] was utilized to assess biological effects of siltation in a numerical fashion. In addition, Chi-square values ($P = <.05$) were determined for numbers of species as a measure of community response.

IV. Results

Benthic samples were collected both upstream and downstream from ongoing construction in four widely separated streams varying in size from very small to moderately large. Streams sampled for benthic organisms were:

1. Unnamed tributary to Totier Creek (Albermarle County);

2. Wilderness Run (Spotsylvania County);
3. Wolf Creek (Bland County); and
4. Unnamed tributary to North Anna River (Orange County).

V. Macrobenthos

Site descriptions and data collected are as follows:

A. Unnamed Tributary of Totier Creek

Totier Creek is located in Albermarle County, Virginia, and is a tributary of the Hardware River, which is part of the James River basin. Collection sites were located adjacent to U.S. Route 20, south of Charlottesville, Virginia *(Figure 1).*

The stream at the downstream collection site (Station 2) was 0.5-1.5 meters wide, approximately 0.5 meters deep, and had a substrate of sand, rubble, and bedrock. The stream had moderate flow, slow to moderate current, and vegetation consisting of widely scattered rooted aquatic plants and filamentous green algae. Shorelines were open pasture and partly wooded with some overhanging vegetation.

At the upstream collection site (Station 1), the stream was 0.5-1.0 meters wide and approximately 0.5 meters deep. The substate was sand, gravel, and rubble. Stream vegetation consisted of some rooted aquatic plants and filamentous green algae. The flow and current were moderate. Shorelines were interspersed with fields and forested areas.

Construction had entered its final stages at the time of sampling, with a box culvert having been placed in the stream and the roadway widened throughout the watershed. Much of the roadway was a new location of some embankments reaching the stream proper. A small section of the stream just upstream from the box culvert appear to have been channelized. The control station (Station 1) was located well above the effects of the channel relocation.

On January 30, 1974, a total of 273 organisms representing 23 species was collected at the upstream station on the unnamed tributary. In contrast, at the downstream station (Station 2), 105 organisms representing 15 species were collected *(Table 1).* Based upon these figures, there were 34 percent fewer species and 62 percent fewer numbers of macrobenthic organisms at the downstream site *(Tables 2* and *3).* The difference in number of organisms at the two sites was deemed significant (χ = .05).

B. Wilderness Run

Wilderness Run, a tributary of the Rappahannock River, was sampled near State Route 3 at the Orange-Spotsylvania County line *(Figure 2).* Fish as well as macrobenthic organisms were collected. Both upstream and downstream stations were bordered by pasture on one bank and woods on the other. The streambed was sand, gravel, and rubble, with some rooted aquatic plants also present. Overhanging vegetation consisting of tree roots and grasses was present along a portion of the streambank. Stream depth ranged from 0.5 to 1.0 meters and width from 5 to 8 meters. Current was slow to moderate.

Construction at this site involved the addition of a parallel bridge which was nearly complete at the time of the initial collection. Traffic had been diverted to the new bridge and only final seeding and cleanup remained to be accomplished.

The upstream and downstream stations at Wilderness Run were the most equal in terms of habitat type of all the sites studied, based upon riffle to pool ratio, substrate type, depth and flow characteristics, and associated vegetation.

On January 24, 1974, a total of 606 macrobenthic organisms representing 24 species was collected at the upstream station. The downstream station produced 233 benthic animals from 21 species, or 12 percent fewer in terms of species and 62 percent fewer in terms of numbers *(Tables 1* through *3).* Five artificial substrates consisting of natural streambed material were placed upstream and five downstream from the construction site on March 1, 1974. Twenty-eight days later, March 29, a basket was removed from each station for analysis of macrobenthic organisms. Thereafter, baskets were removed at weekly intervals. Due to vandalism, only four complete sets of data were available for comparison. The results were as follows:

	Upstream		Downstream	
Date	Number of Species	Number of Species	Number of Species	Number of Species
March 28	16	213	14	257
April 7	18	221	14	73
April 13	18	167	14	310
April 27	18	485	14	669

Artificial substrate populations exhibited a considerable difference from the normal stream populations in that the numbers of individuals at the downstream station exceeded those of the upstream station in three of the four substrate collections. While the study is inconclusive, a possible explanation may be found in faunal drift as a response to the blanketing action of sediments. Location of substrates above the stream bottom permitted a constant flushing of sediment by the normal current, and could have offered a haven for drifting insects. A review of weather data showed that a severe storm occurred in the Wilderness Run area during the week of April 7, 1974. This may explain the unusual results noted in the April 7 sample, where the number of animals was greater at the upstream site than at the lower. It is possible that, in response to highly turbid waters and rapid currents, many of the benthos were flushed out of the downstream substrate. The upstream substrate, while subjected to the same currents, would have been exposed to less turbid waters due to its location upstream from the construction site.

C. Wolf Creek

Wolf Creek is a tributary to the New River and parallels the construction of Interstate Route 77 through a portion of Bland County *(Figures 3* and *4).* Benthic fauna were collected from five stations: Stations 4 and 5, approximately five miles below the construction; Station 3, immediately below the construction; Station 2, which acted as intermediary within the project limits, and Station 1, which was above the influence of all construction activity. Wolf Creek is a fast-flowing stream with moderately high flow. The stream is 10-15 meters wide and 0.5-4.0 meters in depth. The substrate consisted of medium to large rocks, rubble, sand, and bedrock. The shoreline ranged from heavily wooded to open fields.

Wolf Creek is channelized in two sections and was under considerable influence from the ongoing construction activities of Interstate Route 77, a major highway project. Wolf Creek represented the greatest number of variable factors with regard to a comparison experiment.

The initial collection of benthic fauna was made November 15, 1973. At Station 1 (upstream) a total of 541 benthic organisms representing 20 species was collected, while at Station 3 immediately downstream from the construction only 190 organisms from 15 species were taken, resulting in a 65 percent and 25 percent reduction respectively *(Tables 2 through 4).* Approximately five miles downstream from the construction site, benthic fauna was reduced by 54 percent in numbers (246) and 21 percent in species (17). Like the Totier Creek tributary and Wilderness Run, the difference between organisms at the stations was significant but differences in species numbers were not *(Tables 2* and *3).*

A second collection was made on April 9, 1974, while the project was still in a very active stage. At the control station, 28 species were represented in a total of 1,088 organisms. At Station 4, approximately five miles downstream from the project, 22 species and a total of 288 organisms were collected *(Tables 2* and *3).* While the diversity showed some improvement over the November collection (22 species vs. 15 species), the total number of benthic organisms declined further to 74 percent fewer animals than the November control. The downstream macrobenthic community continued to reflect the stress of increased silt loads for the construction, as evidenced by significant differences in numbers of organisms *(Table 2).*

D. Unnamed Tributary of the North Anna River

A small tributary of the North Anna River (York River drainage) was sampled for approximately two years prior to the start of highway construction. The stream is located north of Gordonsville, Virginia, and is crossed by U.S. Route 15 *(Figure 5).* At the downstream collection site (Station 7), the stream was 0.5-2 meters wide and 0.5-1 meters in depth. The streambed consisted of sand, rubble, and small rocks. Vegetation in the form of rooted aquatic plants and overhanging grasses was present. The shoreline consisted of open pasture on both sides of the stream. The control station (Station 1) was 0.5-2 meters wide and 0.5 to one meter in depth and had a substrate of sand, rock, rubble, and some bedrock. The shoreline was wooded on both sides with open pasture in the extreme upstream areas. Flow was moderate with moderate to fast currents.

A box culvert was replaced under the existing highway and a parallel two-lane roadway had been constructed with an extension of the box culvert under this roadway. In-stream silt basins and straw bale barriers at the toe of the fill were utilized to reduce siltation of the steam and downstream pond.

Benthic species and numbers of animals showed extensive changes below the construction site during the construction period. Prior to the start of construction, a well-diversified macrobenthic community existed, as evidenced by the 394 individuals and 30 species collected upstream and the 539 individuals and 29 species collected downstream on March 15, 1973 *(Table 5).* Approximately 30 days after the completion of all construction activities, the downstream numbers had been reduced to 18 species and 131 individuals, or a reduction of 40 percent and 86 percent, respectively *(Table 5).*

After a recovery period of approximately four months, during which a number of heavy late winter and early spring rains flushed part of the sediments from the riffle areas, 31 species and 438 individuals were collected. The number of species had returned to levels noted prior to construction, but the total number of individuals remained at 50 percent of the original population sample *(Table 5).*

The March 1974 downstream collection (Station 2) compared favorably with the upstream collection (Station 1) *(Table 5).* However, the total numbers of individuals were consistently lower in the upstream habitat. This may be due to differences in the particular habitats, and illustrates that comparative sampling should be conducted throughout the duration of construction rather than as a single evaluation. Further, it illustrates the desirability of comparing the habitat productivity prior to and after construction to enhance the reliability of the data.

VI. Fish Sampling Sites

Fishes were sampled at six different sites with only one, Wilderness Run, in common with macrobenthic studies. Collection of fishes were made in the following: (1) Back Creek, Bath County; (2) David Creek, Appomattox County; (3) Deep Run Creek, Stafford County; (4) Wilderness Run, Orange and Spotsylvania Counties; (5) Redbud Creek, Albermarle County, and (6) Foster Branch, Albermarle County.

A. Back Creek

Back Creek is a tributary of the Jackson River in the James River drainage. It flows through a high valley in western Virginia and was subjected to extensive channelization following Hurricane Agnes in 1969. The stream ranged from 5-15 meters wide and 0.5-2.5 meters deep. Flow was low to high and current slow to swift depending upon season. Most of the streambanks were open pastureland, with occasional trees and brush present. Some rooted aquatic plants and filamentous green algae occurred in the stream. the substrate was sand, gravel, large rubble, and bedrock.

Baseline samples (Station 1) were taken from the upper region of Back Creek on June 14, 1973 near the County Route 600 bridge crossing, prior to any road construction activity *(Figure 6)*. A total of 229 fishes representing 21 species was captured. A second collection was made at the site May 24, 1974, during a period of active bridge replacement construction. At that time 165 individuals from 15 species were collected, representing a reduction of 44.8 percent in numbers and 28.6 percent in species *(Table 7)*.

B. David Creek

David Creek, a tributary of the James River in Appomattox County, was studied both for effects of and recovery from siltation. The stream at the downstream site (Station 2) was 6-8 meters wide and 0.5-1.0 meters deep *(Figure 7)*. One shore was wooded, the other was open pasture. The streambed consisted of sand, gravel, rubble, and some bedrock. Flow was slow to moderate and current moderate to fast. The upstream control site (Station 1) was 2-4 meters wide and 0.5-1.5 meters deep. Streambed and flow characteristics were similar to the downstream station. The shoreline was wooded on both sides.

Construction of a new bridge was in the early stages, with bridge piers and the bridge surface erected. Erosion controls consisted of hay bales placed in the stream during pier excavation and a small temporary sediment basin immediately downstream from the construction site.

Fish in David Creek were sampled on May 21, 1974. There was a reduction of 48 percent in numbers of individuals (72 vs. 141) and 31 percent in species (11 vs. 16) at the downstream site as compared to the control station *(Table 8).* These sites were sampled again March 11, 1975 to evaluate the recovery of fish populations following construction. At that time, the downstream station (Station 2) exhibited a dramatic recovery, yielding 360 individuals from 20 species, while the upstream control station was similar to previous levels recorded with 144 individuals and 15 species *(Table 9).*

C. Deep Run Creek

Deep Run Creek, a tributary of the Rappahannock River, was also examined for effects on recovery of fish populations from road construction siltation. The upstream site (Station 1) was 2-4 meters wide and 0.5-1.5 meters deep. Shorelines were wooded; flow and current were low to moderate *(Figure 8).* The streambed was composed of sand and gravel. The downstream station (Station 2) was similar in characteristics to Station 1 except that a rock sediment dam was immediately upstream. Construction of a new bridge at this site was nearly completed. Embankments were seeded and covered with straw.

The initial collection at Deep Run Creek showed a reduction of 34.4 percent in numbers of fishes and 11 percent in species at the downstream station *(Table 6).* Fourteen months later, the downstream area was only 22 percent lower in individuals and 5.9 percent lower in species than the control, indicating some recovery *(Table 10).* Both numbers of species and individuals collected were much greater at both stations during the second sampling period.

D. Wilderness Run

This tributary of the Rappahannock River was sampled for fishes as well as macrobenthic organisms. On January 24, 1974, a total of 113 fishes from 12 species was collected at the upstream station (Station 1) on Wilderness Run, while at the downstream station (Station 2) 73 individuals representing 7 species were taken *(Figure 2, Table 11).* These data indicate that a reduction of 35 percent in diversity of 42 percent in density of fishes occurred in the area under the influence of siltation fromthe construction project. A second collection of fishes was made at Wilderness Run on January 28, 1975, about 12 months after the initial sampling. At this time, the construction effects had stabilized and the soil losses were minimal. Only a small sample of fishes was obtained due to high water, but upstream and downstream data were very similar

(Table 12). At Station 1 (control) 8 species and 57 individuals were collected, while at Station 2 (downstream), 7 species and 57 individuals were taken.

E. Redbud Creek

Redbud Creek is a small tributary of the Rivanna River in the James River drainage *(Figure 9).* The control (Station 1) ranged in width from 1-2.5 meters in width and 0.5-1 meter in depth. The streambed consisted of gravel, sand, and rubble, with little aquatic vegetation present. The shoreline was wooded; flow was moderate and the current slow to moderate. The downstream station ranged from 1.5-2.5 meters in width and 0.5-1 meter in depth. The substrate was gravel, sand, mud, and bedrock. Flow was moderate; the current was slow to moderate. The shoreline was open pasture or partially wooded.

A collection was made on January 2, 1975, when active construction of a box culvert was occurring. There was a 42 percent reduction in the number of fishes downstream (159 vs. 273 individuals) but no difference in number of species *(Table 13).*

F. Foster Branch

A second small tributary of the Rivanna River also was sampled in January 1975 *(Figure 9).* The stream was larger than Redbud Creek, and both upstream and downstream stations were quite similar in habitat characteristics. The streambed consisted of gravel, rubble, and sand; flow and current were moderate, and the streambanks were wooded.

Construction at this site consisted of placement of two box culverts, extensive roadway modification and fill, and limited erosion control measures, principally in the form of loose straw on slopes and a few straw bales near the stream itself. There were extensive areas of bare soil adjacent to Foster Branch.

A total of 161 individuals from 12 species were collected at the upstream station (Station 1), while at the downstream station (Station 2), 109 individuals representing 11 species were taken *(Table 14).* These data represent a 8.3 percent reduction in species and a 32.3 percent reduction in numbers of fishes at the downstream site.

DISCUSSION

The results of these studies on fish and macrobenthic populations have shown that a reduction in both diversity (number of species) and density (number of organisms) occurs when these organisms are exposed to increased siltation and sedimentation associated with highway and road construction. *Tables 2* and *3* and *15* through *17* summarize the results from the study. Reductions in numbers of organisms downstream were usually statistically significant, whereas reductions in numbers of species were not significant. The small sample size for numbers of species reduced the power of the test, but by observation a trend toward reduction of numbers of species downstream from construction is evident.

Singular comparisons of upstream and downstream communities were useful and often indicated that effects had occurred, but the value of multiple observations during the course of construction activity was demonstrated in the study of the tributary to the North Anna River. Comparisons of benthic organisms were made on the basis of upstream versus downstream stations at the individual station compared to its baseline prior to the start of the construction *(Figures 10* and *11).* Both numbers of organisms and species remained fairly constant at the upstream stations, yet wide variations in these parameters occurred downstream. Single observations during most of the study period indicated a reduction in density and diversity downstream. Should an investigation have selected March 15, 1974 as a single sampling date, however, the results would indicate little or no population response to the effects of siltation *(Figures 10* and *11).* Such a technique is not as easily applied to the study of fish populations because they exist in fewer numbers than macrobenthic organisms and may be depleted or completely eliminated by sampling, particularly in small streams.

The peaks in *Figures 10* and *11* on March 15, 1974 represent recovery of macrobenthic populations following cessation of stream construction activities in late November, 1973. This, combined with the sediment-flushing action of late winter and springs rains, produced a recovery of approximately 50 percent of the original population. The December 1974 declines were due to subsequent channelization of the study area and were not directly related to road construction activity. Had this channelization not occurred, the benthic population should have recovered to near its original levels.

Diversity indices based upon the Sequential Comparison index proposed by Cairns and Dickson [1971] and modified by Thomas and Simmons [unpublished] did not produce the clear results anticipated. No significant changes as a result of the effects of siltation could be projected with the index in comparisons of upstream and downstream stations. Its value appears to lie in the prediction of long-term degradation of stream quality rather than as a tool to evaluate short-term or single comparisons of upstream and downstream effects of siltation. For example, the diversity index for macrobenthic organisms at Wilderness Run increased from 0.76 to 0.82 during the study period, while species and organisms dropped by 12.5 percent and 61.5 percent, respectively. Diversity indices at the downstream station (Station 2) of the North Anna River tributary, where previously described analysis of community structure indicated dramatic changes in both density and richness of the fauna especially, follows the curve for declines in numbers of species and organisms *Figures 10* and *11).* While the initial effects of siltation at the downstream station were not statistically significant, the later diversities (after July 1973) were significant at the 95 percent confidence level.

Diversity indices of fish populations appear more consistent, with the upstream stations having higher values than downstream except in one case (Deep Run Creek, *Table 17).* These data were based upon single sample comparisons and relatively low numbers of organisms, which lessens the effectiveness of the Sequential Comparison technique. Nonetheless, it appears both from actual numbers of species and organisms that such a technique does have some value. Recovery data are less clear and probably more indicative of the limitations of single comparisons. Several observations on the same population have proved to be of greater value in evaluating the effects of siltation on the community structure than have the more limited evaluations based on upstream and downstream comparisons.

CONCLUSIONS

1. The analysis of the fish and macrobenthic community response to the effects of increased siltation has demonstrated that both numbers and kinds of organisms are reduced. The richness of fauna (numbers of species) was reduced by an average of 25 percent in macrobenthic organisms and 20 percent in fishes. Density (numbers of organisms) was reduced in average of 66 percent in benthic fauna and 40 percent in fishes. The average for macrobenthic fauna increased to 40 percent and 85 percent in richness and density, respectively, when several observations were made on the same population througout a period of highway construction.

2. The diversity indices produced variable results on initial or single comparisons of upstream and downstream stations. The initial fluctuations of the diversity index indicate that the community response to siltation was across the entire population rather than confined to a few select species. This response by the community, as measured by the index, probably resulted from the fact that siltation is a natural phenomenon and aquatic communities have developed a significant adaptation to it. This is especially true in the Piedmont and Coastal Plain Regions, where aquatic organisms are often subjected to heavy silt loads under natural conditions.

3. The diversity index demonstrated significant differences at the 95 percent confidence level when several observations were made on the same macrobenthic population over a given period of time on a construction event. Investigation at the North Anna tributary demonstrated these long-term effects to be a decline of approximately 20 percent in community diversity over the life of the highway construction. The index was not statistically significant when evaluating the initial responses of the North Anna macrobenthic community.

4. Single comparisons of upstream and downstream effects lacked consistency for projecting aquatic community responses to siltation. The diversity index, the number of species and organisms, was more accurately interpreted when several observations were made on the same population throughout the construction.

5. Drift appears to be a major physical response by the macrobenthic organisms to increased siltation. This is contrary to the commonly held

hypothesis that smothering is a major factor. Drifting organisms repopulated clean substrates in affected stream reaches at a faster rate than substrates in similar but unaffected areas. The drift rate in turbid or silt-laden waters was estimated at 10 times greater than in clear waters. However, no quanititative measure of drift rate was included in this study.

6. Both the fish and macrobenthic communities recover rapidly after the source of the siltation is controlled. Recovery is fostered by the flushing of sediments from riffle areas and the settling of silt in pools permitting repopulation by drifing benthic organism and fishes from unaffected areas. Flow rate and stream gradient are significant factors in this connection.

7. Erosion-control measures were of limited value in the prevention of siltation from highway construction, especially in the early stages. More general and particularly more timely application of one or more erosion-control techniques are recommended.

While this investigation has demonstrated the response of the fish and macrobenthic communities to siltation, it has not fully explored the recovery aspects of the communities or the extent of the stream reach affected. The hypothesis that drift is a major mechanism for repopulation of macrobenthic fauna in stressed habitats clearly needs to be tested in further investigations.

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TABLES

TABLE 1

Benthic Fauna (Species and Numbers of Organisms) Contained in Unnamed Tributary to Totier Creek and Wilderness Run

	Species	**Numbers of Organisms**					
		Tributary to Totier Creek		Wilderness Run			
				Dip Net		Rocks	
		1/30/74		1/24/74		5/3/74	
		Sta. 1	Sta. 2	Sta. 1	Sta. 2	Sta. 1	Sta. 2
Phylum:	**Annelida**	14	5	5	5		
Phylum:	**Arthropoda**						
Class:	Crustacea						
Order:	Amphipoda						
Family:	Gammaridae						
	Crangonyx sp.	26					
Order:	Decapoda						
Family:	Astacidae						
	Cambarus sp.	41	20				
	Cambarus sp.			4	3		
Order:	Isopoda						
Suborder:	Epicaridea						
Family:	Assellidae						
	Asellus sp.	7					
Class:	Insecta						
Order:	Coleoptera						
Family:	Dytiscidae						
	Colpius sp.	4	1	3			
Family:	Elmidae						
	Simsonia sp.			1	1		
	Stenelmis sp.	2				1	
Family:	Gyrinidae						
	Dineutus sp.				1		
Family:	Psephenadae						
	Psephenus sp.			2			
Order:	Diptera						
Suborder:	Orthorrhapha						
Family:	Rhagionidae						
	Atherix sp.	23				4	

TABLE 1 (continued)

	Species	**Numbers of Organisms**					
		Tributary to Totier Creek		Wilderness Run			
				Dip Net		Rocks	
		1/30/74		1/24/74		5/3/74	
		Sta. 1	Sta. 2	Sta. 1	Sta. 2	Sta. 1	Sta. 2
Family:	Simuliidae						
	Simulium sp. A	28		257	56	4	1
	Simulium sp. B			2	2	69	
	Simulium sp. C	(specimens observed but not collected)					
Family:	Tabanidae						
	Tabanus sp.	2					
Family:	Tendipedidae						
	Calopsectra sp.					152	210
	Chironomus sp.	5	17	15	20	72	4
Family:	Tipulidae					2	
	Anthocha sp.					2	
	Tipula sp.	15	13	16	14		
Order:	Ephemeroptera						
Family:	Baetidae						
	Ephemerella sp.			8	6	10	3
	Siphloplecton sp.	12	9	34	6		
Family:	Heptageniidae						
	Iron sp.					3	
Order:	Ephemeroptera						
	Neoephemera sp.	3	9	33	9	2	1
Order:	Odonata						
Suborder:	Anisoptera						
	Boyeria sp.	2		10	6		
	Gomphus sp.	1		3	2		
	Hagenius sp.			1			
Suborder:	Zygoptera						
	Agrion sp.	7	4				
Order:	Plecoptera						
Subfamily:	Acroneuriinae						
	Acroneuria sp.	1	3	26	13		
	Isoperla sp.	1	8	31	12	2	
Order:	Trichoptera						
	Hydropsyche sp.			64	58	19	3
	Macroneum sp.	33	7				
	Pycnopsyche sp.					3	
	Wormaldia sp.			5	6	22	39
	Glossosoma sp.				3		
	Rhyacophila sp. A	25	3	2			
	Rhyacophila sp. B.	13	1				

TABLE 1 (continued)

	Species	Numbers of Organisms					
		Tributary to Totier Creek		Wilderness Run			
				Dip Net		Rocks	
		1/30/74		1/24/74		5/3/74	
		Sta. 1	Sta. 2	Sta. 1	Sta. 2	Sta. 1	Sta. 2
Phylum:	**Mollusca**						
Class:	Gastropoda						
Order:	Ctenobrachiata						
	Campeloma sp.	6	1	14	6		
Order:	Pulmonata						
	Helisoma sp.			2			
Class:	Pelecypoda						
Order:	Heterodonta						
	Sphaerium sp.			54	2		

Tentative classification.

TABLE 2
Community Structure—Percent Change in Numbers Of Macrobenthic Organisms as a Result of Increased Siltation

Site	Number of Organisms Upstream	Downstream	Percent Change	χ^2
Tributary to Totier Creek	273	105	61.5%	16.09*
Wilderness Run	606	233	61.5%	165.82*
Wolf Creek (1)	541	190	65.6%	168.53*
Wolf Creek (2)	1088	288	73.5%	241.11*

Average Decrease in Numbers of Organisms—66%
*Significant at $<.05$.

TABLE 3
Community Structure—Percent Change in Numbers Of Macrobenthic Species as a Result of Increased Siltation

Site	Number of Species Upstream	Downstream	Percent Change	χ^2
Tributary to Totier Creek	23	15	34.3%	1.68NS
Wilderness Run	24	21	12.5%	0.20NS
Wolf Creek (1)	20	15	25.0%	0.71NS
Wolf Creek (2)	28	22	21.4%	0.72NS

Average Decrease in Numbers of Species—23%.
NS indicates not significant; $\chi = .05$.

TABLE 4
Benthic Fauna (Species and Numbers of Organisms) from Wolf Creek

	Species	**Numbers of Organisms**					
		11/15/73			4/9/74		
		Sta. 1	Sta. 3	Sta. 5	Sta. 1	Sta. 3	Sta. 4
Phylum:	**Annelida**	1	4		8	1	48
Phylum:	**Arthropoda**						
Class:	Crustacea						
Order:	Decapoda						
	Cambarus sp.	11	1		9		8
	Orconectes sp.			5			
Class:	Insecta						
Order:	Coleoptera						
	Stenelmis sp.	6	1	12	68		1
Family:	Psephenidea						
	Psephenus sp.	3	1	8	60		6
Order:	Diptera						
	Simulium sp.				1		
	Chironomus sp.		1	5	16		5
	Antocha sp.	8	4		19		2
	Tipula sp.			3	3		1
Order:	Ephemeroptera						
	Ephemerella sp.				17	1	18
	Siphloplecton sp.	9	5	1	16	5	
	Stenonema sp.	11	25	38	16	34	9
	Neoephemera sp.				54		
Order:	Hemiptera						
	Hydrophilus sp.			1	1		
Order:	Megaloptera						
	Corydalus sp.	3	3	6	8		3
Order:	Odonata						
	Boyeria sp.	2	1	10	1		1
	Gomphus sp.	1					1
	Agrion sp.	1	12	12	1		2
Order:	Plecoptera						
	Taeniopteryx sp.	2		11			
	Paragnetina sp.	5	7	2	13		1
	Neophas-ganophera sp.				6	1	
	Isoperia sp.				15	6	

TABLE 4 (continued)

	Species	Numbers of Organisms					
		11/15/73			4/9/74		
		Sta. 1	Sta. 3	Sta. 5	Sta. 1	Sta. 3	Sta.4
Order:	Trichoptera						
	Branchycentrus sp.	2			14		1
	Helicopsyche sp.	55			57		2
	Hydropsyche sp.		68	6	46		1
	Goera sp.	1			44		
	Pycnopsyche sp.				4	1	
	Psilotreta sp.	35			173		2
	Glossosoma sp.	17					1
	Rhyacophila sp.			5	1		1
Phylum:	**Mollusca**						
Class:	Gastropoda						
Order:	Ctenobranchiata						
	Campeloma sp.	360	54	114	407		170
Order:	Pulmonata						
	Helisoma sp.		3	8			
Class:	Pelecypoda						
Order:	Heterodonta						
	Sphaerium sp.	9			10		4

Tentative Classification.

TABLE 5
Benthic Fauna (Species and Numbers of Organisms) of the Tributary to North Anna River

	Species	**Numbers of Organisms**							
		Upstream (Station 1)		Downstream (Station 2)					
		3/15/73	3/15/74	3/15/73	7/14/73	11/2/73	11/27/73	3/15/74	12/17/74
Phylum:	**Annelida**	21	24	2	4			6	32
Phylum:	**Arthropoda**								
Class:	Crustacea								
Order:	Amphipoda								
	Crangonyx sp.	6	5	35	1	2	28	12	6
Order:	Decapoda								
	Cambarus sp.	14	9	19	20	14	6	12	2
Class:	Insecta								
Order:	Coleoptera								
	Colpius sp.							1	
	Colpius sp.	1	2	3	14		28	4	
	Simsonia sp.	3	6	2	4	2		1	
	Dineutus sp.			2					
	Halipus sp.							2	
Order:	Diptera								
	Atherix sp.			2				2	1
	Simulium sp. A	1	2	5				1	
	Simulium sp. B	1	2						
	Tabanus sp.	1	1	5	1	1	2	4	

	Tipula sp.	51	54	20	6	17	1	20	38
Order:	Ephemeroptera								
	Siphloplecton sp.	14	5	15	3	12		34	2
	Stenonema sp.			(specimens observed but not collected)					
	Neoephemera sp.	102	77	75		13	4	31	9
Order:	Hemiptera								
	Sigara sp.			5	8			1	
	Microvelia sp.							1	
	Hydropilus sp.					3			
Order:	Megaloptera								
	Chauliodes sp.	4	8	1	7	9	1	2	4
Order:	Odonata								
Suborder:	Anisoptera								
	Boyeria sp.	1	1	2	9	23	3	1	
	Cordulegaster sp.		1					2	1
	Macromia sp.	1			1	4			
Suborder:	Zygoptera								
	Agrion sp.	1	3	23	1	6	13	4	
	Argia sp.			2	2		1		
Order:	Plecoptera								
	Acroneuria sp.	47	54			68	6	20	3
	Perlesta sp.	3		20		23			
	Isoperla sp.	12	15	4	18		3	5	115
	Pteronarcys sp.					8			
	Hydropsyche sp.	8	7	9	20	29	2	4	13
	Limnephilus sp.	6	11	44				9	
	Pycnopsyche sp.	31	37	153	3			16	1
	Psilotreta sp.	1	1	1	1	2	1	1	
	Wormaldia sp.	7	5	8				19	
	Glossosoma sp.	19	24	60				10	
	Rhyacophila sp.	27	21	10	2			34	1

(continued)

TABLE 5 (continued)

	Species	Numbers of Organisms							
		Upstream (Station 1)		Downstream (Station 2)					
		3/15/73	3/15/74	3/15/73	7/14/73	11/2/73	11/27/73	3/15/74	12/17/74
Phylum:	**Mollusca**								
Class:	Gastropoda								
Order:	Ctenobranchiata								
	Campeloma sp.	1	1	4	10	11	4	10	
Order:	Pulmonata								
	Helisoma sp.	1					3		
Class:	Pelecypoda								
Order:	Eulamelli-branchiata								
	Elliptio sp.	1				1			
Order:	Heterodonta								
	Sphaerium sp.	3	2	2	1		1	3	1

Tentative Classification.

TABLE 6
Number of Fishes Collected at Deep Run

	Station 1 1/1/74	Station 2 1/1/74
Nacomis leptocephalus (bluehead chub)	12	3
Rhinichthys atratulus (blacknose dace)	2	–
R. cataractae (longnose dace)	3	–
Semotilus corporalis (fallfish)	2	8
Notropis analostanus (satinfin shiner)	–	3
Hypentelium nigricans (northern hogsucker)	4	–
Noturus insignis (margined madtom)	1	1
Cottus bairdi (mottled sculpin)	5	–
Etheostoma nigrum (Johnny darter)	5	4
Lethenteron lamottei (American brook lamprey)	1	1
Ambloplites rupestris (rockbass)	–	3
Lepomis gibbosus (pumpkinseed)	–	2

Station 1	Station 2
9 species	8 species
35 fishes	23 fishes
Diversity index = 0.77	Diversity index = 0.84

Decrease in number of fishes–34.3%
Decrease in number of species–11.1%

TABLE 7
Number of Fishes Collected at Back Creek

	Station 1 6/14/73	Station 2 5/24/74
Notropis cornutus (common shiner)	56	19
N. atherinoides (emerald shiner)	35	–
N. ardens (rosefin shiner)	1	1
Exoglossum maxillingua (cutlips minnow)	3	1
Clinostomus funduloides (rosyside dace)	23	45
Phoxinus oreas (mountain redbelly dace)	1	16
Rhinichthys cataractae (longnose dace)	10	16
R. atratulus (blacknose dace)	4	2
Nocomis leptocephalus (bluehead chub)	16	22
Semotilus corporalis (fallfish)	11	4
Catostomus commersoni (white sucker)	1	–
Moxostoma rhothoecum (torrent sucker)	9	5
Noturus insignis (margined madtom)	5	4
Cottus bairdi (mottled sculpin)	112	12
Micropterus dolomieui (smallmouth bass)	1	–
Ambloplites rupestris (rockbass)	1	–
Salvelinus fontinalis (eastern brook trout)	1	1
Etheostoma olmestedi (tessalated darter)	2	1
E. flabellare (fantail darter)	24	1
E. longimanum (longfin darter)	1	1

(continued)

TABLE 7 (continued)

Station 1	Station 2
21 species	15 species
299 fishes	165 fishes
Diversity index = 0.83 (average value)	Diversity index = 0.78 (average value)

Decrease in number of fishes—44.8%.
Decrease in number of species—28.6%.

TABLE 8
Number of Fishes Collected from David Creek

	Station 1 5/21/74	Station 2 5/21/74
Notropis cornutus (common shiner)	4	1
N. ardens (rosefin shiner)	8	–
Clinostomus funduloides (rosyside dace)	9	–
Rhinichthys cataractae (longnose dace)	11	10
Campostoma anomalum (stoneroller)	1	5
Nocomis leptocephalus (bluehead chub)	20	5
Semotilus corporalis (fallfish)	3	–
N. analostanus (satinfin shiner)	–	2
Moxostoma rhothoecum (torrent sucker)	39	6
Hypentelium nigricans (northern hogsucker)	1	–
Notorus insignis (margined madtom)	20	35
Cottus bairdi (mottled sculpin)	14	–
Anguilla rostrata (American eel)	1	1
Lepomis auritus (redbreast sunfish)	–	1
Lepomis cyanellus (green sunfish)	1	–
Etheostoma flabellare (fantail darter)	4	5
E. olmstedi (tessalated darter)	2	–
Percina notogramma (stripeback darter)	3	–
Percina crassa (Piedmont darter)	–	1

TABLE 8 (continued)

Station 1	Station 2
16 species	11 species
141 fishes	72 fishes
Diversity index = 0.82	Diversity index = 0.68

Decrease in number of fishes—48.9%
Decrease in number of species—31.3%

TABLE 9
Recovery of Fishes in David Creek

	Station 1 3/11/75 Number	Station 2 3/11/75 Number
Notropis cornutus (common shiner)	23	10
N. analostanus (satinfish shiner)	64	17
N. hudsonius (spottail shiner)	1	36
N. ardens (rosefin shiner)	10	70
N. procne (swallowtail shiner)	1	–
Campostoma anomalum (stoneroller)	7	15
Rhinichthys cataractae (longnose dace)	7	10
Nocomis leptocephalus (bluehead chub)	6	15
N. atherinoides (emerald shiner)	–	2
Phoxinus oreas (mountain redbelly dace)	–	26
Pimephales notatus (bluntnose minnow)	–	3
Semotilus corporalis (fallfish)	1	102
Notorus insignis (margined madtom)	2	5
Cottus bairdi (mottled sculpin)	5	4
Hypentelium nigricans (northern hogsucker)	2	–
Moxostoma rhothoecum (torrent sucker)	6	29
Catostomus commersoni (white sucker)	–	1
Etheostoma flabellare (fantail darter)	3	9
E. vitreum (glassy darter)	1	–

TABLE 9 (continued)

	Station 1 3/11/75 Number	Station 2 3/11/75 Number
Percina crassa (Piedmont darter)	6	2
E. olmstedi (tessalated darter)	–	2
E. longimanum (longin darter)	–	1
Lepomis auritus (redbreast sunfish)	–	1

Station 1

15 species
144 fishes
Diversity index = 0.73

Station 2

20 species
360 fishes
Diversity index = 0.83

TABLE 10
Recovery of Fishes in Deep Run Creek

	Station 1 3/10/75 Number	Station 2 3/10/75 Number
Notropis cornutus (common shiner)	56	58
N. analostanus (satinfish shiner)	44	27
N. hudsonius (spottail shiner)	14	11
Pimephales notatus (bluntnose minnow)	14	–
Rhinichthys cataractae (longnose dace)	22	–
Rhinichthys atratulus (blacknose dace)	2	2
Ericymba buccata (silverjaw minnow)	1	11
Semotilus corporalis *(fallfish)*	9	116
Nocomis leptocephalus (bluehead chub)	66	6
N. atherinoides (emerald shiner)	–	1
Clinostomus funduloides (rosyside dace)	1	17
Itctalurus natalis (yellow bullhead)	1	1
Notorus insignis (margined madtom)	–	1
Cottus bairdi (mottled sculpin)	60	1
Hypentelium nigricans (northern hogsucker)	4	1
Catostomus commersoni (white sucker)	–	2
Lepomis gibbosus (pumpkinseed)	3	–
Lepomis macrochirus (bluegill)	2	–
Etheostoma nigrum (Johnny darter)	30	3

TABLE 10 (continued)

	Station 1 3/10/75 Number	Station 2 3/10/75 Number
Lethenteron lamottei (American brook lamprey)	1	–
Ammocoetes (larval lamprey)	3	–
Ambloplites rupestris (rockbass)	–	1

Station 1	Station 2
17 species	16 species
332 fishes	259 fishes
Diversity index = 0.84	Diversity index = 0.70

TABLE 11
Number of Fishes Collected at Wilderness Run

	Station 1 1/24/74	Station 2 1/24/74
Notropis cornutus (common shiner)	3	30
N. procne (swallowtail shiner)	2	–
Clinostomus funduloides (rosyside dace)	4	1
Rhinichythys atratulus (blacknose dace)	11	–
Nocomis leptocephalus (bluehead chub)	18	20
Semotilus corporalis (fallfish)	–	9
Noturus insignis (margined madtom)	5	–
Cottus bairdi (mottled sculpin)	20	9
Lepomis macrochirus (bluegill)	2	1
L. auritus (redbreast sunfish)	2	1
Etheostoma nigrum (Johnny darter)	19	3
E. longimanum (longfin darter)	20	–
Percina notogramma (stripback darter)	7	–

Station 1	Station 2
12 species	8 species
113 fishes	73 fishes
Diversity index = 0.84.	Diversity index = 0.62

Decreases in number of fishes–35.4%
Decreases in number of species–41.7%

TABLE 12
Recovery of Fishes at Wilderness Run

	Station 1 1/28/75 Number	Station 2 1/28/75 Number
Notropis cornutus (common shiner)	3	15
N. procne (swallowtail shiner)	1	–
Rhinichythys atratulus (blacknose dace)	4	–
R. cataractae (longnose dace)	2	–
Nocomis leptocephalus (bluehead chub)	6	16
Hypentelium nigricans (northern hogsucker)	2	–
Cottus bairdi (mottled sculpin)	33	20
Etheostoma nigrum (Johnny darter)	–	3
Lethenteron lamottei (American brook lamprey)	–	1
Lepomis macrochirus (bluegill)	–	1
L. cyanellus (green sunfish)	–	1

Station 1	Station 2
8 species	7 species
57 fishes	57 fishes
Diversity index = 0.57	Diversity index = 0.66

TABLE 13
Number of Fishes Collected from Redbud Creek

	Station 1 1/2/75	Station 2 1/2/75
Notropis cornutus (common shiner)	18	7
N. analostanus (satinfin shiner)	1	2
Clinostomus funduloides (rosyside dace)	57	59
Phoxinus oreas (mountain redbelly dace)	30	4
Rhinichthys cataractae (longnose dace)	1	2
R. atratulus (blacknose dace)	7	11
Nocomis leptocephalus (bluehead chub)	56	23
Semotilus corporalis (fallfish)	7	–
Noturus insignis (margined madtom)	6	2
Moxostoma rhothoecum (torrent sucker)	56	26
Catostomus commersoni (white sucker)	–	6
Anguilla rostrata (American eel)	1	–
Etheostoma olmstedi (tesselated darter)	21	5
E. flabellare (fantail darter)	12	11
Petromyzon marinus (sea lamprey)	–	1

Station 1	Station 2
13 species	13 species
273 fishes	159 fishes
Diversity index = 0.82	Diversity index = 0.76

Decrease in number of fishes—41.8%
No change in number of species—0.0%

TABLE 14
Number of Fishes Collected from Foster Branch

	Station 1 1/9/75	Station 2 1/9/75
Notropis cornutus (common shiner)	10	10
N. hudsonius (spottail shiner)	1	1
Clinostomus funduloides (rosyside dace)	57	41
Phoxinus oreas (mountain redbelly dace)	8	11
Rhinichthys cataractae (longnose dace)	1	–
R. atratulus (blacknose dace)	4	6
Nocomis leptocephalus (bluehead chub)	35	5
Semotilus corporalis (fallfish)	–	9
Noturus insignis (margined madtom)	12	1
Moxostoma rhothoecum (torrent sucker)	12	21
Catostomus commersoni (white sucker)	2	–
Etheostoma olmstedi (tesselated darter)	10	1
Etheostoma flabellare (fantail darter)	9	3

Station 1	Station 2
12 species	11 species
161 fishes	109 fishes
Diversity index = 0.76	Diversity index = 0.69

Decrease in number of fishes–32.3%
No change in number of species–8.3%

TABLE 15
Community Structure—Percent Change in Numbers Of Fishes as a Result of Increased Siltation

Site	Number of Fishes Collected Upstream	Downstream	Percent Change	χ^2
Back Creek	299	165	44.8%	38.69*
David Creek	141	72	48.9%	22.35*
Deep Run Creek	35	23	34.3%	2.48NS
Wilderness Run	113	73	35.4%	8.60*
Redbud Creek	273	159	41.8%	30.08*
Foster Branch	161	109	32.3%	10.01*

Average decrease in number of fishes—39.6%

Recovery				
David Creek	141	360	150.0%	95.73*
Deep Run Creek	332	250	22.0%	9.01*
Wilderness Run	57	57	0.0%	0.0NS

* indicates significance at $\chi = .05$; NS indicates not significant.

TABLE 16

Community Structure—Percent Change in Numbers Of Fish Species as a Result of Increased Siltation

Site	Number of Fish Species Collected Upstream	Downstream	Percent Change	χ^2
Back Creek	21	15	28.6%	1.0 NS
David Creek	16	11	31.3%	.92 NS
Deep Run Creek	9	8	11.1%	.05 NS
Wilderness Run	12	7	41.7%	1.31 NS
Redbud Creek	13	13	0.0%	0.0 NS
Foster Branch	12	11	8.3%	.04 NS

Average decrease in number of species—20.2%

Recovery				
David Creek	15	20	33.3%	.71 NS
Deep Run Creek	17	16	5.9%	.03 NS
Wilderness Run	8	7	12.5%	.06 NS

* indicates significance at $\chi = .05$.; NS indicates not significant.

TABLE 17
Diversity Indices—Fishes

Site	Upstream	Downstream
Back Creek	0.83	0.78
David Creek	0.82	0.68
Deep Run Creek	0.77	0.84
Wilderness Run	0.84	0.62
Redbud Creek	0.82	0.76
Foster Branch	0.76	0.69
Recovery		
David Creek	0.73	0.83
Deep Run Creek	0.84	0.70
Wilderness Run	0.57	0.66

FIGURES

FIGURE 1
Benthic Collection Site: Unnamed Tributary to Totier Creek

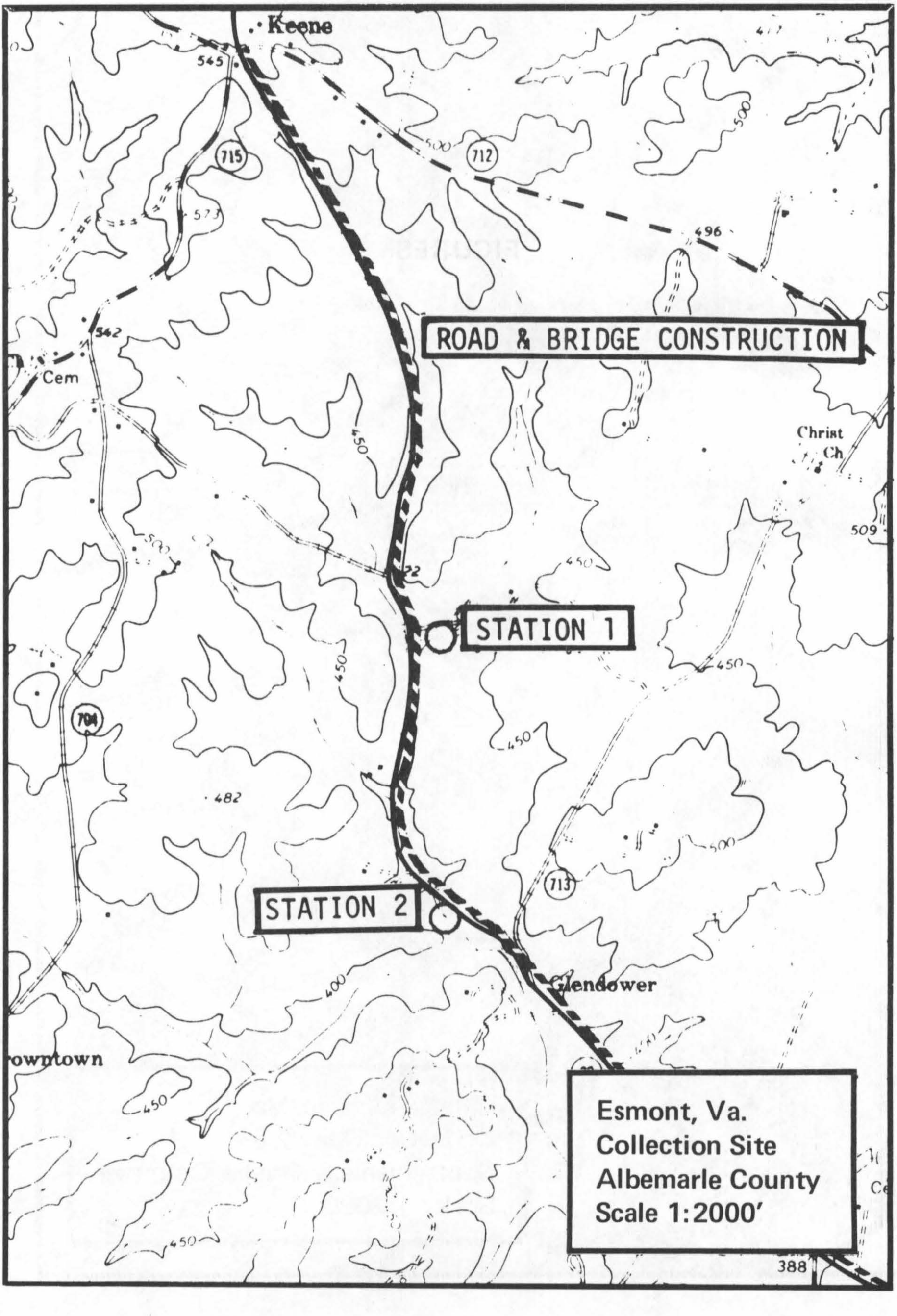


FIGURE 2
Benthic Collection Site: Wilderness Run

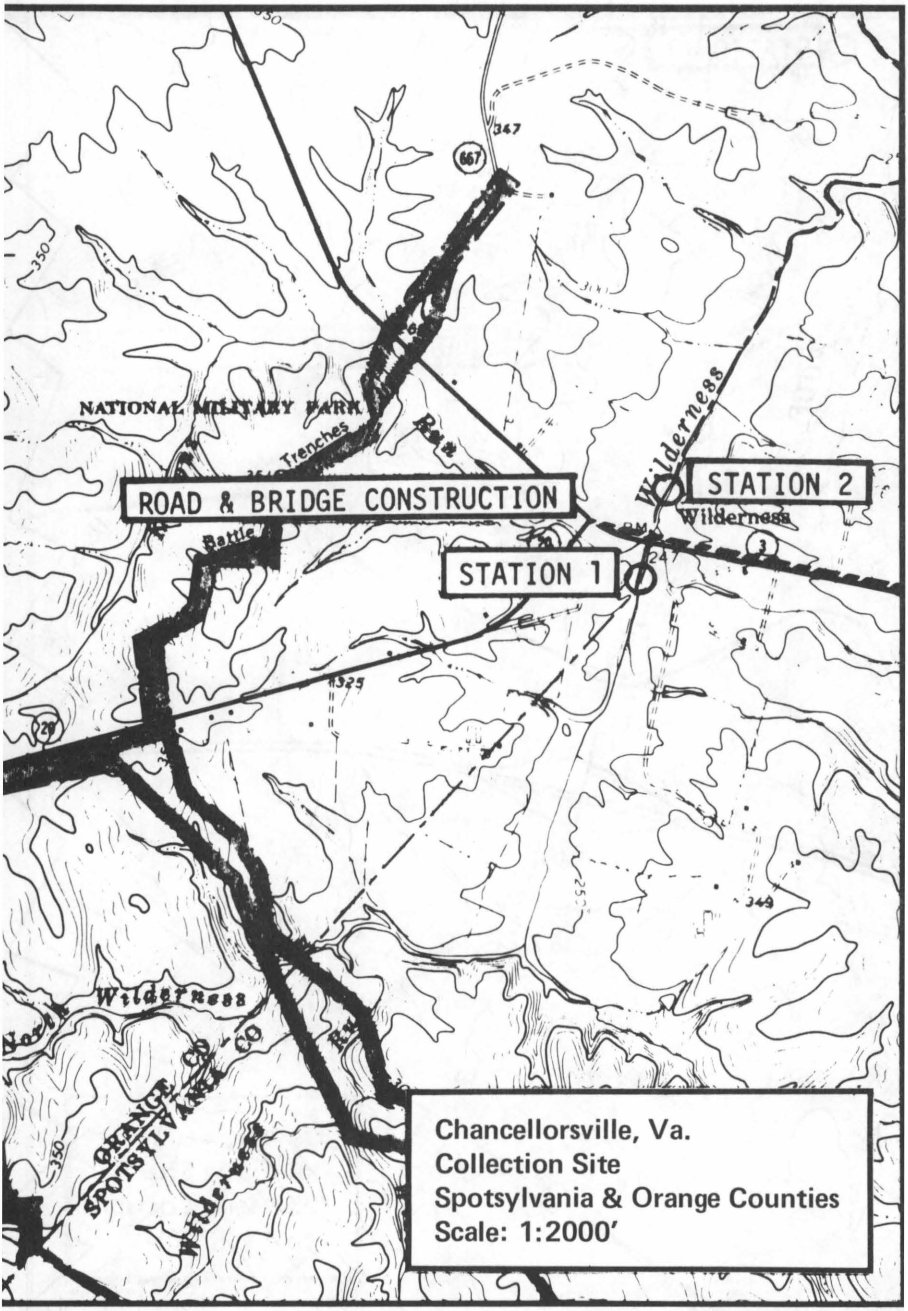
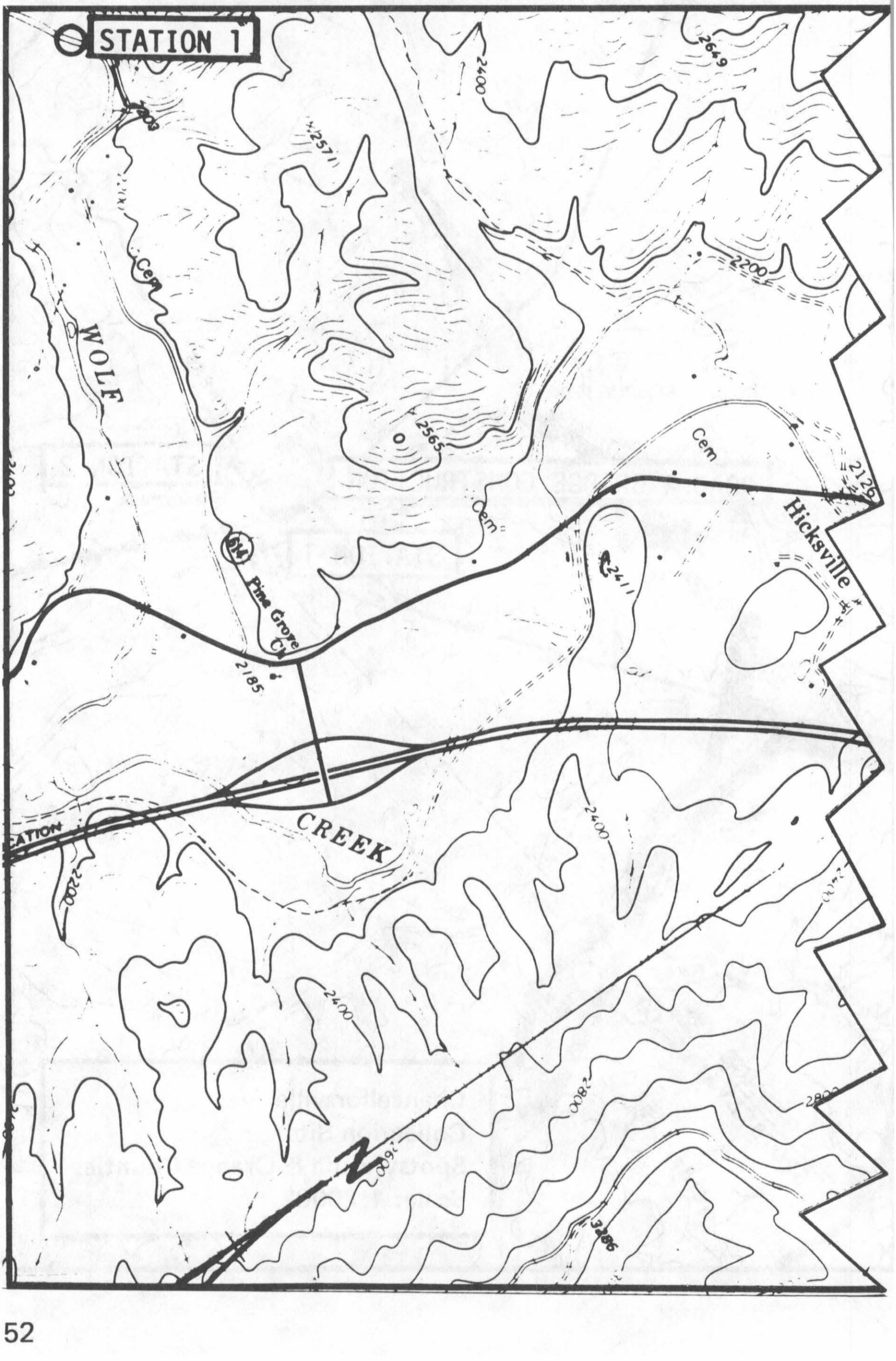


FIGURE 3

Benthic Collection Site: Wolf Creek (Sheet A)



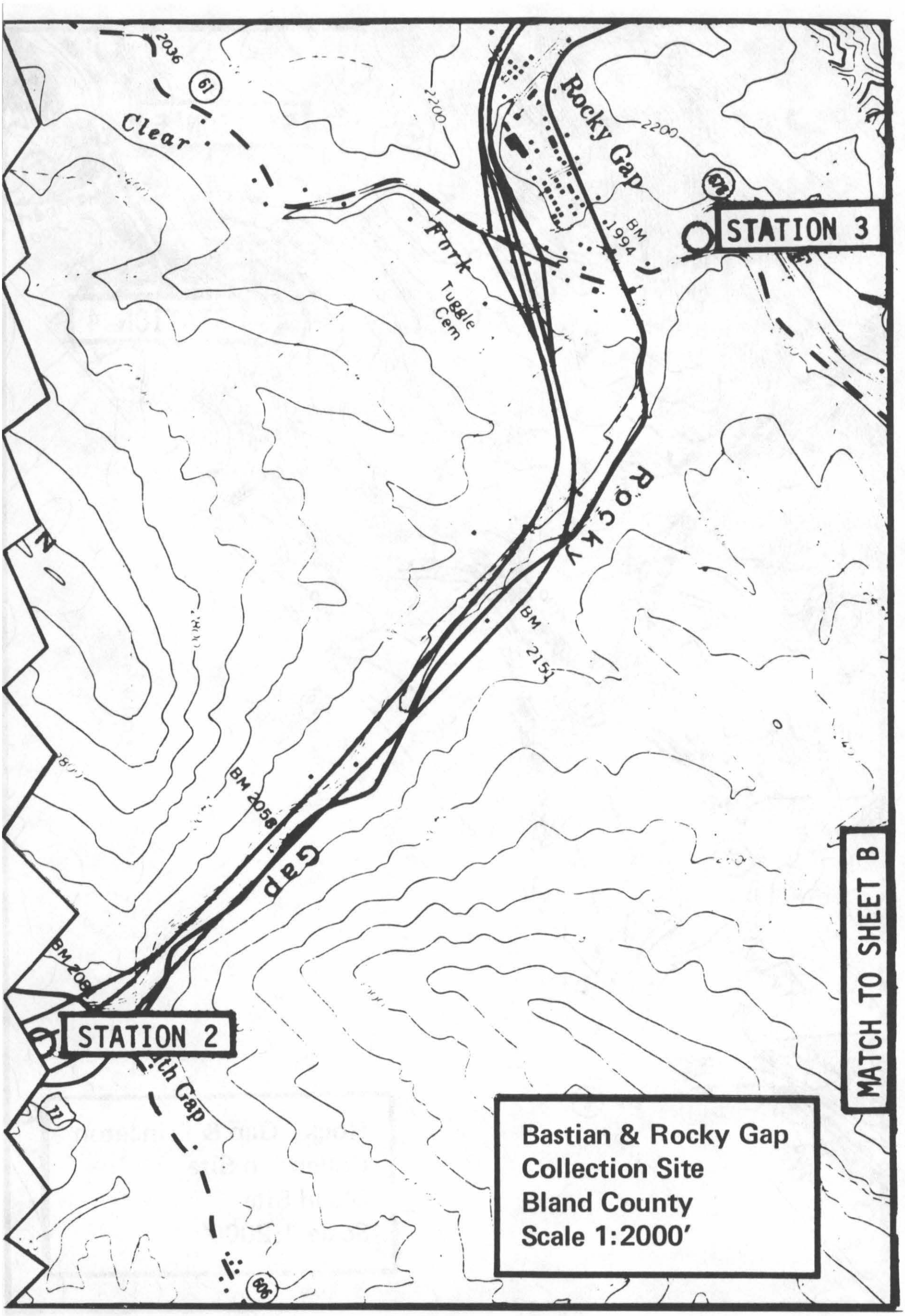

Clear
Fork
Tuggle Cem
Rocky Gap
BM 1994
STATION 3
ROCKY
BM 2151
BM 2058
Gap
BM 208
STATION 2
MATCH TO SHEET B
Bastian & Rocky Gap
Collection Site
Bland County
Scale 1:2000'
606

FIGURE 4
Benthic Collection Site: Wolf Creek (Sheet B)

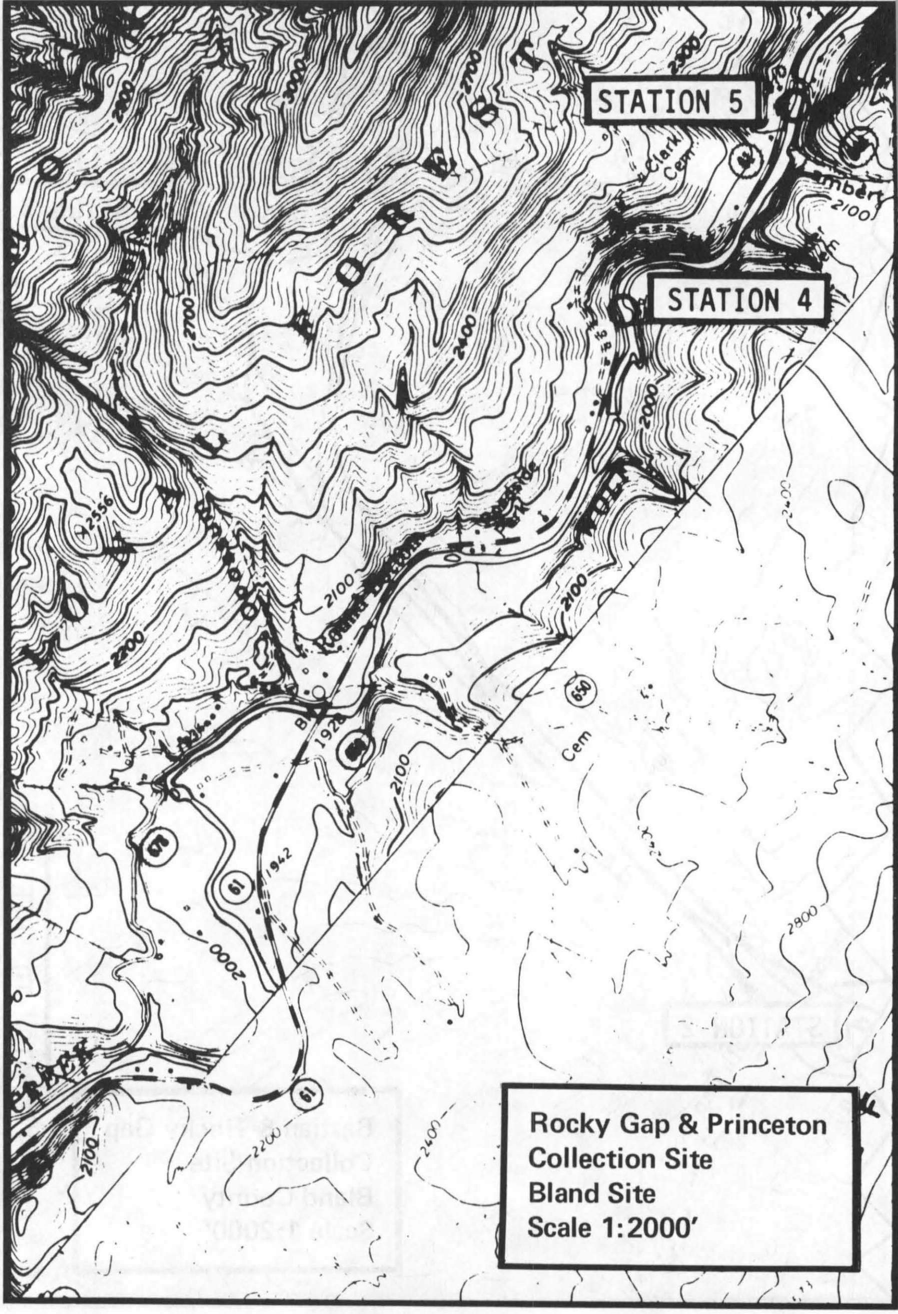


FIGURE 5
Benthic Collection Site: Tributary to North Anna River

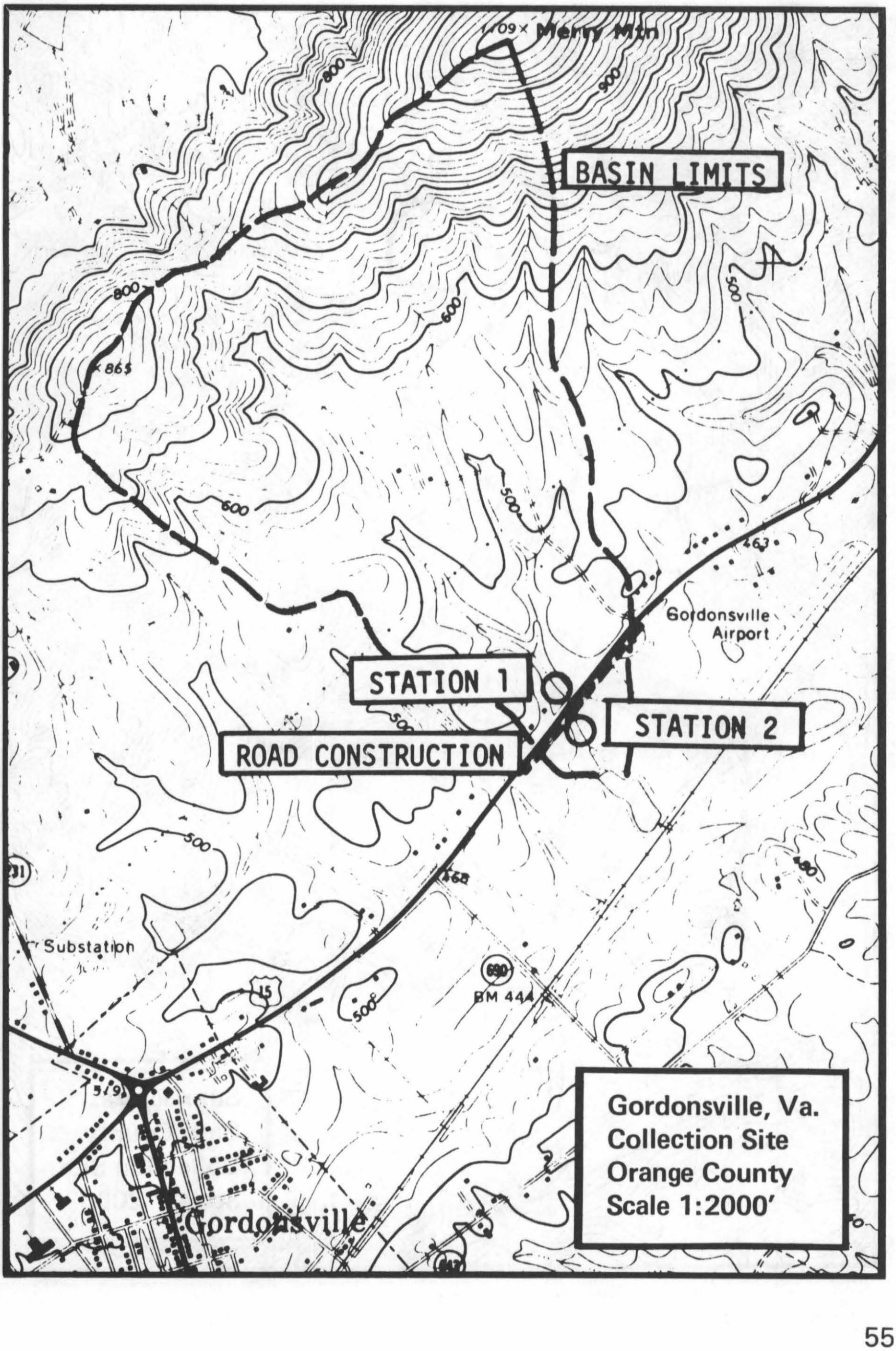


FIGURE 6
Fish Collection Site: Back Creek

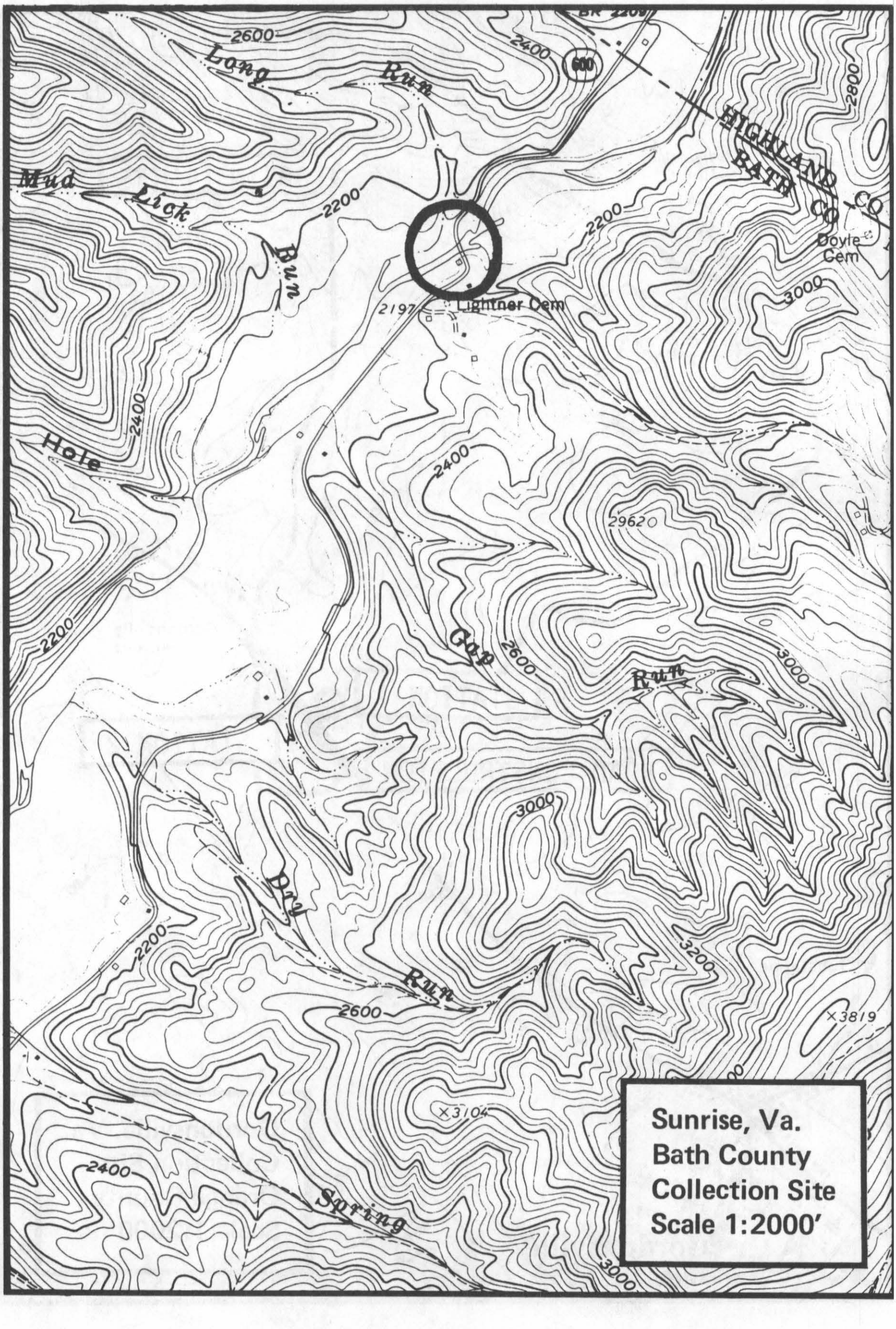


FIGURE 7
Fish Collection Site: David Creek

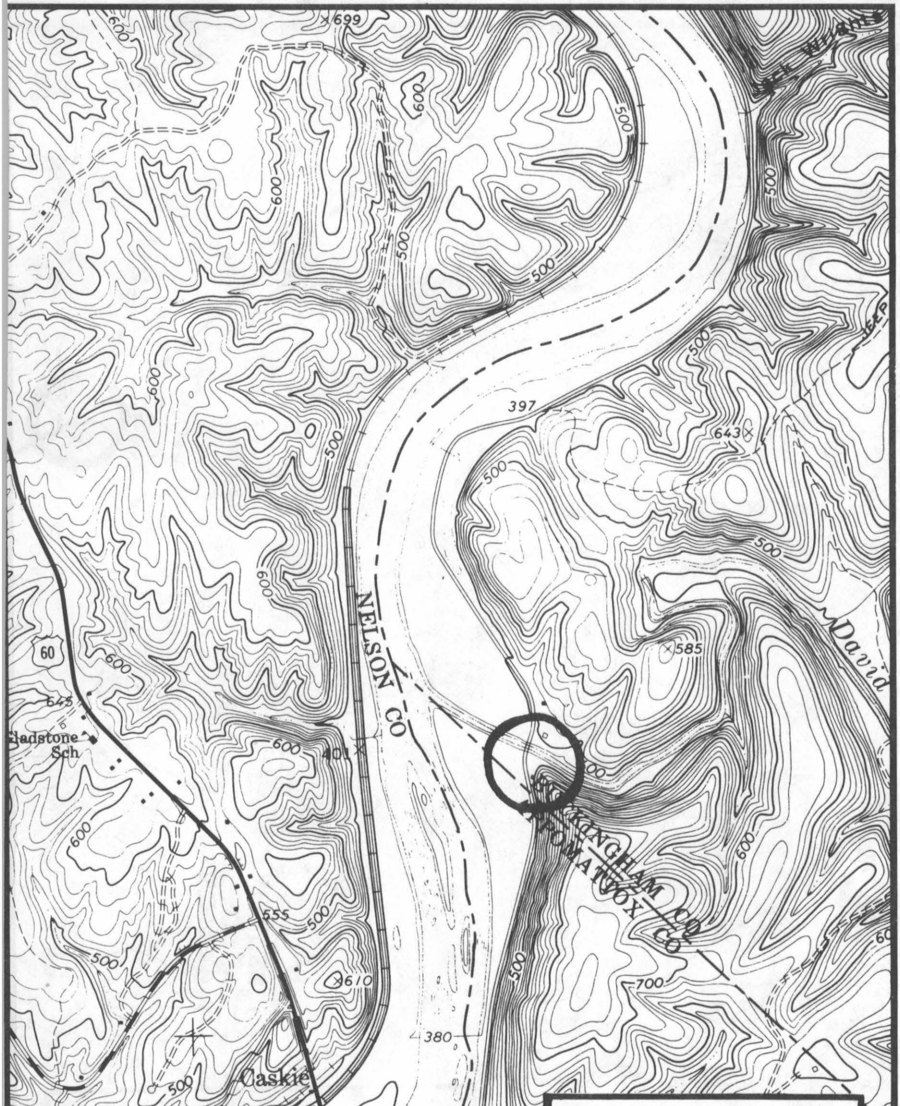


FIGURE 8
Fish Collection Site: Deep Run

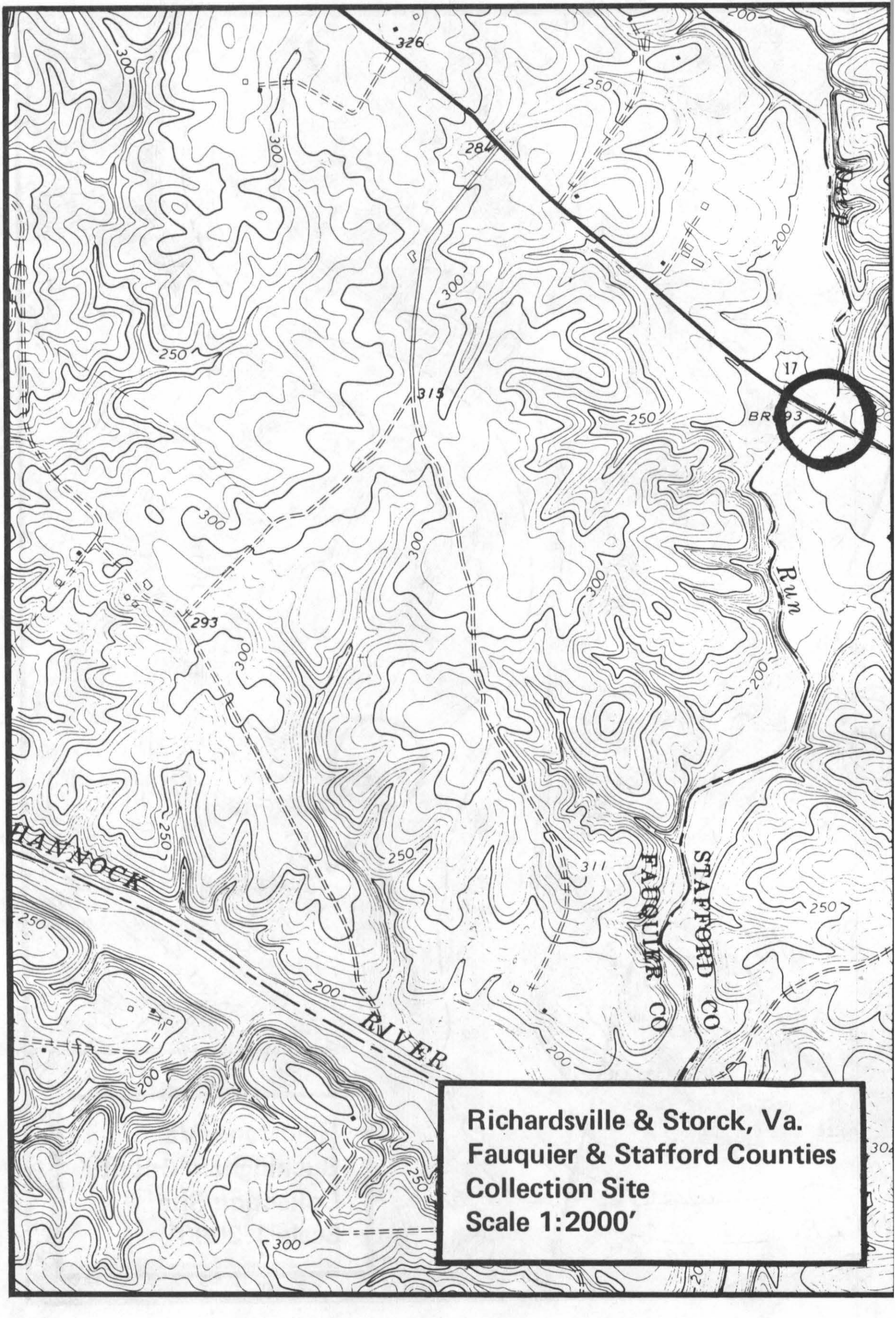


FIGURE 9

Fish Collection Site: Redbud Creek and Foster Branch

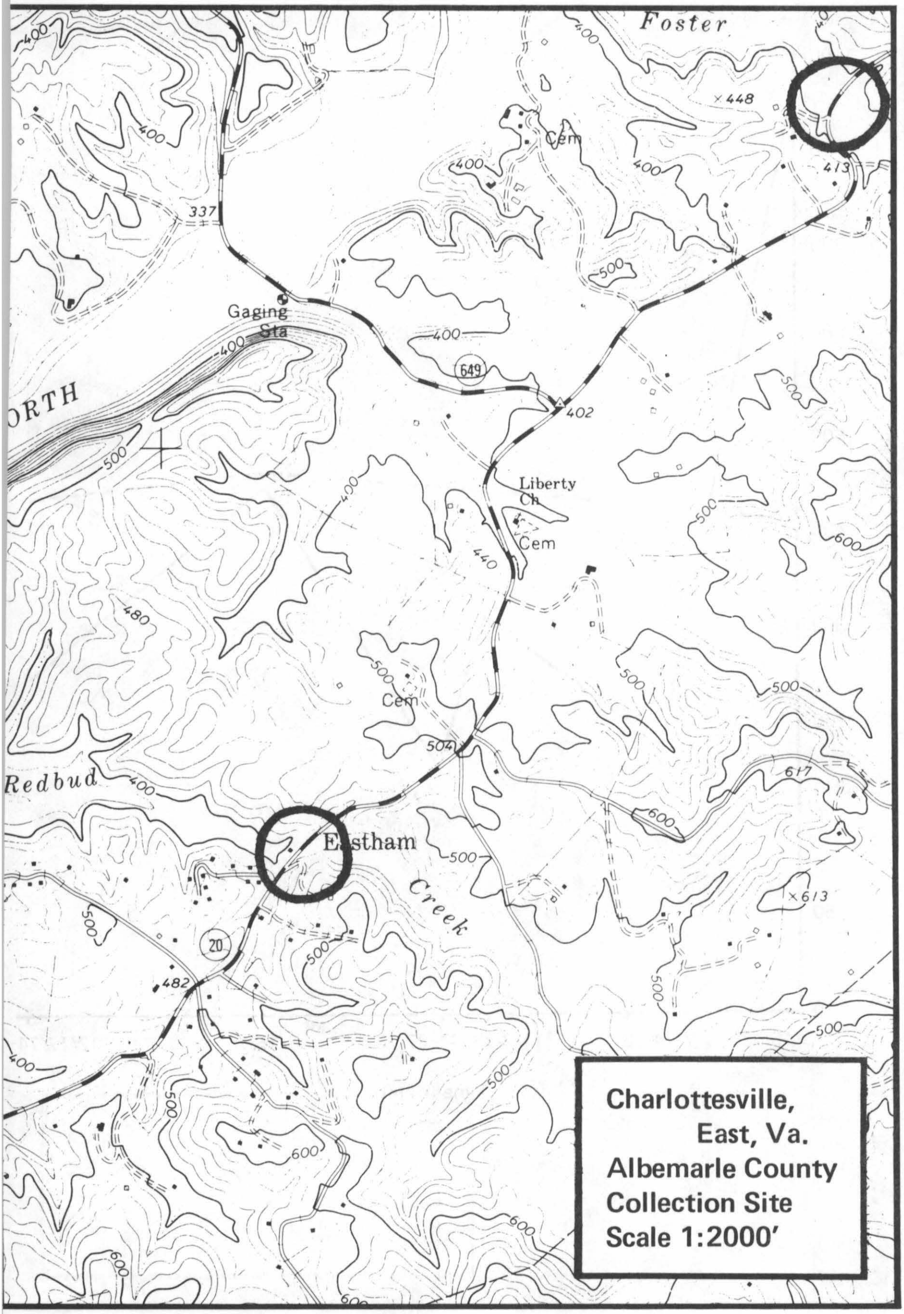


FIGURE 10

Comparisons of Numbers of Benthic Organisms Up and Downstream of a Highway Construction Site—Tributary to the North Anna River

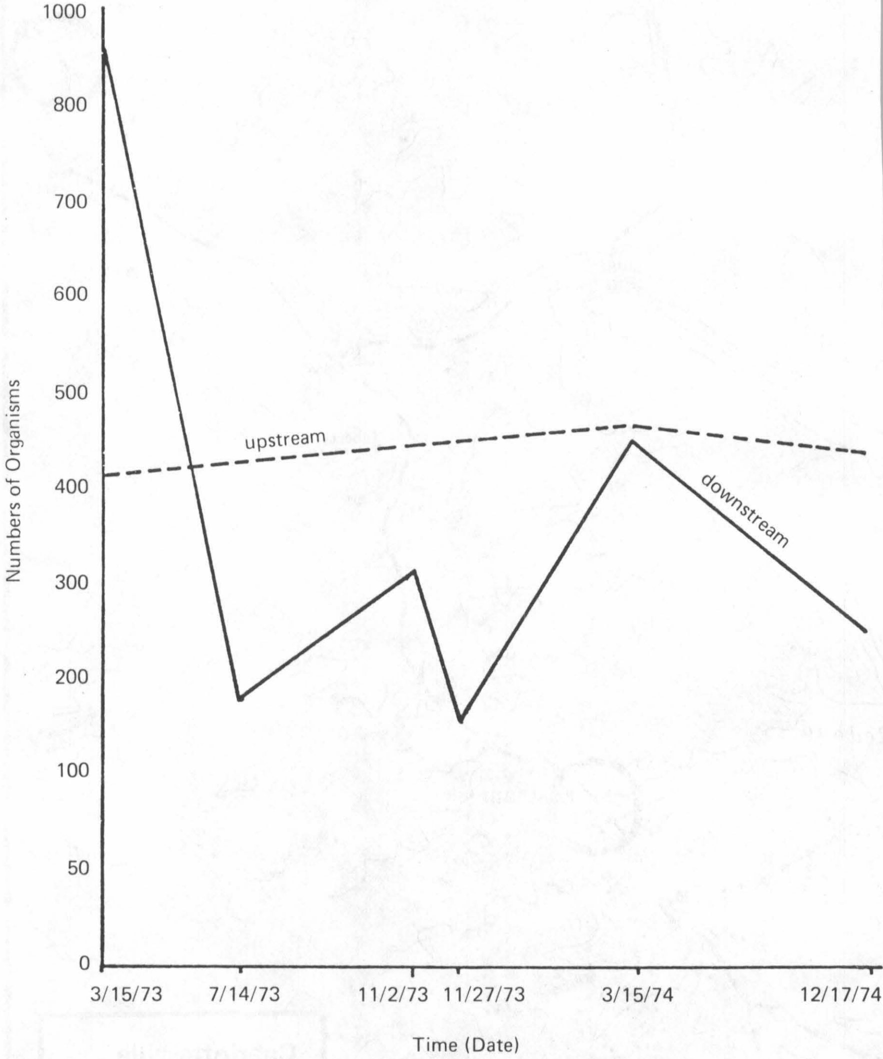
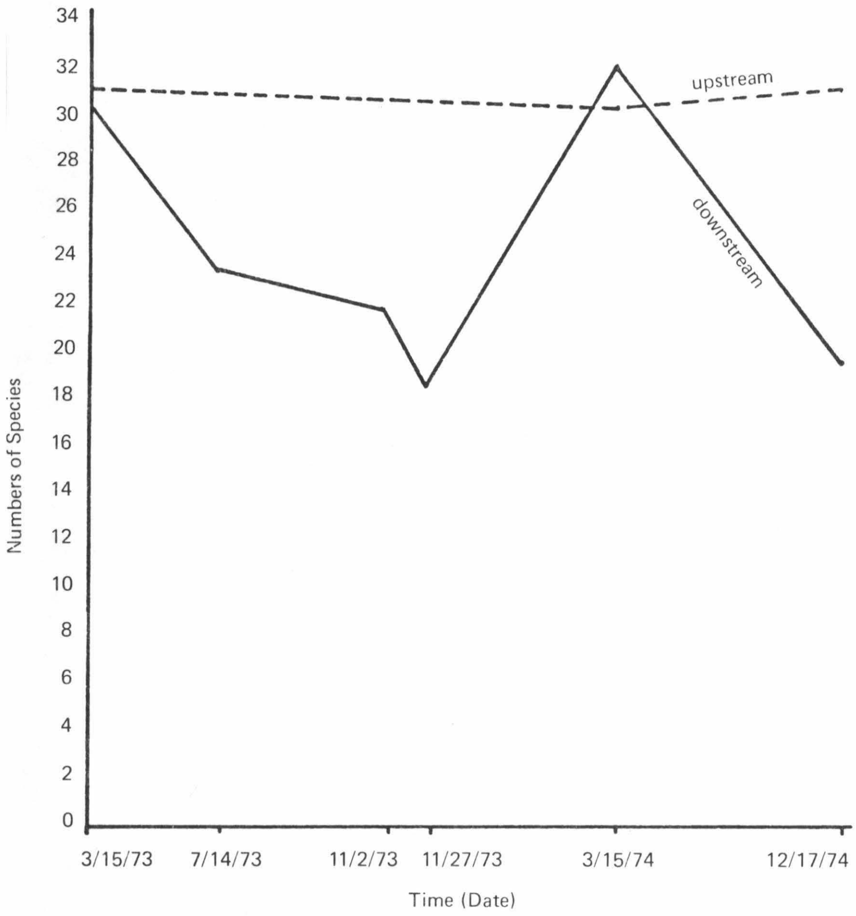


FIGURE 11
Comparison of Numbers of Benthic Species Up and Downstream of a Construction Site–Tributary to the North Anna River



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- It studies the state's water and related land-use problems, including their ecological, political, economic, institutional, legal, and social implications.
- It sponsors and administers research investigations of these problems.
- It collects and disseminates information about water resources and water resources research.
- It provides training opportunities in research for future water scientists enrolled at the state's colleges and universities.
- It provides other public services to the state in a wide variety of forms.

More information on programs and activities may be obtained by contacting the Center at the address below.

X/

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