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A PRE-IMPOUNDMENT STUDY OF THE NORTH ANNA RIVER, VIRGINIA

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PREFACE

As our population continues to grow, it is evident that there is an increasing demand for more convenience. More convenience implies, in part, a greater demand for electrical energy. As the electrical industry expands to provide a more leisurely life, water power will, by necessity, have to be utilized in one way or another. The harnessing of a potentially available water resource usually results in the damming of a river and subsequent creation of a reservoir. A pre-impoundment study, if considered before plans are finalized, will enable all concerned to view the natural resource before it is modified or changed. The natural resource, in this case a river, can then be evaluated for its potential as a recreational resource, industrial resource (coolant, raw water supply, diluant, etc.), public water supply, or agricultural resource (irrigation, water source for livestock, digestion and dilution of feedlot runoff, etc.). In the past, little effort has been made to study the total resource potential of a river and then evaluate what is to be gained when a reservoir is created.

Once plans are finalized to harness a river, pre-impoundment studies are particularly valuable in evaluating potential water quality hazards that can be corrected before they become a water quality problem in the reservoir. Comprehensive pre-impoundment research programs are also needed to gain insight into the amount of time required for a community to shift from a lotic to lentic environment. This in turn should assist other state agencies in fish stocking programs and enhance fishery management (What value is there in stocking a lake in which there is no food?). Pre-impoundment studies should also assist biologists and engineers alike in predicting the effects of low flow augmentation on existing water quality in the river below the dam.

A portion of the North Anna River has been impounded to serve as a coolant for a nuclear powered electrical generating facility. The pre-impoundment study on the North Anna River provides necessary information to evaluate the current water quality deterioration caused by the acid mine drainage from Contrary Creek. A baseline of information is now present which will enable future investigators to assess the degree to which the presence of the reservoir ameliorates the influence of acid mine drainage.

Moreover, with the advent of atomic reactors, which will be providing greater amounts of electrical energy in the near future, the demand will increase for information concerning the impact of the thermal effluent and possible radioactive contamination in aquatic environments which are also to be used for recreational purposes. Using this pre-impoundment study as a baseline for future observations, a continued detailed study of the North Anna Reservoir and remaining river over a period of several years will provide a basis through which the effects of nuclear powered electrical generation on water quality and the general aquatic environment can be evaluated. Such a study also forms a baseline for future observations with regard to alterations in community structures as the habitat changes from a lotic to lentic environment.

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INTRODUCTION

Location and Hydrology

Virginia Electric and Power Company (VEPCO) is building a 13,000-acre reservoir on the North Anna River which will extend through Louisa, Spotsylvania, and Orange Counties, Virginia (Figures 1 and 2). This impoundment will provide cooling water for a 4,000,000-kilowatt nuclear powered electrical generating facility being constructed on the impoundment in Louisa County near Mineral, Virginia (Figure 1).

The reservoir will drain approximately 343 square miles or approximately 78% of the total river basin. The North Anna River has very few municipalities or industries in its drainage basin; land use in the area is primarily agricultural (crops, livestock, or timber). Approximately 3,600 acres of the reservoir will consist of cooling lagoons which will retain the thermal effluent from the power plant. The remaining area of the reservoir, 9,400 acres, will be available for recreational use. The normal pool elevation will be at 250 feet MSL (mean sea level) and the lake will be 80 feet deep at the dam. The dam was completed in January 1972. The first reactor is to begin operation March 1, 1974, and approximately 1600 cubic feet per second of water will be needed for cooling this reactor. Units 2, 3, and 4 are scheduled to begin operation on March 1, 1975, 1977, and 1978, respectively (VEPCO, personal communication). At maximum operating capacity, 4% of the reservoir volume per day will be needed for cooling. A summary of morphometric data is presented in Table 1, and engineering features of limnological interest and importance are given in Table 2.

The North Anna River is a major tributary of the York River which flows into the Chesapeake Bay. The North Anna and South Anna Rivers meet to form the Pamunkey River which in turn unites with the Mattaponi River at West Point, Virginia, and forms the York River. The North Anna River originates in the upper Piedmont Province of Orange County and flows southeast for about 60 river miles before joining the South Anna River on the Coastal Plain. In the upper half of its course, the North Anna River forms the boundary between Spotsylvania and Louisa Counties; in its lower half, it divides Caroline and Hanover Counties. The drainage area of the North Anna is approximately 439 square miles, and the 40-year average discharge is 375 cubic feet per second (Anon., 1970). The maximum recorded flow was 24,300 cubic feet per second on August 21, 1969, and the minimum recorded flow was one cubic foot per second on September 30, 1932. Available records on discharge indicate that river flow varies sharply with rainfall. The gradient of the North Anna varies considerably over its course. Figure 3 is a diagram of the river's gradient from the headwater regions through the pre-impoundment area. Station sites as well as the completed dam are indicated in Figure 3.

Geology and Mining Activities

The major portion of the drainage basin of the North Anna River is located in the north-central part of the Piedmont physiographic province of Virginia. This province is bordered on the east by the Coastal Plain Province and on the west by the Blue Ridge Province. The drainage basin consists of gently rolling terrain with broad, flat-topped hills and narrow, eastward sloping valleys. The surface of the Piedmont Province exhibits a slight southeastward slope from an altitude of approximately 1000 feet at the western margin to about 200 feet at the eastern margin.

The Piedmont Province contains a greater variety of mineral resources than either of the other two provinces. Many of these minerals are of commercial importance. Pyrite, associated with gold, silver, lead, and zinc, is probably more abundant than any of the other minerals and occurs in many places throughout the gold-pyrite belt in the province. The portion of the belt through Louisa and Spotsylvania Counties has been extensively mapped (Cline, et al., 1921).

One of the main tributaries of the North Anna River is Contrary Creek (Figure 2). The land adjacent to the headwaters of this stream was the site of extensive mining operations from 1882 to 1920. Although many minerals were mined, the primary elements sought were iron and sulfur in the form of iron pyrite – FeS_2. During this time (commercial operation: 1885 to 1920), the three different mines in operation produced nearly 6,883,000 tons of pyrite which constituted approximately 13.2% of the national output. A comprehensive history of the ownership and mining activities of the properties has been discussed in detail by Katz (1961), Painter (1905a, 1905b), and Watson (1907).

The ore was mined, milled, and washed at the mine sites, and the tailings were deposited along the stream bank (Painter 1905a, 1905b). It has been shown that sulfuric acid is produced when the sulfide is exposed to air and water (Parsons, 1968). As a result, sulfuric acid has been introduced into Contrary Creek, not only from the washings of the mining era, but also from subsequent drainage of the tailings along the stream bank. Essentially then, Contrary Creek and the North Anna River below the entrance of Contrary Creek have suffered from acid drainage for nearly 100 years. Figure 4 is an aerial photograph of a portion of the Contrary Creek Basin approximately three miles below the mine sites in Louisa County. State Route 642 and the bridge across Contrary Creek are in the foreground. Figures 5, 6, and 7, taken from the bridge seen in Figure 4, show the erosional effects caused by the acid mine drainage.

Current Water Quality Standards for the North Anna River

The Virginia State Water Control Board (1970) has classified all free-flowing tributaries of the York, Mattaponi, and Pamunkey Rivers as III-A. This would include the North Anna River, a free-flowing tributary of the Pamunkey. A body of water designated III-A is classified as a free-flowing stream somewhere between the crest of the mountains and the coastal zone. The waters are generally satisfactory for use as public or municipal water supply, secondary contact recreation, propagation of fish and aquatic life, and other beneficial uses. The specific water quality standards for such bodies of water are as follows:

Dissolved Oxygen	
Minimum	4.0 mg/l
Daily Average	5.0 mg/l
pH	6.0 to 8.5
Temperature	
Rivers —	
Rise above natural	5°F (2.8°C)
Maximum	90°F (32°C)
Impoundments —	
Permitted rise above normal temperature before addition of heat	3°F (1.7°C)

Coliform Organisms

Monthly average value not more than 5000/100 ml (MPN or MF count). Not more than 5000 MPN in more than 20% of samples in any month. Not more than 20,000 MPN in more than 5% of such samples. Fecal coliforms (multiple-tube fermentation of MF count) not to exceed a log mean of 1000/100 ml. Not to equal or exceed 2000/100 ml in more than 10% of samples.

A special standard which applies to the North Anna reservoir is as follows:

Discharge for Proposed Reservoir

40 cfs – minimum instantaneous release at all times. During period of filling – 150 cfs February through June (Minute 39, State Water Control Board, June 14-15, 1971).

SELECTION AND DESCRIPTION OF STATIONS

Selection of Stations

Initially, this investigation began as a routine study of the existing water quality of a pre-impoundment basin. However, after a cursory examination in 1968, it was obvious that the water quality in the pre-impoundment basin was strongly influenced by acid drainage from Contrary Creek. As discussed earlier, Contrary Creek and the North Anna River below their confluence had suffered from the effects of acid drainage from the spoil banks at the mine site for nearly 100 years.

The North Anna River is inaccessible along much of its length, and routine physical and chemical collections were possible only at bridge sites (Stations I through VI). Almost every bridge crossing was used within the pre-impoundment basin. In addition, a station was selected both above upper water level of the future impoundment and approximately two miles below the proposed dam site. For biological collections, stations were selected on the basis of accessibility and riffle development in an effort to assess the effects of the acid pollution. Accordingly, one control station was selected approximately 75 yards above State Route 208 (Station IV); at the first riffle area below the confluence with Contrary Creek (Station B.C.C.), and two stations at the lower end of the pre-impoundment basin (Stations VI and VII). The river was not sampled regularly for biota above Station IV at State Route 208 due to the consistent blockage of the river by massive log and brush jams. A float trip down the river above Station IV in 1969 showed that this area of the river could not be collected on a routine basis. The brush jams persisted until the confluence of the North Fork of the North Anna River with the North Anna River proper.

Stations were also established on Contrary Creek (L-4), a small tributary of Contrary Creek (L-3), and the tributaries of the North Anna which would form the holding lagoons for heated water in the impoundment (L-5 through L-8). Other stations shown in Figure 2 were also visited, but with less frequency.

Description of Major Biological Stations

<u>Station IV</u>

The river at this station was approximately 40 to 50 feet wide and almost completely arched by trees. A large sand bar, covered with water willow, *Justicea americana* (L.) Vahl, split the river into two channels immediately upstream from the bridge. The riffle area began approximately 25 feet above the sand bar and persisted along each side of the sand bar and graded into a mud-sand bottom at the bridge. The pool area sampled was immediately above the riffle area. On the outside bend of the river, large boulders and a mud bottom were found in the pool area. Extensive leaf banks were present on the inside bend at the beginning of the riffle area. The riffle area was only moderate at best and a considerable amount of leaf debris was found throughout the riffle area.

Station B.C.C. – First Riffle Area
Below Confluence With Contrary Creek

This area was approximately 2000 feet below the confluence with Contrary Creek. The area immediately below the confluence was not sampled due to the lack of substrate and the presence of quicksand. This station was usually reached via canoes or john boats due to the dense vegetation along the banks. The river at this station was channeled to the north side and passed over a large log and across a bed of large flat rocks before spreading over a sandy bottom. The river at the pool site, immediately above the riffle area, was approximately 40 feet wide and attained depths of 5 to 6 feet. Upon being channeled to the north side, the river width decreased to approximately 20 feet. The rock slabs were covered with blue-green algae, predominately *Schizothrix friesii*. An open pasture was on the north bank at the riffle area while the south bank was very steep and wooded. Leaf banks were present just above and below the riffle area. A trough was present on the south side at the station opposite the riffle area and in high water during the winter months water coursed through the trough, creating a large island in the middle of the river.

Station VI – State Route 601

This station was located approximately 12 miles below the confluence of the North Anna with Contrary Creek. The river here was also channeled to the south side of the basin. An island split the river immediately below the first riffle area of large boulders. Upon reforming below the island, the river then passed into a trough and over another extensive riffle area. Large leaf banks were located on the north side of the island and the bottom consisted chiefly of muck and mud. Prior to channelization, the river was approximately 90 feet wide; after channelization the width decreased to 45 feet. In both riffle areas, the rocks were large, but movable, in contrast to the plate-like formations at the station immediately below the entrance of Contrary Creek.

The river was densely wooded on the north side, but open to a farm on the south.

Station VII – State Route 658

This station was approximately 14 miles below the confluence of the North Anna with Contrary Creek. At this station both banks were heavily wooded and the tree canopy along the banks nearly covered the stream. The river was split into two channels by a large island at the bridge. Both channels had a substantial riffle area and leaf banks were abundant above and below the riffle areas. Water willow was in abundance along the edges of the river bank and island. The channel on the north side was approximately 35 to 40 feet wide, and the channel on the south side approximately 45 to 50 feet. The island separating the two channels was about 25 to 30 feet wide.

Station L-4 – Contrary Creek at State Route 659

Contrary Creek exhibited an anastomosing pattern. Due to the erosion in the basin, none of the stream channels were permanent. At the bridge on State Route 659, the channel was 20 to 25 feet wide. A deciduous forest bordered the creek on the east, while a mixed forest of pine and deciduous trees bordered on the west. The stream bottom contained mostly fine sand, hard clay, or debris.

Station L-3 –Tributary of Contrary Creek (Avis' Trib)

This small woodland stream was the first upstream tributary on the east bank of Contrary Creek. Avis' Trib was approximately 1200 feet long from its origin to the junction with Contrary Creek. The banks were densely populated with birch which formed a complete canopy over the stream. The streambed varied in width through the study area (approximately 200 feet) from 1 foot in some of the riffle areas to 6 feet in some of the larger pools. Flow, maintained by the natural drainage of water from the surrounding woodlands, fluctuated considerably. The bottom of this small tributary was composed of sand and leaves in the pool areas and gravel and small rocks in the riffles.

Station L-5 – First Tributary
Below Reactor Site (Mel's Creek)

The collection of macrobenthos on this stream (which will form the first lagoon) was taken approximately four miles northeast of State Route 652. Mel's Creek is a small tributary of the North Anna River and, due to its isolation, was sampled only once. The stream at the collection site meandered around logs, limbs, and other debris and had long deep pools (1 to 3 feet) and short riffle areas. The stream was approximately 4 to 8 feet wide through the collecting site. The bottom of the pools consisted of decaying leaf and other vegetative matter covering coarse sand and silt. The riffle areas consisted of coarse sand and gravel. Large beds of Potamogeton and Elodea almost covered the entire streambed in some places. The banks were very low and densely thicketed with little or no canopy over the stream.

Station L-6 – Elk Creek

Elk Creek is a major tributary to the North Anna River in the pre-impoundment basin. The collecting site was located immediately downstream from the bridge on State Route 614. The creek had a very sluggish flow with long deep pools (2 to 4 feet deep) and one short sandy riffle area. The sediment of the pools consisted of coarse leaf and stick debris over a fine sandy bottom. The banks were densely wooded and formed a complete canopy over the stream. The stream was approximately 15 feet wide throughout the collecting site. Large mats of Typha had colonized the sides of the pools at the bridge.

Station L-7 – Pond Creek

Pond Creek is a tributary of Elk Creek, but it will also be a major arm of the cooling lagoon complex. Pond Creek, in contrast to the other streams, flowed through an open pasture at the collecting site upstream from the bridge on State Route 652. The creek was very narrow, 2 to 4 feet, but had a rapid flow. A few short riffles of gravel were present, but the major portion of the collecting site was dominated by narrow pools, 1 to 3 feet deep. Grass, from the surrounding pasture land, grew luxuriantly along the stream's edge. During high water through the months of December to April this grassy environment became a favorite habitat for many invertebrates. Fine leaf debris and twigs covered the sandy pool bottom.

Station L-8 – Reed's Creek

Reed's Creek will form the last major arm of the lagoon system. The collecting station was located on both sides of the bridge at State Route 652. The area was densely wooded and the banks were low and vertical. The stream was approximately 5 feet wide through the study area. It was characterized by a shallow, rapid flow through short pools and long riffle areas. The pool sediments consisted of coarse sand and gravel with small banks of leaf detritus. The riffle areas consisted of coarse gravel and small rocks.

METHODS

Collection of Samples

Collections were made predominantly at the stations indicated in Figure 2. Samples for bacteriological and routine chemical analyses were collected on a monthly basis while samples for detailed chemical analyses (nutrients, etc.) were collected on a quarterly basis. Biological collections used to evaluate community structure were also collected on a seasonal basis (summer, fall, winter). Qualitative biological collections used to supplement the evaluation of the benthic community were made at irregular intervals.

Physical

Temperature was measured with a calibrated long stem thermometer by immersing the thermometer until equilibration was established.

Flow rate data were obtained on a daily basis from a calibrated discharge station near Doswell, Virginia. The station is approximately 20 miles below the dam site of the impoundment basin and is maintained by the Virginia Department of Conservation and Economic Development, Division of Water Resources. According to their information, approximately 78% of the flow measured at Doswell flows through the proposed dam site. (See Table 3.)

Water samples collected for analyses of total non-filterable solids were filtered through 0.45-micron Millipore filters that had been previously dried and weighed on a Mettler Balance. After filtration, filters were again dried and reweighed to determine the dry weight of the suspended, non-filterable solids. The filters were subsequently ashed at 500°C for two hours to evaluate the organic and inorganic content of the suspended, non-filterable material.

Turbidity values were estimated by means of a Bausch and Lomb Spectronic 20 and are expressed in Jackson Turbidity Units (JTU).

Chemical

Oxygen samples were collected with a sewage sampler and were analyzed by the Alsterberg (Azide) Modification of the Winkler Method (American Public Health Association, et al., 1960).

Alkalinity samples were also collected with a sewage sampler and analyzed by the potentiometric method after establishing a differential titration curve (American Public Health Association, et al., 1960).

The hydrogen ion concentration was determined electronically with a Corning pH Meter.

Some nutrient samples were analyzed with a Bausch and Lomb Spectronic 20 and Hach chemical reagents. Standard curves were established for each type of analysis performed. Other nutrient samples were analyzed by the State Water Control Board. The analyses of those samples were congruent with the type of analyses which the Board performs.

Qualitative samples were collected with a D-frame aquatic dip net.

Quantitative samples were also collected with D-frame dip nets, but collections were made for specified periods of time with an equal amount of effort being expended at each collection site (Macan, 1958; Roback, et al., 1969; Frost, et al., 1971). This procedure was utilized in lieu of other more quantitative means for several reasons. The nature of the river bottom substrate did not lend itself to sampling with conventional square foot devices, due to the paucity of riffles in the river. The bottom was composed primarily of sand, leaf debris, logs, and pools, rather than the typical rubble-cobblestone bottom where such square foot devices are usually employed. In addition, the water level in the river during the winter months physically prohibited the use of hand-operated, unit area, bottom sampling devices. A ponar dredge (~ 45 lb) was used on one occasion during high water, but proved to be equally unsuccessful due to the velocity of the river current.

Moreover, the purpose of the study was to sample and evaluate the entire macrobenthic community in the pre-impoundment basin, rather than a specific habitat. Hence, it seemed more reasonable to utilize a method which would transect all available types of habitat.

Furthermore, by obtaining a relatively large sample of the benthic community, the material utilized for community structure analysis could also be utilized for radiological analysis. The background radiation was expressed as picocuries/milligram wet weight of tissue. Thus, duplication of effort was eliminated.

Community structure at the various stations was analyzed as a diversity index based on the sequential analysis technique of Cairns, et al. (1968). Samples collected in the field were immediately preserved in formalin and subsequently sorted in the laboratory.

Bacteriological

Water samples for bacteriological analysis were collected in sterilized bottles and carried through the Confirmed Test of the Multiple Tube Fermentation Technique (American Public Health Association, et al., 1960). The density of the coliform group was expressed as the Most Probable Number/100 ml of water (MPN/100 ml). Part of the water samples were also carried through the Presumptive Test with Buffered Azide Glucose Glycerol Broth (BAGG) for the determination of fecal streptococci.

Radiochemical

Radiochemical analyses were conducted on biological samples by the Virginia State Department of Industrial Hygiene and the Virginia Electric and Power Company and were congruent with the type of radiological analyses which the respective agencies perform. Analysis was made for the following gamma emitters: Barium - 140, Cerium - 144, Cesium - 127, Iodine - 131, Iron - 59, Potassium - 40, Ruthenium - 103, Zinc - 65, and Zirconium-Niobium - 95.

RESULTS AND DISCUSSION

Physical Aspects

Flow Characteristics

The North Anna River meanders slowly through Piedmont Virginia. The drainage basin has very few municipalities or industries; most of the area is farmed for agricultural crops, livestock, or timber. The river suffers from a paucity of rock outcroppings which would lend to the formation of extensive riffle areas. The few riffle areas present within the pre-impoundment basin are mostly the remains of old mill dams which have been broken down and strewn along the immediate river bottom. The riverbed within the pre-impoundment basin is characteristic of a depositional area, and the major portion of the bottom is characterized by shifting sand. Aside from the few riffles, the only permanent substrates are the large logs, limbs, and accompanying leaf debris which are common constituents on the river bottom. Where sandbars attain some degree of permanence, water willow (Justicia americana (L.) Vahl.) is quick to colonize and in turn affords a suitable habitat for many macrobenthic organisms which would otherwise not be able to survive.

Discharge data[1] show that the highest flow rates occur in early spring (March-April) which corresponds with runoff from spring rainfall. The maximum mean monthly discharge of 222 cfs in April 1969 is overshadowed only by the record flood (Camille) in August 1969, when the mean monthly value of 2,688 cfs was recorded. The maximum flow during the flood peak was 24,300 cfs. Flow rate in the North Anna River was quite variable and closely related to precipitation in the area.

Temperature

Temperature values in the river were very constant through the pre-impoundment basin on any given collection date. The annual temperature of the main river in the pre-impoundment basin makes an excursion of approximately 31°C. Water temperature is 5.0°C or lower during the months of December through February. Ice formation was quite common in the river during January and February 1969. In some cases the river was completely

[1] Available in tabular form from the Bureau of Water Resources, State Water Control Board, 11 South 10th Street, Richmond, Virginia 23219.

frozen over except for a small mid-channel. The temperature climbed rapidly through April and remained in the middle 20's ($^{\circ}$C) throughout the summer months. The temperature began to decline in August and fell rapidly through October. Figure 8 shows the annual temperature cycle of the river in the pre-impoundment basin. Each value is an average for the river on that date. Raw data are tabulated in Appendix 1.

Total Non-Filterable Solids

Initially it seemed that the fluctuation in the sediment load carried by the river would be demonstrable within the station sites established in the pre-impoundment basin. However, the data reinforce Minckley's observation (1963) that the concept of a water column, long used in lentic studies, is not applicable in lotic investigations. There was much variation in the sediment concentration at the station sites, and no relationship to river mile was evident. The collection sites were not close enough to measure shifts in sediment loads. As an illustration of this, collections were made at Stations I and II on February 26, 1970. A new bridge was being constructed on this date at Station I and the sediment load was high (88.9 mg/l) for this station. However, the river had deposited this load and returned to normal 11.5 miles farther downstream. Moreover, on two occasions, September 20, 1969, and January 20, 1970, the level of suspended solids rose from 41.3 to 203.4 mg/l and 45.2 to 130.7 mg/l, respectively, between two stations only 1.6 river miles apart. There is no known major source of sediment influx through this distance.

Even though there was considerable variation at individual stations, a statistical comparison between the stations (4) upstream and downstream (3) from Contrary Creek showed a significant difference in non-filterable solids at the 10% level (t_{73} = 1.3176). Contrary Creek usually carries very little suspended material. Parsons (1968) stated that acid polluted streams are usually clear because of oxidation and subsequent precipitation of the metals, which pulls the other suspended material from the water. The average of eight total solids samples taken from this tributary, exluding flood or high water conditions, was 15.8 mg/l. Under high water or flood conditions, this value rose to 1623.0 mg/l. Evidently Contrary Creek loads the downstream area with sediment under flood conditions and the sediment is sporadically removed. The tributaries to the North Anna, which will eventually form the cooling lagoons, averaged 8.4 mg/l.

To date no known standards have been imposed regarding total non-filterable solids on Virginia's Waters. Cairns (1968) states that arbitrary standards of fixed concentrations cannot be set for all systems; rather the tolerance range for the respective drainage system and region should be established. The recommendation for Settleable Solids by the National Technical Advisory Committee to the Secretary of the Interior (1968) is such that settleable materials should not be added to natural waters in quantities that adversely affect the natural biota. Since no definitive standards are available, it is difficult to determine whether or not the sediment load is excessive or minimal in the North Anna River.

Based upon the National Technical Advisory Committee's standards for settleable solids, waters containing 80 to 400 mg/l suspended solids are unlikely to support good freshwater fisheries. Waters containing 25 to 80 mg/l suspended solids can usually support a good or moderate fishery. As Appendix 2 shows, the North Anna River rarely exceeded 80 mg/l of non-filterable solids. Based upon this criterion, one would expect the fishery of the river to be good or moderate. However, the density and quality of fishes collected in the North Anna River, below the confluence with Contrary Creek, indicated a very poor fishery (Simmons and Reed, in press).

Turbidity measurements also failed to show major differences between the area upstream from Contrary Creek and that below. Of the 60 turbidity readings taken in the pre-impoundment basin on the North Anna River itself, 96.6% were over 25 JTU, 60% over 50 JTU, 25% over 75 JTU, and 10% over 100 JTU. The greatest turbidity occurred in September 1969, when nearly all stations registered over 100 JTU. The area below Contrary Creek on this date averaged 149 JTU. The lowest turbidities were during the months of February and March. Probably the sudden thunderstorms during the summer months created a greater level of turbidity than at other times. It is also possible that during the summer months the unconsolidated silt from the stream bottom could also have been resuspended which would have increased the turbidity levels (Stuart Neff, personal communication). During the winter months when the ground is frozen and torrential rains are less frequent, the effects of turbidity are lessened.

As with the total non-filterable solids, the turbidity values for Contrary Creek were low. The values over the period of study averaged 62 JTU with a range between 30 JTU and 109 JTU. The tributaries of the river forming the future lagoons averaged 41 JTU with a range between 26 JTU and 56 JTU.

Chemical Aspects

Oxygen

Figure 8 and Appendices 4 and 5 show the average oxygen levels in the North Anna River in the pre-impoundment basin. As the data show, the concentrations (and percent saturation) were highest during the winter months. The lowest oxygen value obtained prior to dam construction, 6.4 mg/l, was in August 1969, and the highest values, greater than 13.0 mg/l, occurred in January 1969. Even during the summer months, oxygen saturation values were usually in excess of 80%. During the spring of 1970, lower than normal oxygen values were obtained at Station VI, immediately below the dam site. In comparison to the previous year at the same time, the oxygen concentration was depressed approximately 2 mg/l. On any given collection date, the oxygen concentration in the river was greatest at Station III. This was due to the collection of water samples at a bridge immediately below a small waterfall at Holladay Mill Pond. The increase was quickly lost, however, and saturation values returned to normal.

Alkalinity and pH

Analyses of water samples for alkalinity and pH showed that the river water was neutral-basic with soft-medium hardness. These values are shown in Appendices 6 and 7.

Alkalinity values ranged between 11 and 33.0 mg/l with values at Station V (below Contrary Creek entrance) being lower than Station IV (above Contrary Creek entrance). A statistical comparison of the alkalinities between the upstream and downstream stations from Contrary Creek showed a significant difference at the 10% level ($T_{85} = 4.8524$).

Minerals and Nutrients

The chemical analyses of nutrients also showed a great deal of variation between stations. As would be expected, iron, magnesium, and sulfur (in the form of sulfates) were the most abundant. Iron was usually present at concentrations near 1.0 mg/l. The concentration of magnesium was greater, usually being several milligrams per liter higher below the entrance of Contrary Creek. On February 16, 1969, the concentration of magnesium reached 13.88 mg/l at Station V, 4 miles below Contrary Creek. The value then dropped to 3.07 mg/l within 8.6 miles. Sulfate concentrations varied considerably and were not always associated with the area immediately below the entrance of contrary Creek. Concentrations of copper usually ranged between 0.5 and 1.0 ppm and zinc near 1.0 ppm. As with the nutrients, the concentration of these metals was not always greatest immediately below Contrary Creek.

The State Water Control Board reported a fish kill below Contrary Creek on September 28, 1970. Investigators were on the scene at the next high water period on October 22, 1970, and reported 1.91 mg/l zinc, 0.02 mg/l chromium, 0.23 mg/l lead, 8.2 mg/l copper, and 28.0 mg/l of iron at State Route 652 on Contrary Creek. The discharge rate of the North Anna River was 39 cfs on October 21, increased to 84 cfs on October 24, and decreased to 57 cfs on October 28. From October 1 to October 15, the discharge rate in the river ranged between 14 and 18 cfs. Approximately 0.50 inches of rain fell in the area on October 15 and 1.40 inches on October 21.

Analysis of the water and a water-sediment slurry on Contrary Creek at a low flow period showed considerable quantities of iron, silicon, calcium, aluminum, magnesium, barium, titanium, lead, manganese, copper, and zinc. A summary of the analysis is presented in Table 4.

Mackenthum (1968) proposed that the concentration of phosphorus in flowing water should not exceed 0.1 mg/l if biological nuisances are to be avoided. Phosphorus values exceeded this recommended level only once during the study. The extremely high phosphorus values observed in May 1969 were probably due to the result of agricultural fertilizing (Taylor, 1967; Wadleigh, 1970). This collection date was a peak river flow after a rainfall. Reid (1961) states that the nutrient level of streams varies considerably with discharge rate. Usually the concentrations increase as the flow rate rises and then diminish as the flushing action of water subsides.

Benthic Studies

The greatest contrast in water quality in the pre-impoundment basin centered around the effects of drainage from Contrary Creek upon the macrobenthic communities (Table 5). Figure 9 summarizes the tabulated data and shows the mean seasonal diversity index of macrobenthic communities for one year in the study area. As Figure 9 illustrates, the range of the diversity indices at the control station (Station IV – State Route 208) was very small (SD = ±0.02); whereas, the range at the farthest point downstream (Station VII – State Route 658) was four times greater (SD = ±0.08). Contrary Creek showed the greatest range of community diversity (SD = ±0.19) and always exhibited the lowest diversity index at any time. Using the Wilcoxon Rank Sum Test (Wilcoxon and Wilcox, 1964) a statistical comparison of diversity indices between the control station (State Route 208), and the stations below the entrance of Contrary Creek showed no significant differences of diversity indices (critical difference = 32) at the 5% level. This would indicate that the river recovers immediately below the Contrary Creek entrance. However, a different picture emerges if population sizes, species numbers, and composition of community structure are compared between these two stations.

Figures 10 through 14 and Table 7 summarize the macrobenthic collections at the river stations and on Contrary Creek. Although there was some variation of representation of the various orders between seasons, the more sensitive macrobenthic groups (Plecoptera, Ephemeroptera, Trichoptera, and Mollusca) (Gaufin and Tarzwell, 1952; Gaufin, 1958) were well represented at all times at the control station. Shifts of representation in the natural community were mainly due to alternations of density between the Plecoptera, Ephemeroptera, and Trichoptera. On one occasion (spring 1970) at the station below Contrary Creek the Diptera showed a wide departure from an otherwise stable level. This departure was due to the increased density of Simulium.

Figure 11 shows the results of the collections at the first riffle area below the confluence of the North Anna River and Contrary Creek. The fall 1969 collection is not included in Figure 11 because the samples were improperly preserved after establishing the fall diversity index and were lost. Based upon the other collections, however, it can be seen that the Plecoptera, Trichoptera, and Diptera were the dominant macrobenthic groups collected at this station. The dominant plecopterans collected were Perlesta placida and Acroneuria sp., and Hydropsyche sp. was the dominant caddisfly collected. The dominant dipteran alternated between the occurrence of Simulium and several species of Chironomidae. The superabundance of Simulium during the spring of 1970 was the main reason for the large number of Diptera collected during the spring season. It is important to remember that the density of organisms collected from this station was very low when compared with the other stations (Table 6). It appears that the density of the community at this station is more indicative of acid mine stress, rather than the presence or absence of any particular species group (Keup, 1966).

Station VI (State Route 601) was an excellent habitat for collecting. Several distinct habitats prevailed in the collecting area. However, as Table 6 shows, the density of the macrobenthic fauna was lower here than at the upstream control station and the diversity was much less. It is also important to note that the molluscan elements had not returned. Figure 12 shows the results of seasonal collections at this station. The sensitive insect orders were well represented, but the overall density was lower than observed at the control station (Station IV – State Route 208). The large percentage of Hemiptera collected in the summer 1969 collection was due to the fact that on this date the river was exceptionally high and the students were unable to collect in the riffle areas. As a result, most of the collecting was made at the river's edge where the corixids, particularly, occurred in large numbers.

Figure 13 shows an analysis of community structure at Station VII. Again, while the more sensitive insect orders have become re-established, the molluscan species have not. The mollusks at Station IV represented 23 to 44% of the benthic community. Table 6 lists the values for sample size and species numbers for the stations considered in the study. Even though there was no significant difference between the diversity indices at Station IV (control) and the downstream stations, there was a significant difference ($P \leqslant 0.1$) between the sample size ($t_6 = 3.0681$) and the number of species represented ($t_6 = 1.7521$) at Station VII (farthest downstream station). Great care was taken during the first three collecting periods to see that equivalent amounts of time were spent at each station. The sample sizes at Station IV were very consistent; whereas, the sample size at Station VII varied considerably. The increase in the sample size at Station IV for the summer season, 1970, was due to a longer collection time being spent at the station. The basin was being cleared, and an effort was made to obtain as many organisms as possible. Since the sample size at Station VII did not show a corresponding increase, it is difficult to assess the significance of an extended collecting time on the sample size at Station VII. The inability of the diversity indices to show a significant difference probably originates from the small sample sizes in some of the collections at Station VII. Cairns, et al. (1968), in proposing the technique, stated that approximately 200 to 250 organisms are needed to obtain a valid index. As Table 6 shows, this number was not obtained on two occasions.

As stated earlier, the diversity index on Contrary Creek was consistently lower than any of the other stations. Figure 14 shows the seasonal composition of the macrobenthic community on this acid polluted stream. Note that the dominant order was the Diptera and this consisted of one chironomid species close to Chironomous attenuatus. The majority of the other species collected were surface water forms such as Gerris conformis or Dineutus vittatus. Other species of aquatic insects were collected, but nearly all of these consisted of last instar stages. All species of aquatic insects, other than the chironomid species, could be found in the unpolluted upstream tributaries of Contrary Creek. Since only the last instar forms were found, it would appear that the macrobenthic fauna on Contrary Creek, other than the chironomids, is derived from the drift fauna from upstream tributaries (Waters, 1961a, 1961b).

One such tributary, L-3 (Avis' Trib), was studied in detail for nearly a year in relation to using a new artificial substrate (Simmons and Winfield, 1971). The results of the substrate study provided a detailed analysis of the macrobenthic community and many organisms indicative of clear, cool, unpolluted streams were present. Some of these included such species as Heteroplectron americanum, Anisocentropus pyraloides (Trichoptera), Cordulegaster fasciatus (Odonata), and Nigronia serricornis (Megaloptera). Community structure was evaluated in 1969 before basin clearing began and in 1970 after the area had been cut over and the marketable timber removed. Figure 15 shows that in 1969 the diversity index was 0.92 and that the Annelida, Odonata, Megaloptera, and Trichoptera were well represented in the community. The Diptera constituted less than 5% of the community. During the spring of 1970 the area was logged. All of the riffle and pool areas were covered with sediment and by the 1970 collecting period, the bottom area could best be described as a silt-sand habitat. Figure 16 shows that the Diptera, which occupied less than 5% of the community in June 1969, composed nearly 85% of the community in June 1970. The other groups, particularly the Annelida, showed a drastic decline. As a result, the community diversity index declined to 0.58. The results of the study on Avis' Trib agree with those of Aggus and Warren (1965) who found that the Diptera "appeared to increase" after the clearing of the Beaver Reservoir Basin. The resulting observation is that the quality of water in Contrary Creek probably approached Avis' Trib (Station L-3) as observed in June 1969 before the mining activities began.

After the first summer of collecting, it was established that the sample sizes at Station VII were consistently lower than observed at Station IV, and the molluscan species had not become re-established at Station VII. A study was undertaken during the fall of 1969 to evaluate the community structure in the tributaries of the North Anna River which would form the lagoon system in the new reservoir (Stations L-5, L-6, L-7, and L-8) (Thomas and Simmons, 1970). Figures 17 through 20 represent the results of the study. The investigation revealed that five of the seven molluscan species collected at Station IV could be found in one or more of the tributaries. It is a well-established fact that benthic invertebrates exhibit drift, and Hynes (1970) has reviewed the subject in detail. Although drift studies have indicated that the gastropod species drift very little (Hynes, 1970), it is reasonable to assume that these species are being introduced into the recovery area, but are failing to become re-established. Even though the pelecypod species would not fall into the drift category, it would seen that these species would be well adapted for re-introduction into these areas through the glochidia's obligatory parasitization of fish (Coker, et al., 1921).

The effects of the acid drainage from Contrary Creek were studied during September 1954 by the Limnology Department of the Academy of Natural Sciences of Philadelphia (1955). Their study extended from the confluence of Contrary Creek and the North Anna River downstream approximately 40 miles to State Route 602. Their studies also showed that the station at State Route 208 was "healthy," while the stations below the entrance of Contrary Creek showed the effects of the acid drainage. The Academy distributed their stations from State Route 208 to State Route 602 just below Doswell, Virginia, and found that complete recovery did not occur in the river.

Bacteriology

The coliform and fecal streptococci count showed considerable longitudinal variation in the river at any collecting period. The variation between collecting periods appeared to be more closely related to rainfall and river discharge than any other variable. The coliform density was greatest on September 20, 1969, and January 20, 1970. There was a tendency for the mean density of coliforms above State Route 208 to be greater than those from the area from State Route 208 to State Route 658 (1930.0, N = 38 vs 1648.4, N = 68; where N = the number of observations at the respective stations above and below Contrary Creek). The exact coliform discharges above State Route 208 were not identified. The tributaries which will form the lagoon system in the reservoir showed considerably lower mean coliform counts than those observed in the river. Of the three tributaries studied, Reed's Creek showed the lowest mean density: Elk Creek = 618.3 (N = 6); Pond Creek = 594 (N = 5); Reed's Creek = 145 (N = 4). Contrary Creek had the lowest mean density of coliforms observed anywhere in the study, 104 (N = 12).

The highest fecal streptococci counts also occurred on September 20, 1969, and January 20, 1970. Like the coliform counts, the mean density of fecal streptococci was greatest above State Route 208 (631, N = 19 vs 316.2, N = 34). The tributaries of the North Anna which will form the lagoon system showed little variation in fecal streptococci densities. Elk Creek showed a mean density of 143.3 (N = 3), Pond Creek 53 (N = 3), and Reed's Creek 55 (N = 2). The densities observed in the tributaries, as can be seen, were considerably lower than those observed in the main river. Contrary Creek showed the lowest mean fecal streptococci density of any area studied, 13.8 (N = 8). The raw data for both types of densities can be found in Appendices 9 and 10.

Radioisotopes

Appendix 11 shows a tabulation of samples sent to VEPCO and Department of Industrial Hygiene. VEPCO reported that gamma scans indicated less than five picocuries (pCi) per total sample for the following isotopes: Fe - 59, Co - 60, Zr - 95, Ru - 106, and Cs - 137. The Department of Industrial Hygiene counted beta radiation in the mussel sample and reported the activity as shown in Appendix 11. As can be seen from the data, the background radiation levels are below the recommended level of the water quality standard proposed by the Virginia State Water Control Board (1970).

CONCLUSIONS

The North Anna River is a typical Piedmont river showing a natural paucity of riffle areas. The major portion of river bottom consists of a mud-sand bottom interspersed with tree debris. The stream fauna is indicative of a warm water depositional habitat.

The information gathered thus far on existing water quality conditions in the pre-impoundment area on the North Anna River shows that Contrary Creek has severely altered the macrobenthic communities below its confluence with the North Anna River. Even though the drainage from Contrary Creek is consistently acidic, the alteration in community structure appears to be due to the presence of heavy metals and silt draining from Contrary Creek rather than the creek's low pH. Available water chemistry analyses indicate that the river is periodically "slugged" with heavy metals and silt at the onset of rainfall periods.

Even though the diversity indices indicate that the North Anna River recovers below the entrance of Contrary Creek, a biological interpretation reveals that the river does not recover biologically at the lowest station, which is 14 miles below the entrance of Contrary Creek. The biological interpretation is based upon the fact that the molluscan portion of the macrobenthic community never became re-established below the entrance of Contrary Creek within the study area. Even though the molluscan species are probably being reintroduced from the tributaries, they are failing to become re-established.

Above the entrance of Contrary Creek, all of the major groups of the macrobenthos could be found. The mollusca were particularly well represented in the community and composed from 22.3 to 44.4% of the community. Observations at the control station (Station IV – State Route 208) showed that the maximum variation within any group between seasons was approximately 20%. Other groups showed less than 10% between seasons. The control station also exhibited the most consistent density and greatest number of species. The macrobenthic groups at the other stations, on and below Contrary Creek, showed greater variation of representation, density, and number of species present. The density of the benthos at the stations below the entrance of Contrary Creek was particularly variable.

The point at which the North Anna River recovered, to the extent that the macrobenthic community was comparable in diversity and members to the area above Contrary Creek, was not determined during this phase of the study.

The drainage from Contrary Creek had no effect on the temperature, oxygen, nutrient, or bacteriological levels in the North Anna River. The coliform density in the river, although occasionally high, does not appear to constitute a major water quality deterrent to the future impoundment. Analyses showed that the background radiation levels were also very low, even in the macrobenthic samples collected on Contrary Creek. The greatest deterrent to water quality in the river and future reservoir is and will continue to be the persistent drainage of sediment and heavy metals associated with the mined and eroded areas on Contrary Creek.

Since the old spoil banks and mine sites on Contrary Creek will not be covered by the impoundment, precautions should be taken to halt any erosion, siltation, and heavy metal introduction into the new reservoir. Otherwise, the reservoir will probably concentrate these biological deterrents and could become a biological desert. Flushing of the impoundment during periods of heavy rainfall could cause the further deterioration of the biological communities below the impoundment site.

The results of the study thus far support the observation that the Virginia Electric and Power Company is building their impoundment on the most suitable Piedmont river because, ecologically speaking, the water quality is such that the existing biological community has been seriously damaged by the drainage from Contrary Creek. The presence of the impoundment will in all probability enhance the future water quality of the North Anna River Basin and increase the recovery rate of the area below the dam. The recovery zone is expected to move upstream as the drainage effects of Contrary Creek subside.

Additional Studies

Virginia Electric and Power Company supported a study during the summer of 1971 to locate and define the recovery zone of the North Anna River. The recovery area was found to be immediately below the confluence of the North Anna and South Anna Rivers. A detailed report of the results of the summer study has been submitted to the Virginia Electric and Power Company and published results will be forthcoming.

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TABLES

TABLE 1

MORPHOMETRIC DATA OF PROPOSED RESERVOIR ON THE NORTH ANNA RIVER[1]

Type of dam	Compacted earth
Length of dam	3,000 feet
Drainage area	343 square miles
Approximate total area	14,500 acres
Approximate area available for recreational use	9,400 acres
Approximate area used to hold thermal effluent	3,600 acres
Volume - acre feet at 250 ft elevation	360,000 acre feet
Volume - cubic feet at 250 ft elevation	15.7×10^9 cubic feet
Approximate length of reservoir	15 miles
Normal pool elevation	250 MSL
Depth of water at dam	80 feet
Length of shoreline	105 miles
Maximum recorded flow of river	24,300 cfs (August 21, 1969)
Minimum recorded flow of river	1 cfs (September-October, 1932)

[1]Condensed from brochure submitted by VEPCO to the Virginia State Water Control Board for certification of project.

TABLE 2

ENGINEERING FEATURES OF PROPOSED IMPOUNDMENT OF LIMNOLOGICAL INTEREST AND IMPORTANCE[2]

Type of electrical generating facility	Nuclear powered
Potential number of generating units	4
Potential kilowatt capability	4,000,000
Proposed beginning of commercial operation of first unit	1974
Amount of water needed for cooling unit No. 1	1,600 cfs
Amount of water needed for cooling at maximum operating capacity	4% of reservoir volume per day
Minimum flow guaranteed regardless of reservoir level	40 cfs
Maximum temperature of discharge into treatment lagoon at maximum operating capacity	38°C
Projected maximum temperature in lake at maximum operating capacity	32°C

[2] Ibid. p. 12.

TABLE 3

LOW FLOWS FROM ADOPTED FLOW FREQUENCY CURVES
NORTH ANNA RIVER NEAR DOSWELL, VIRGINIA
DRAINAGE AREA = 439 SQUARE MILES[3]

Duration	Recurrence Interval in Years				Most Probable	Mean
	2	5	10	30		
1 Day	35.0 cfs	10.0 cfs	5.0 cfs	2.0 cfs	49.0 cfs	27.0 cfs
7 Days	45.0 cfs	15.0 cfs	6.5 cfs	3.0 cfs	58.0 cfs	38.0 cfs
30 Days	70.0 cfs	25.0 cfs	12.0 cfs	5.0 cfs	–	–
60 Days	85.0 cfs	35.0 cfs	20.0 cfs	10.0 cfs	–	–
120 Days	150.0 cfs	55.0 cfs	40.0 cfs	28.0 cfs	–	–
274 Days	220.0 cfs	150.0 cfs	140.0 cfs	100.0 cfs	–	–

Average Flow Over 35-Year Period = 380 cfs

[3]Virginia Department of Conservation and Economic Development. Division of Water Resources. Vol. III – Hydrologic Analysis, York River Basin. Planning Bulletin 227.

TABLE 4

ANALYSES OF WATER AND WATER/SEDIMENT
(SIMULATED HIGH DISCHARGE)
DURING LOW FLOW CONDITIONS ON CONTRARY CREEK
AT STATE ROUTE 522, AUGUST 10, 1970

Element (ppm)	Water	Water/Sediment
Iron	78.09	465.04
Silicon	51.05	465.04
Calcium	21.62	36.54
Aluminum	18.62	212.59
Magnesium	28.23	93.01
Barium	nil	2.49
Boron	trace	nil
Titanium	nil	6.31
Lead	0.34	2.16
Manganese	3.84	2.96
Gallium	nil	0.16
Nickel	0.02	0.04
Vanadium	nil	0.08
Copper	0.19	0.73
Sodium	trace	23.58
Zinc	9.61	10.63
Silver	nil	0.02
Cobalt	0.13	0.14
Potassium	trace	trace
Strontium	0.04	0.16
Chromium	0.01	0.24
Other Elements	nil	nil
Total Solids, mg/l	1045.35	3288.83
Sulfate ash, mg/l	600.73	3321.73
% of T. S.	57.47	101.00

TABLE 5

DIVERSITY INDICES OF THE CONTROL, POLLUTED AND RECOVERY STATIONS IN THE PRE-IMPOUNDMENT AREA ON THE NORTH ANNA RIVER

Station No.	IV State Route 208	L-V State Route 652 Contrary Creek	Below Entrance Contrary Cr.	VI State Route 601	VII State Route 658
Diversity Index					
Summer - 1969	0.93	0.20	0.83	0.58	0.99
Fall - 1969	0.92	0.01	0.56	0.72	0.87
Spring - 1970	0.90	0.50	0.80	0.93	0.90
Summer - 1970	0.96	0.06	0.70	0.92	0.77
Mean	0.92	0.19	0.72	0.78	0.88
S. D.	0.0217	0.1907	0.1054	0.1462	0.0785

TABLE 6

SAMPLE SIZES AND NUMBER OF SPECIES COLLECTED AT THE CONTROL, POLLUTED AND RECOVERY STATIONS IN THE PRE-IMPOUNDMENT AREA ON THE NORTH ANNA RIVER

Station No.	IV		L-V				VI		VII	
Location	State Route 208		State Route 652 Contrary Creek		Below Entrance of Contrary Creek		State Route 601		State Route 658	
Collection Period	Sample size	No. of species	Sample size	No. of species	Sample size	No. of species	Sample size	No. of species	Sample size	No. of species
Summer - 1969	1152.0	49.0	208.0	9.0	77	24	729	33	495.0	42.0
Fall - 1969	1174.0	46.0	135.0	4.0			838	38	80.0	34.0
Spring - 1970	1128.0	31.0	45.0	3.0	149	15	68	18	51.0	18.0
Summer - 1970	2848.0	48.0	833.0	10.0	140	12	596	35	313.0	34.0
Mean	1575.5	43.0	305.3	6.5	122.0	17	557.8	31	234.8	32.0
S. D.	734.9	7.3	310.1	3.0	32.0	5.1	295.5	7.7	181.4	8.7
S. E. Mean	367.4	3.6	155.1	1.5	18.5	2.9	147.7	3.9	90.7	4.4
95% Conf. Limits	720.2	7.2	303.9	3.0	36.2	5.8	289.6	7.6	177.7	8.5

TABLE 7

REPRESENTATION OF MAJOR MACROBENTHIC GROUPS AT THE MAJOR BIOLOGICAL STATIONS IN THE NORTH ANNA STUDY
(Percent of Community Population)

	Annelida	Amphipoda	Decapoda	Odonata	Ephemeroptera	Plecoptera	Hemiptera	Megaloptera	Trichoptera	Lepidoptera	Coleoptera	Diptera	Mollusca
State Route 208													
Summer '69	0.5	0.1	2.5	1.5	21.7	13.2	0.9	0.4	23.3	0.2	2.5	0.7	27.3
Fall '69	1.1	0.1	0.4	4.8	14.7	1.1	0.1	0.7	29.9	-	1.1	2.2	44.4
Spring '70	0.4	-	0.4	0.4	2.5	16.4	-	0.1	35.9	0.1	0.4	14.3	29.4
Summer '70	-	-	0.8	1.8	16.0	8.0	0.1	0.1	43	-	5.0	0.8	22.3
Contrary Creek													
Summer '69	-	-	-	0.5	-	1.0	3.3	1.8	1.0	-	2.4	89.9	-
Fall '69	-	-	-	1.0	-	-	1.5	-	-	-	1.5	96.0	-
Spring '70	-	-	-	-	-	11.0	-	-	-	-	2.2	86.0	-
Summer '70	-	-	-	0.1	-	-	0.6	0.1	0.1	-	3.0	96.0	-
Below Contrary Creek													
Summer '69	-	-	11.6	6.0	9	6	5.0	9	31.1	-	9	11.6	-
Spring '70	0.7	-	-	-	0.7	16.2	-	-	18.9	-	-	52	-
Summer '70	-	-	5.0	-	-	32.1	1.4	-	49.3	-	3.6	8.6	-
State Route 601													
Summer '69	3.5	-	6.0	2.7	3.6	4.3	72	0.2	1.4	-	3.8	2.2	-
Fall '69	0.4	0.7	1.5	1.5	13.1	0.2	2.2	3.3	56.8	-	8.6	11.5	-
Spring '70	7.4	-	4.8	-	1.5	19.1	-	20.6	16.2	-	5.9	25.0	-
Summer '70	0.8	-	3.5	0.7	5.9	44.0	0.5	1.2	27.7	0.2	5.2	10.4	-
State Route 658													
Summer '69	0.8	-	4.9	11.8	5.8	26.6	2.2	5.8	29.1	0.4	10.7	16.2	-
Fall '69	-	-	1.3	1.0	18.8	-	1.3	1.3	12.5	-	4.3	12.5	-
Spring '70	-	-	2.0	6.0	7.1	33.0	-	-	20.0	-	7.1	24.0	-
Summer '70	-	-	1.5	4.0	2.0	47.0	4.0	2.0	16.0	-	6.0	4.0	-

FIGURES

FIGURE 1. PROPOSED IMPOUNDMENT ON THE NORTH ANNA RIVER.

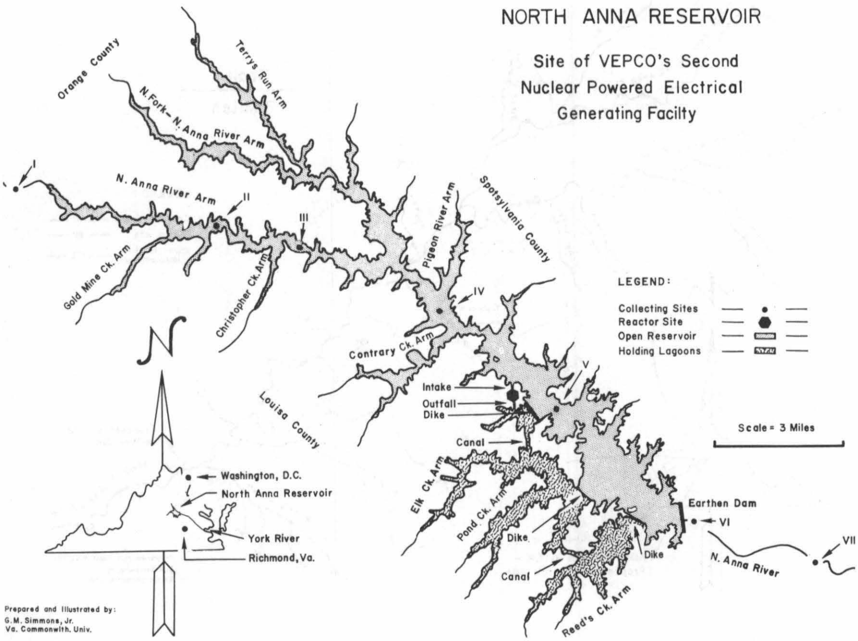


FIGURE 2. DRAINAGE BASIN OF PROPOSED IMPOUNDMENT SHOWING COLLECTING SITES.

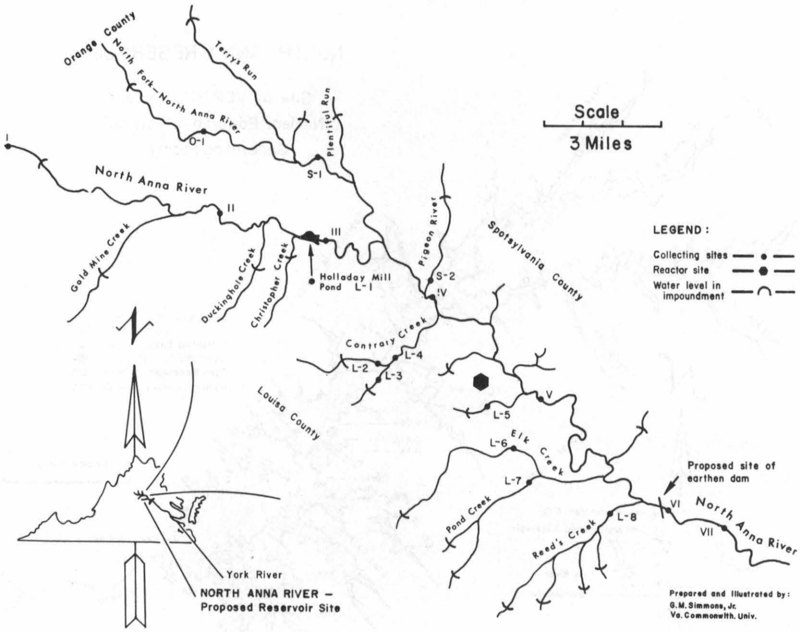


FIGURE 3. LONGITUDINAL PROFILE OF NORTH ANNA RIVER THROUGH THE PRE-IMPOUNDMENT BASIN.

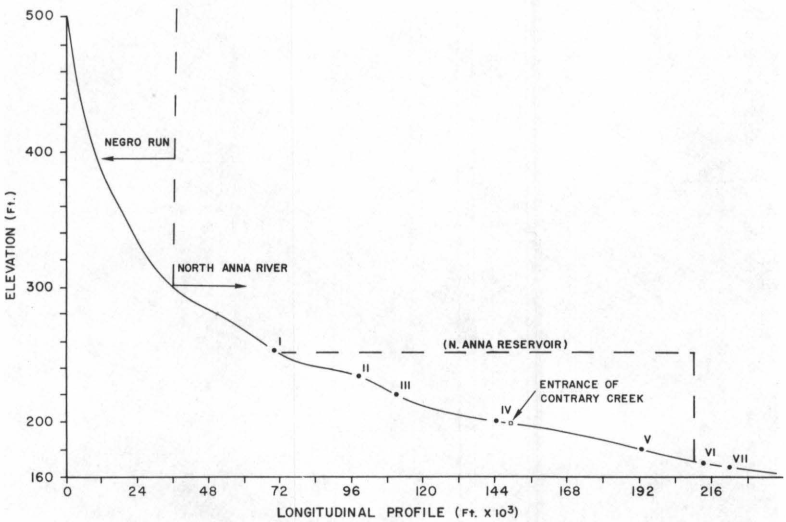


FIGURE 4. AERIAL PHOTOGRAPH OF A PORTION OF THE CONTRARY CREEK BASIN. STATE ROUTE 652 - STATION L-4 AND BRIDGE ACROSS CONTRARY CREEK ARE IN FOREGROUND.

FIGURE 5. EROSIONAL EFFECTS OBSERVED FROM BRIDGE ON STATE ROUTE 652 ACROSS CONTRARY CREEK. LEFT OF CENTER UPSTREAM VIEW.

FIGURE 6. EROSIONAL EFFECTS CAUSED BY ACID MINE DRAINAGE AS OBSERVED FROM BRIDGE ON STATE ROUTE 652 ACROSS CONTRARY CREEK. CENTER UPSTREAM VIEW.

FIGURE 7. EROSIONAL EFFECTS CAUSED BY ACID MINE DRAINAGE AS OBSERVED FROM BRIDGE ON STATE ROUTE 652 ACROSS CONTRARY CREEK. RIGHT OF CENTER UPSTREAM VIEW.

FIGURE 8. SUMMARY OF TEMPERATURE, OXYGEN, AND PERCENT SATURATION OF OXYGEN FOR THE STUDY PERIOD IN THE PRE-IMPOUNDMENT BASIN.

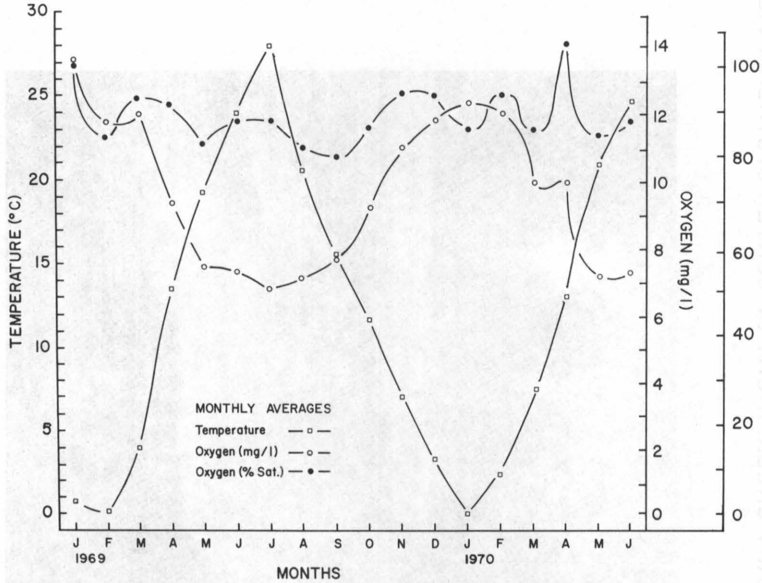


FIGURE 9. SUMMARY OF DIVERSITY INDICES IN THE NORTH ANNA RIVER FOR THE PERIOD OF STUDY.

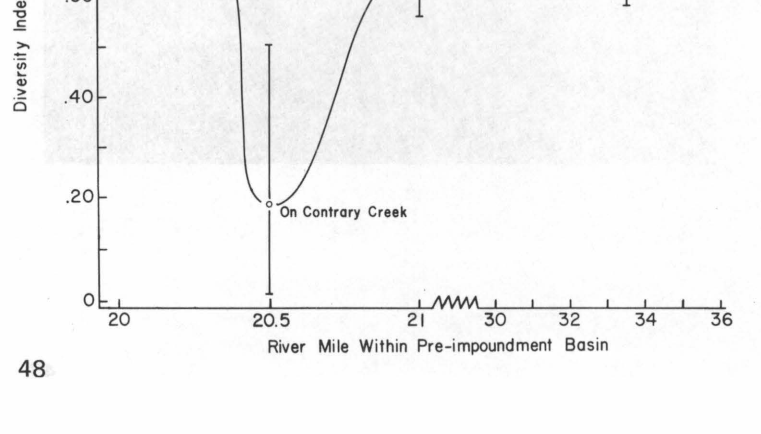


FIGURE 10. COMMUNITY STRUCTURE OF MACROBENTHOS AT STATE ROUTE 208 FOR THE PERIOD OF STUDY.

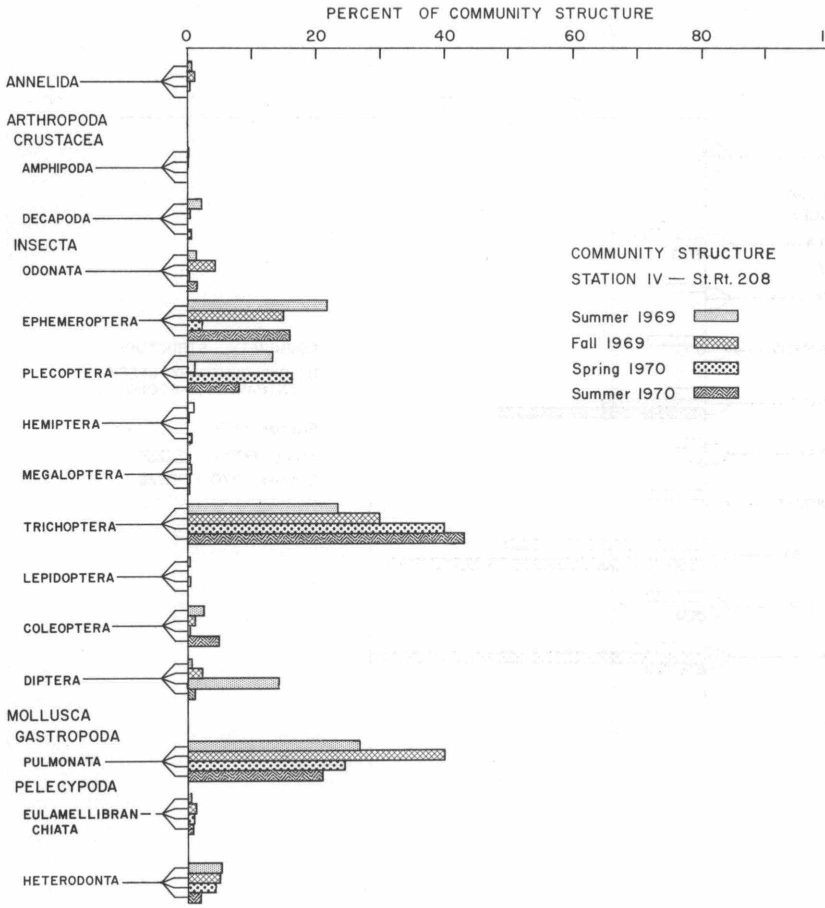


FIGURE 11. COMMUNITY STRUCTURE OF MACROBENTHOS BELOW THE CONFLUENCE OF THE NORTH ANNA RIVER AND CONTRARY CREEK.

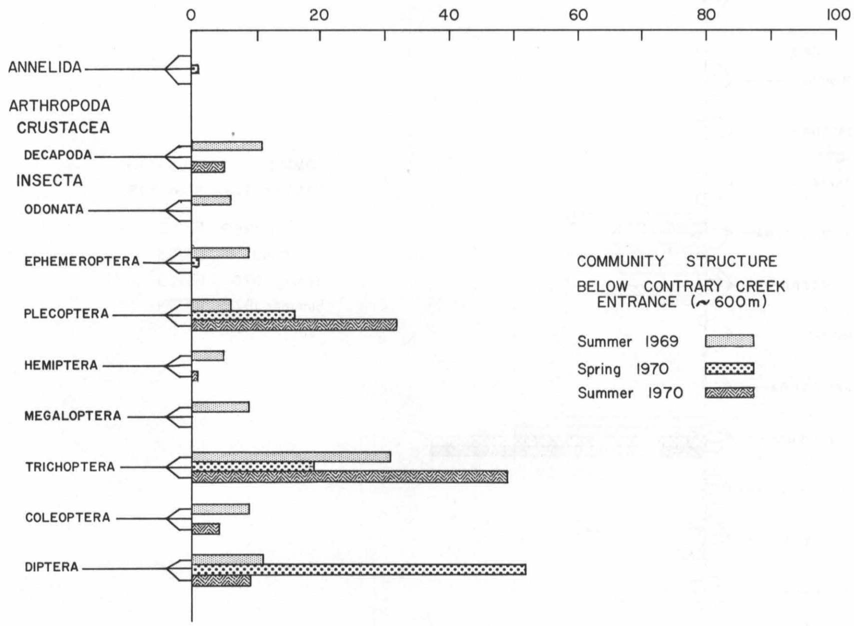


FIGURE 12. COMMUNITY STRUCTURE OF MACROBENTHOS AT STATE ROUTE 601 FOR THE PERIOD OF STUDY.

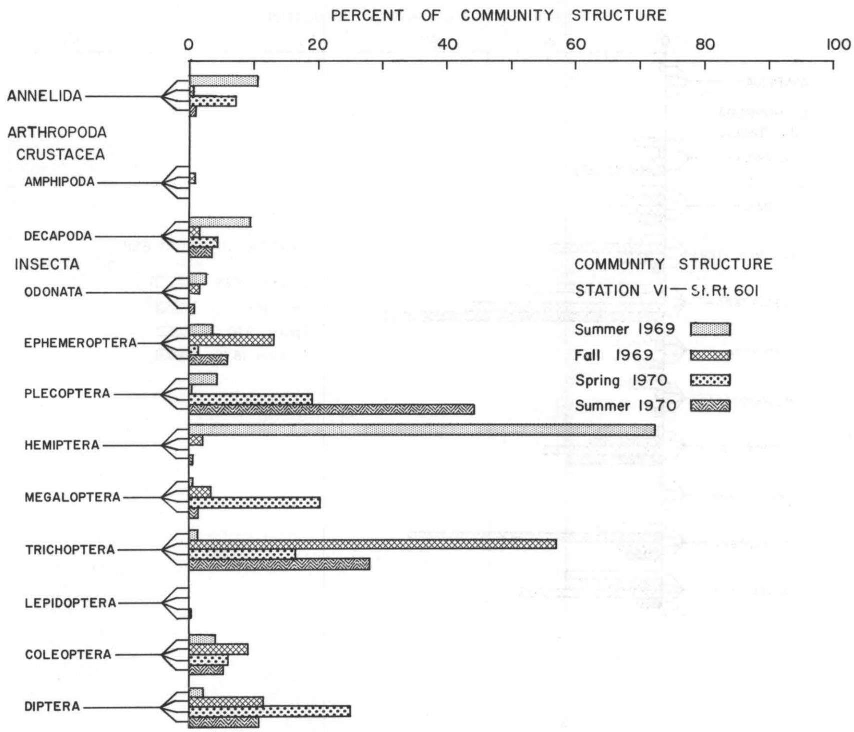


FIGURE 13. COMMUNITY STRUCTURE OF MACROBENTHOS AT STATE ROUTE 658 FOR THE PERIOD OF STUDY.

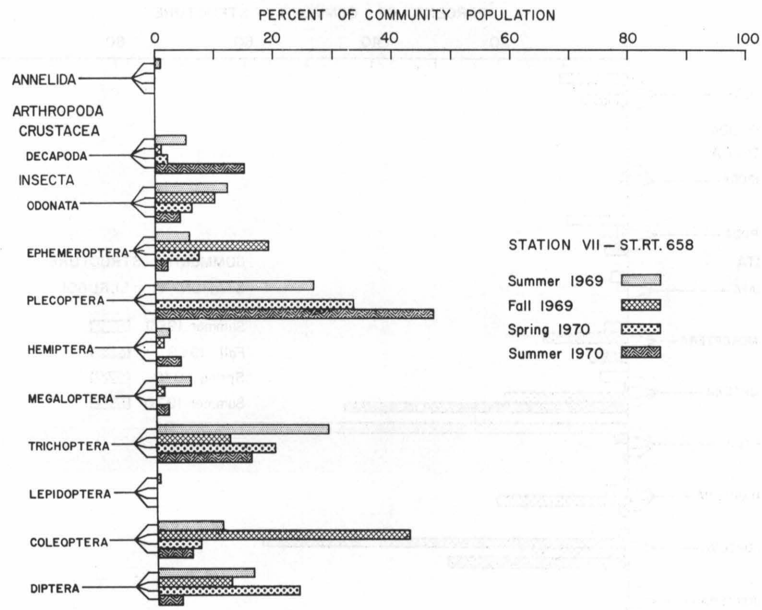


FIGURE 14. COMMUNITY STRUCTURE ON CONTRARY CREEK AT STATE ROUTE 652.

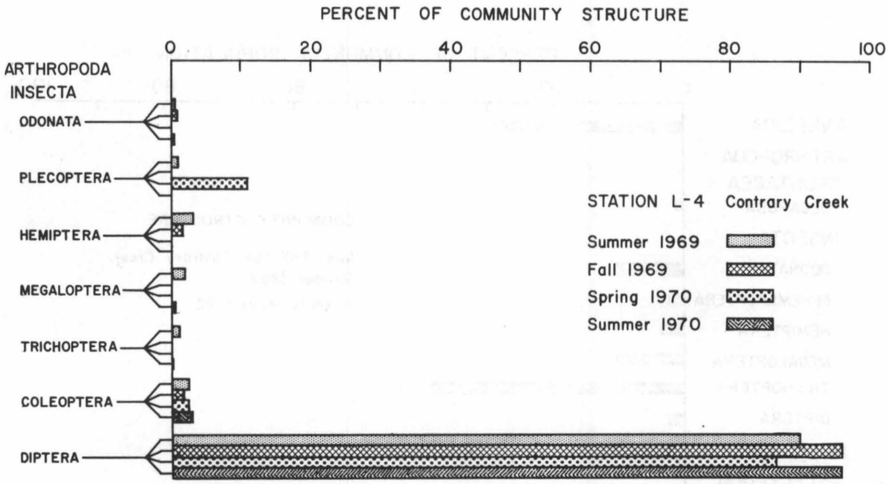


FIGURE 15. COMMUNITY STRUCTURE OF MACROBENTHOS ON CONTRARY CREEK TRIBUTARY BEFORE VEGETATION REMOVED.

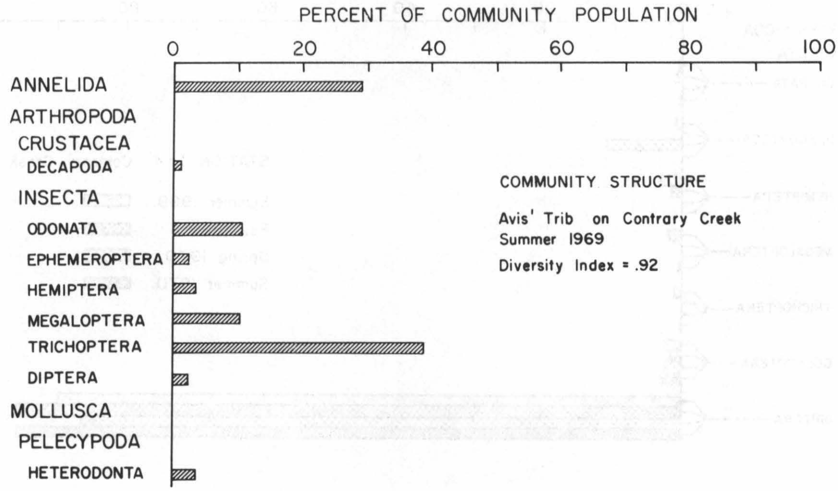


FIGURE 16. COMMUNITY STRUCTURE OF MACROBENTHOS ON CONTRARY CREEK TRIBUTARY AFTER VEGETATION REMOVAL.

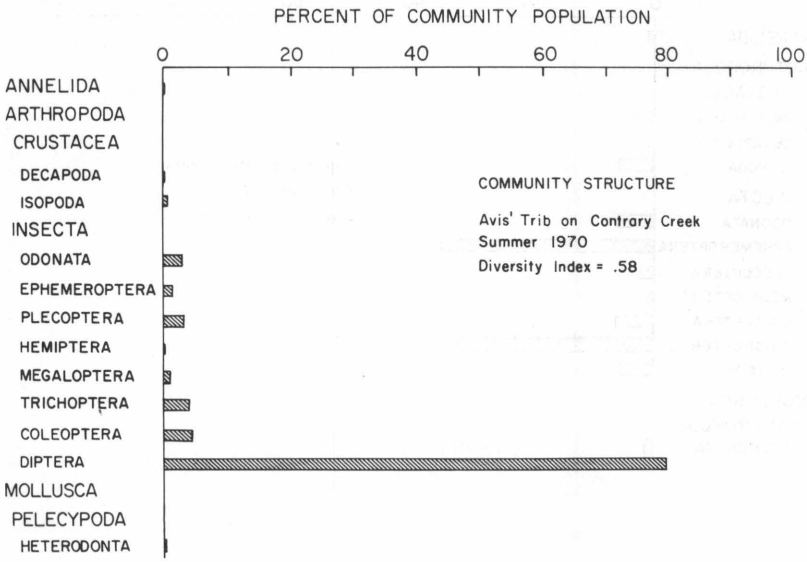


FIGURE 17. COMMUNITY STRUCTURE IN MEL'S CREEK AT STATION L-5 DURING EARLY FALL, 1969.

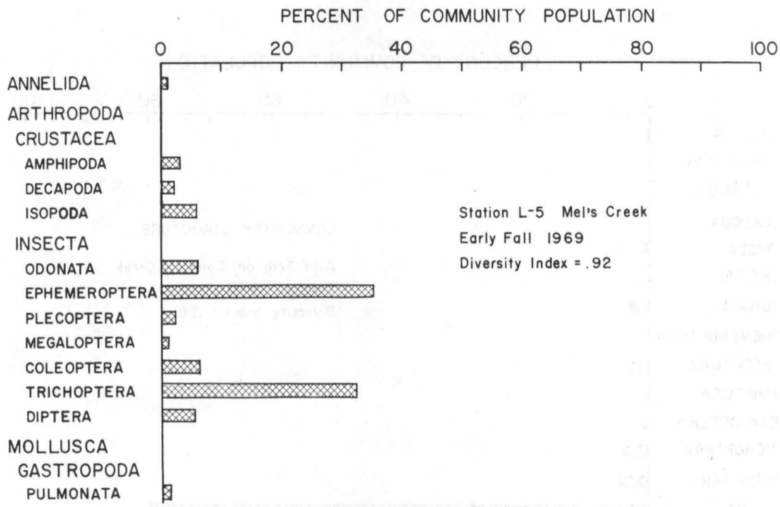


FIGURE 18. COMMUNITY STRUCTURE IN ELK CREEK AT STATION L-6 DURING EARLY FALL, 1969.

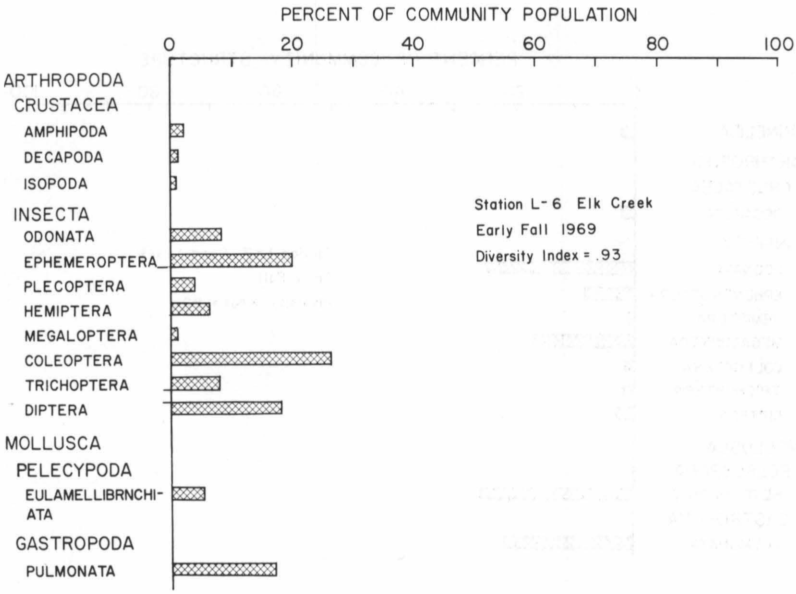


FIGURE 19. COMMUNITY STRUCTURE IN POND CREEK AT STATION L-7 DURING EARLY FALL, 1969.

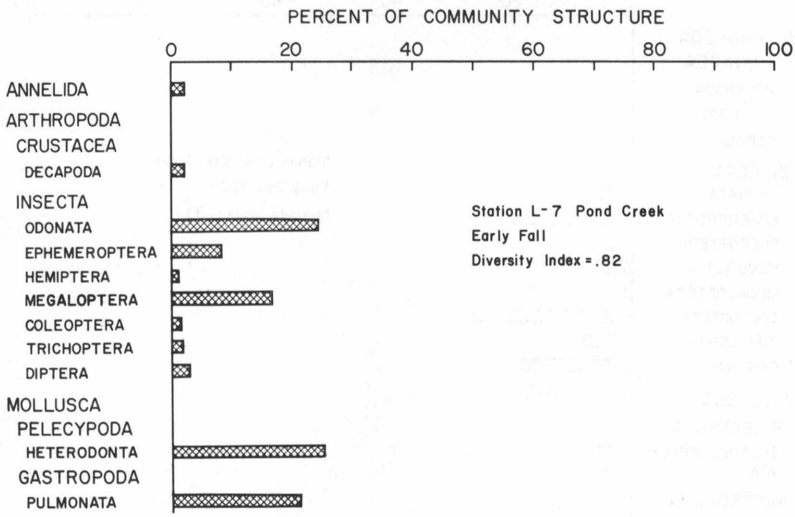
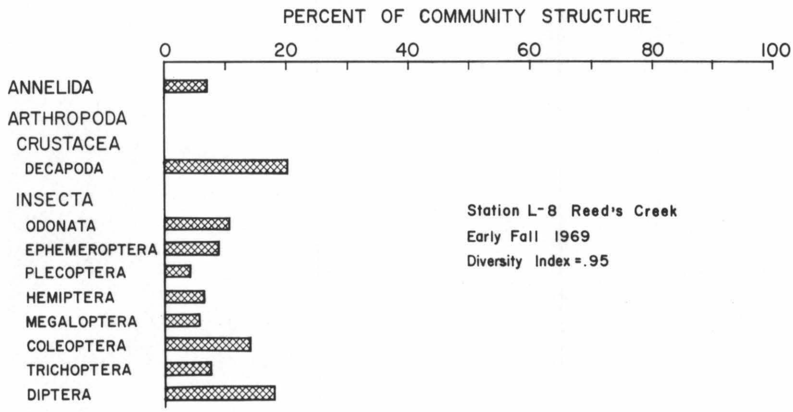


FIGURE 20. COMMUNITY STRUCTURE IN REED'S CREEK AT STATION L-8 DURING EARLY FALL, 1969.



APPENDICES

APPENDIX 1

Temperature
(°C)

Collection Site	I	II	III	IV	V	VI	VII	
State Route No.	669	522	719	208	614	601	658	Mean
1968								
December 15	0.5	--	0.5	--	--	0.5	0.5	0.5
1969								
January 19	1.5	--	2.0	1.5	2.0	2.0	2.0	1.8
February 16	1.0	--	0.5	0.5	0	0	0	0.3
March 16	5.0	4.0	4.5	4.0	3.5	3.0	3.0	3.9
April 22	12.0	14.0	14.0	14.0	14.0	14.0	13.5	13.5
May 20	--	19.0	19.5	20.0	18.5	19.5	18.5	19.2
June 19	--	--	--	--	--	20.0	--	24.0 (June 19–25)
June 25	--	--	--	28.0	--	--	--	
July 1	--	--	--	31.0	--	--	--	28.0 (July 1–3)
July 3	--	--	--	--	--	--	25.0	
August 13	19.0	19.0	21.0	20.0	21.0	22.0	22.0	20.6
September 20	16.0	16.0	16.0	16.0	15.5	15.0	15.0	15.6
October 28	11.0	11.0	11.0	11.0	12.0	11.0	11.0	11.1
November 26	8.0	8.0	7.0	6.5	7.0	7.0	6.0	7.0
December 16	4.0	3.5	3.5	4.0	3.0	3.0	2.0	3.3
1970								
January 20	--	0	0	0	0	0	0	0
February 26	3.0	3.0	3.0	3.5	4.0	4.0	3.5	3.4
March 24	7.0	7.0	7.0	7.5	8.0	8.0	8.0	7.5
April 21	13.0	13.0	14.0	15.0	15.0	16.0	15.0	13.1
May 14	19.5	20.0	20.0	21.0	21.0	21.0	21.0	20.5
May 21	--	--	--	20.0	--	24.0	--	22.0
June 19	--	--	--	--	--	27.0	26.0	26.5
June 24	--	--	--	21.0	21.0	--	--	21.0

APPENDIX 2

Total Non-filterable Solids
(mg/l of non-filterable material)

Collection Site	I	II	III	IV	V	VI	VII
State Route No.	669	522	719	208	614	601	658
1969							
January 19							
Dry wt.	191.5	--	137.5	196.0	244.0	1220.5	239.0
Loss on Ign.	--	--	--	--	--	--	--
February 16							
Dry wt.	4.0	--	8.5	41.0	10.0	8.0	22.5
Loss on Ign.	38%	--	0%	20%	5%	25%	20%
March 16							
Dry wt.	(lost)	11.5	10.4	10.1	13.6	19.3	(lost)
Loss on Ign.	(lost)	4%	0%	0%	2%	38%	(lost)
April 22							
Dry wt.	--	15.0	11.0	12.0	28.5	10.5	8.5
Loss on Ign.	--	37%	29%	50%	69%	24%	47%
June 19							
Dry wt.	--	--	--	--	--	60.0	--
Loss on Ign.	--	--	--	--	--	17%	--
June 25							
Dry wt.	--	--	--	18.0	--	--	--
Loss on Ign.	--	--	--	53%	--	--	--
July 3							
Dry wt.	--	--	--	--	--	--	3.5
Loss on Ign.	--	--	--	--	--	--	43%
August 13							
Dry wt.	18.8	38.2	6.7	7.9	96.5	6.2	9.0
Loss on Ign.	47.9%	64.4%	(lost)	3.8%	89.4%	(lost)	(lost)
September 20							
Dry wt.	16.7	65.7	13.7	34.2	21.6	41.3	203.4
Loss on Ign.	13.2%	0%	78.1%	19.0%	(lost)	30.7%	19.9%
October							
Dry wt.	--	--	10.8	8.9	3.2	11.7	--
Loss on Ign.	--	--	--	--	--	--	--
November 26							
Dry wt.	--	7.2	6.8	1.9	26.4	3.1	9.3
Loss on Ign.	--	30.6%	45.6%	(lost)	31.1%	(lost)	36.6%
December 16							
Dry wt.	9.0	16.7	9.4	11.5	11.9	28.0	13.1
Loss on Ign.	65.6%	16.2%	27.6%	83.5%	22.7%	84.6%	6.9%
1970							
January 20							
Dry wt.	24.9	25.1	20.5	36.9	42.5	45.2	130.7
Loss on Ign.	8.0%	17.9%	(lost)	3.3%	(lost)	(lost)	37.3%
February 26							
Dry wt.	88.9	14.0	12.5	9.4	11.7	11.9	9.5
Loss on Ign.	61.6%	82.9%	53.6%	86.2%	50.4%	41.2%	58.9%
March 24							
Dry wt.	13.1	27.1	16.5	22.8	33.2	35.0	--
Loss on Ign.	74.1%	57.1%	77.5%	51.7%	61.1%	56.5%	--

APPENDIX 3

Turbidity
(Jackson Units)

Collection Site	I	II	III	IV	V	VI	VII
State Route No.	669	522	719	208	614	601	658
1969							
January 19	32	--	49	47	44	42	47
February 16	26	--	36	49	47	32	51
March 16	30	39	39	44	47	42	51
April 22	--	39	44	42	51	39	47
May 20	--	56	54	49	47	62	39
June 19	--	--	--	--	--	120	--
September 20	120	95	90	117	147	150	150
November 26	--	61	56	47	54	47	47
December 16	36	64	65	51	61	75	56
1970							
January 20	54	73	75	84	95	99	92
February 26	--	39	30	20	30	30	22
March 24	47	64	61	65	86	84	81

APPENDIX 4

Oxygen
(mg/l)

Collection Site	I	II	III	IV	V	VI	VII	
State Route No.	669	522	719	208	614	601	658	Mean
1968								
December 15	11.6	--	10.9	--	--	10.2	11.7	11.1
1969								
January 19	13.3	--	13.4	13.6	13.7	13.7	13.7	13.6
February 16	12.0	--	12.0	11.8	11.8	11.8	11.8	11.7
March 16	11.8	12.2	12.5	11.9	11.2	11.8	11.8	11.9
April 22	11.9	9.3	9.1	9.1	8.8	8.4	8.7	9.3
May 20	--	7.3	7.8	7.2	7.8	7.3	7.6	7.5
June 19	--	--	--	--	--	7.6	--	7.3
June 25	--	--	--	7.0	--	--	--	
July 1	--	--	--	6.8	--	--	--	6.8
July 3	--	--	--	--	--	--	6.8	
August 13	7.1	6.4	7.4	7.1	7.3	7.1	7.2	7.1
September 20	7.8	7.4	8.4	7.8	7.7	7.6	7.7	7.8
October 28	--	--	10.0	9.5	9.0	8.2	--	9.2
November 26	--	10.8	10.0	11.2	11.2	11.6	11.3	11.0
December 16	11.9	12.0	12.4	11.9	11.7	11.8	11.8	11.9
1970								
January 20	12.5	11.8	13.0	12.6	12.5	11.7	11.4	12.2
February 26	11.9	12.1	12.6	11.9	11.9	11.8	11.7	12.0
March 24	10.1	10.6	10.9	10.6	10.0	8.6	10.2	10.1
April 21	--	9.3	10.5	10.9	9.3	10.5	10.4	10.1
May 14	--	7.4	8.0	--	7.6	5.6	--	7.1
June	--	--	--	8.2	7.5	5.9	7.0	7.2

APPENDIX 5

Oxygen
(percent saturation)

Collection Site	I	II	III	IV	V	VI	VII	
State Route No.	669	522	719	208	614	601	658	Mean
1968								
December 15	83	--	78	--	--	73	84	79.5
1969								
January 19	98	--	100	100	102	102	102	100.6
February 16	87	--	86	84	83	83	83	84.3
March 16	95	96	100	94	87	90	90	93.1
April 22	105	93	91	91	88	84	86	91.1
May 20	--	81	88	81	86	82	84	83.7
June 19	--	--	--	--	--	86	--	88.0
June 25	--	--	--	90	--	--	--	
July 1	--	--	--	92	--	--	--	88.0
July 3	--	--	--	--	--	--	84	
August 13	79	71	85	81	84	84	85	81.3
September 20	81	77	88	81	79	78	79	80.4
October 28	--	--	93	89	--	77	--	86.3
November 26	--	94	85	94	95	98	94	93.3
December 16	94	93	96	94	90	91	88	92.3
1970								
January 20	88	83	92	89	88	82	80	86.0
February 26	90	92	96	92	94	93	91	92.6
March 24	86	90	92	91	87	75	89	87.1
April 21	--	91	105	111	95	138	106	107.7
May 14	--	84	91	--	95	65	--	83.8
June	--	--	--	94	86	74	87	85.3

APPENDIX 6

Alkalinity
(mg/l $CaCO_3$)

Collection Site	I	II	III	IV	V	VI	VII
State Route No.	669	522	719	208	614	601	658
1968							
December 15	30	--	25.0	--	--	--	12.0
1969							
January 19	20.5	--	25.0	23.5	23.0	29.0	21.5
February 16	27.0	--	28.0	29.0	25.0	24.0	25.0
March 16	23.0	25.0	24.0	22.0	21.0	20.0	17.0
April 22	25.0	33.0	23.0	26.0	19.0	26.0	26.0
May 20	--	27.0	30.0	--	20.0	13.0	30.0
June 19	--	--	--	--	--	14.0	--
June 25	--	--	30.0	--	--	--	--
July 1	--	--	--	--	15.0	--	--
July 3	--	--	--	--	--	--	33.0
August 13	30.0	28.0	24.0	28.5	20.0	21.0	18.5
September 20	21.0	--	--	30.0	16.0	--	18.0
November 26	--	24.0	25.0	25.0	23.0	21.0	23.0
December 16	23.0	20.0	19.0	20.0	16.0	17.0	16.0
1970							
January 20	23.0	18.0	20.0	16.0	13.0	14.0	12.0
February 26	--	20.0	21.0	21.0	18.0	16.0	17.0
March 24	21.0	18.0	17.0	20.0	16.0	14.0	16.0
April 21	--	--	--	--	--	--	--
May 14	26.0	26.0	30.0	--	--	11.0	--

APPENDIX 7

pH
(1/log [H^+])

Collection Site	I	II	III	IV	V	VI	VII
State Route No.	669	522	719	208	614	601	658
1968							
December 15	6.3	--	6.3	--	--	--	6.0
1969							
January 19	6.1	--	6.4	6.3	6.2	6.0	6.0
February 16	6.5	--	6.8	6.8	6.8	6.8	7.4
March 16	7.4	7.2	7.5	7.5	7.4	7.6	7.6
April 22	7.3	7.2	7.5	7.5	7.4	7.2	7.3
May 20	--	7.6	7.3	--	7.1	7.1	7.1
June 19	--	--	--	--	--	7.7	--
June 25	--	--	--	7.4	--	--	--
July 1	--	--	--	--	6.7	--	--
July 3	--	--	--	--	--	--	7.2
August 13	7.4	7.2	7.3	7.3	7.2	7.6	7.3
September 20	7.8	--	--	7.8	7.8	--	8.2
November 26	--	7.4	7.6	7.2	7.3	7.6	7.3
December 16	7.4	7.5	7.4	7.4	7.3	6.8	7.4
1970							
January 20	8.4	8.5	8.1	8.2	8.3	8.2	8.2
February 26	--	7.8	7.6	7.5	7.5	7.5	7.7
March 24	7.3	7.5	7.5	7.6	7.4	7.5	7.5
April 21	--	--	--	--	--	--	--
May 14	7.8	8.0	8.0	--	--	7.7	--

APPENDIX 8

Water Chemistry
(mg/l)

February 16, 1969

State Route No.	658	601	614	208	719	669
Total PO_4	.03	.03	.05	.06	.04	.02
Total N	.24	.24	.13	.17	.27	.22
Nitrates	.19	.19	.23	.26	.23	.21
Zinc	.77	.77	.11	.23	.08	.03
Iron	.98	.98	1.15	.86	.77	.64
Copper	.11	.11	.09	.08	.03	.02
Mg	3.07	3.07	13.88	2.28	1.80	1.89

May 20, 1969

State Route No.	658	614	208	719	522
Total PO_4	27 ppm	--	--	26 ppm	--
Total NO_3	0.5 ppm	--	--	0.7 ppm	--
SO_4	.4 ppm	--	--	>1 ppm	--
Zn	.14	.27	.07	.03	.04
Copper	0.07	.07	.06	.05	.05
Iron	1.04	.85	.99	.92	1.03
Mg	5.22	5.19	3.47	3.15	4.63
Mn	neg	--	--	neg	--

August 13, 1969

State Route No.	601	614	208	719	669
Total PO_4	.03	0	.05	.04	0
Total NO_3	.5	.5	.4	.5	.5
SO_4	16.0	8.0	4.0	4.0	3.0
Zn	0.5	0.5	0.5	0.5	0.8
Iron	2.2	1.5	1.7	1.3	1.5
Mn	2.0	2.0	2.0	2.0	2.0

November 26, 1969

State Route No.	658	601	614	208	719	522	Cont. Cr.
Total PO_4	.07	.04	.17	.09	.05	.06	.04
Total NO_3	0	.20	.20	.20	0	0	.20
Total SO_4	6.0	4.50	4.50	1.50	1.50	1.50	85.0
Zn	.50	.50	.80	.50	.30	.50	2.0
Fe	>1.00	>1.00	<.10	<.10	<.10	.10	>1.0
Mn	1.50	1.50	1.50	<1.0	1.50	1.50	2.50

February 26, 1970

State Route No.	669	522	719	208	622	601	658
Total N	.30	.70	.30	.25	.30	.30	.30
Nitrate N	.30	.30	.30	.25	.30	.25	.03
Total P	.05	.05	.05	.05	<.05	<.05	.05
Ortho P	.05	.03	.04	.04	.03	.04	.04
Zn	.09	1.90	.04	.06	.16	.17	.17
Fe	.84	.85	.79	.81	.96	.88	1.12
Cu	.04	1.40	.04	.05	.08	.08	.07
Mn	.08	.56	.13	.13	.15	.18	.16
Mg	1.22	1.81	1.44	1.31	2.33	2.06	2.19

APPENDIX 9

Coliform Density
(MPN/100 ml)

Collection Site	I	II	III	IV	V	VI	VII	C.C.
State Route No.	669	522	719	208	614	601	658	
1968								
December 4	--	--	--	>40	10	40	--	--
December 15	920	--	>40	--	--	--	10	--
1969								
January 19	920	--	240	540	--	50	10	--
February 16	110	--	540	130	50	10	20	10
March 16	90	540	1610	220	240	20	51	--
April 4	--	--	--	--	--	--	--	4
April 22	--	130	920	350	350	40	540	--
May 20	--	920	1610	540	920	350	1610	130
June 19	--	--	--	--	--	5420	--	--
June 25	--	--	--	1720	--	--	--	--
July 1	--	--	--	2780	--	--	5420	--
August 13	1720	5420	3480	2400	1720	1300	790	--
September 20	>5420	>5420	>5420	>5420	>5420	>5420	>5420	490
September 27	--	--	--	1090	--	--	790	--
October 28	--	--	110	220	(lost)	330	--	0
November 26	--	50	280	280	240	110	130	20
December 16	>1610	>1610	>1610	>1610	540	1610	90	20
1970								
January 20	>5420	3450	>5420	>5420	5420	>5420	3450	210
February 26	(lost)	140	790	330	110	110	170	10
March 14	--	--	--	60	--	110	540	--
March 24	260	1090	1720	1720	5420	5420	5420	0
April 21	--	2400	3480	2210	3480	340	5420	130
May 14	>5420	1300	1720	>5420	--	1410	--	20

APPENDIX 10

Fecal Streptococci Density
(MPN/100 ml)

Collection Site	I	II	III	IV	V	VI	VII	C.C.
State Route No.	669	522	719	208	614	601	658	
1969								
September 20	--	75420	1300	330	1300	1720	3480	80
September 27	--	--	--	140	--	0	70	--
October 28	--	--	50	130	0	20	--	0
November 26	--	50	30	60	50	30	40	0
December 16	70	170	170	50	60	130	60	0
1970								
January 20	700	1410	90	210	240	410	1090	10
February 26	--	20	0	50	0	110	0	0
March 14	--	--	--	60	--	110	540	--
March 24	50	1090	20	20	20	0	--	20
May 14	230	330	790	220	--	0	--	0

APPENDIX 11

Samples from North Anna River for Radiological Analyses: to Virginia Electric and Power Company

Above Contrary Creek at State Route 208

Elodea
E-1 - 125.80 g
E-2 - 128.25 g
E-3 - 74.75 g

Hydrodictyon
H-1 - 42.15 g
H-2 - 28.35 g
H-3 - 34.60 g

Algae and Sediment
A&S A - 43.55 g
A&S B - 96.50 g
A&S C - 46.50 g

Niads (*E. complanata* and *E. productus*), sample split
State Route 208
101 A - Approx. 90.45 g - 101 B
102 A - Approx. 80.60 g - 102 B
103 A - Approx. 108.65 g - 103 B
NA-21 - 57.60 g
NA-17 - 38.30 g
NA-12 - 57.50 g
NA-27 - 64.10 g

Gyrinids (7/3/70 and 8/5/70 mixed)
NA-5 - 23.85379 g (1 beetle = 0.07314 g)
NA-11 - 25.52800 g (1 beetle = 0.11028 g)
NA-22 - 20.96945 g (1 beetle = 0.08193 g)

Crayfish (8/5/70 and 8/7/70)
Above Contrary Creek
NA-10 - 46.34353 g (6 crayfish, 7-8 mm long)
NA-4 - 50.65086 g (50 crayfish, 3-4 mm long)
NA-16 - 44.67626 g (48 crayfish, 3-4 mm long)
NA-6 - 31.29 g

<u>Campeloma</u>
NA-3 - 62.83562 (1 snail = 2.09308 g)
NA-18 - 64.75000 (1 snail = 0.50033 g)
NA-1 - 79.54034 (1 snail = 0.50033 g)

<u>Goniobasis</u>
NA-23 - 100.50 g (1 snail = 2.83337 g)
134 - 107.75 g (1 snail = 0.35533 g)
135 - 313.20 g (1 snail = 0.35533 g)

Grab Sample
NA-24 - 5.64 g

Dragonflies
NA-14 - 1.09 g

Below Contrary Creek at State Route 601

<u>Corydalus</u> - 10.2205 g

Algae and Sediment
A&S 1 - 9.45 g
A&S 2 - 5.40 g
A&S 3 - 20.20 g

Gyrinids
NA-20 - 23.45 g
NA-7 - 16.90 g
NA-9 - 13.15 g

Crayfish
NA-31 - 15.00 g

Grab Sample
NA-28 - 8.05 g

On Contrary Creek - August 24, 1970

<u>Chironomus attenuatus</u>
NA-29 - 3.85 g
NA-33 - 3.75 g
NA-30 - 2.35 g

Grab Sample
NA-25 - 1.75 g

Samples Submitted
to the Department of Industrial Hygiene

Beta Count Analyses of Mussels

Isotope	Picocuries/g wet meat
Iodine - 131	0.098 ± 0.021
Ruthenium-Rodium - 106	1.22 ± 0.27
Cesium - 137	0.073 ± 0.031
Zircon - 95	0.031 ± 0.006
Zinc - 65	0.0122 ± 0.042
Barium - 140	0.040 ± 0.02
Potassium - 40	0.0012 ± 0.0004

1 liter of mussels consisting of <u>Elliptio complanata</u> and <u>Elliptio productus</u>, taken above Contrary Creek at State Route 208.

WATER RESOURCES RESEARCH CENTER
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