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THE DISTRIBUTION OF MACROINVERTEBRATES ALONG THE IMPOUNDED MIDDLE CHATTAHOOCHEE RIVER

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Columbus State University

The College of Science

The Graduate Program in Environmental Science

The Distribution of Macroinvertebrates along the Impounded Middle Chattahoochee River.

A Thesis in

Environmental Science

by

Page Jones

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

August 2001

I have submitted this thesis in partial fulfillment of the requirements for the degree of Master of Science.

16 July 2001
Date

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Abstract

This project was part of a series of investigations designed by the Columbus (Georgia) Water Works to evaluate composition of the macroinvertebrate fauna of the mainstem of the middle Chattahoochee River, as well as its tributaries. An additional objective of the survey was to characterize impacts of storm events on urban streams and the mainstem of the Chattahoochee River. This portion of the study was designed to assess composition of benthic communites of an urbanized river in which flow regime is altered by a series of impoundments. Nine dams currently regulate flow of the mainstem of the middle reach of the Chattahoochee River. Invertebrates were collected quarterly from fall of 1998 through fall of 1999 in tailwaters of four dams, as well as at two non-impounded sites. A vast majority of invertebrates collected were members of the family Chironomidae. Data analysis was conducted to determine whether effects of a series of dams were cumulative, ameliorative, or neutral. Altered streamflow is an inevitable result of the impoundment of riverine systems. A modified flow regime involves a broad range of responses within the ecosystem. Macroinvertebrates are particularly sensitive to disruptions in flow, since most are able to survive only within a distinct range of hydraulic parameters, including discharge, velocity, and surface elevation. While disturbances in the macroinvertebrate fauna may be observed downstream of a reservoir, effects of a cumulative system of reservoirs may result in perturbations that are unique in complexity. Conclusions of this study suggest that homogeneity within the chironomid community may be cumulatively increased downstream as a result of a series of impoundments. The flow regime downstream of each impoundment is governed by the function of the reservoir. Hence, the suite of conditions that apparently resulted in the observed community composition in the middle Chattahoochee River may not be present in other lotic ecosystems that are regulated by a series of impoundments.

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Acknowledgements

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Dedication

This work is dedicated to my parents, Rudolph and Porchia Jones, for their immeasurable support.

INTRODUCTION

Currently, most large rivers in the United States contain at least one impoundment. Dams serve a wide variety of purposes and may operate in different ways. These differences determine impact of regulation on ecosystems of rivers. Among the many potential physical and chemical alterations, discharge patterns and thermal regime of releases from a reservoir may adversely affect downstream fauna.

Temperature often plays a major role in the way that macroinvertebrates are affected by releases of regulated flow from impoundments. Thermal modifications are clearly observed immediately downstream of dams with releases from the hypolimnion. These deep release dams, serving to generate hydropower or to provide storage, are common in North America. Cold water from the hypolimnion of a reservoir decreases river temperatures during summer and increases them during winter in some areas. While abundance of mayflies may increase below a hypolimnetic release, species diversity often decreases. Lehmkuhl (1972) observed a drastic reduction in the species richness of mayflies caused by a hypolimnial release dam on the South Saskatchewan River in Canada. Only 40% of the species found upstream of the dam were present within 100 kilometers downstream. This decrease in mayfly diversity was attributed to an altered temperature regime. Several of the affected mayflies have univoltine summer cycles, in which eggs are in diapause for an extended period. Emergence of adults is preceded by a brief period of growth, which requires increased temperature, as a cue to break diapause. For example, Lehmkuhl demonstrated that the river did not attain temperature requirements necessary for *Ephoron album* to emerge as an adult. Depressed temperatures did not reach the freezing point, a condition essential for the eggs to break diapause. In addition, several months of warm temperatures were required for nymphs to develop. There were other species that had univoltine winter cycles, in which eggs had a short period of development, though the nymphal stages required nearly a year to complete. For example, *Ephemera simulans* needs a certain number of degree days in order for nymphs to mature. However, cold temperatures downstream of the dam did not allow the required number of degree days to be attained.

Two ephemerellid mayflies responded differently to altered flow regimes of the Kootenai and Flathead Rivers in Montana (Perry *et al.* 1986). Selective withdrawal techniques as a dam release strategy mitigated the temperature regime so that it was only moderately altered. Both *Drunella flavilinea* McDunnough and *Serratella tibialis* McDunnough had higher densities in regulated reaches. The two species seemed to benefit from abundance of periphyton, produced as a result of increased light penetration downstream of the reservoir. Seston released from the reservoir was also a significant food source. *D. flavilinea* appeared to be more sensitive to impacts of altered flow, because adults emerged later in regulated reaches, where summer temperatures were depressed. In a separate study by Pearson *et al.* (1969), a summer generation of *Baetis* species was found to be almost eliminated as a result of cold-water releases that delayed hatching below Flaming Gorge Dam, Utah.

Hypolimnial releases inhibit temperature maxima that are necessary to trigger successive stages of the life cycles. Voelz and Ward (1996) studied distribution of caddisflies in a Rocky Mountain stream with a hypoliminial release dam. Filter-feeding caddisflies, *Brachycentris occidentalis* and *Arctopsyche grandis,* were frequently observed along the length of the stream. Longitudinal distribution of the two species was clearly distinct. *A. grandis* reached maximum density 2.3 kilometers downstream of the impoundment and declined farther downstream as *B. occidentalis* increased. *A. grandis* was often the only Trichopteran found near the dam. *B. occidentalis* was prevalent at the site that was farthest downstream. The well-defined distribution patterns are considered to be partially the result of variation in water temperature and food availability along the regulated stream. Influence of temperature was included as a factor, because reduced summer temperatures directly downstream of the dam seemed to be ideal for *A. grandis.* This species is normally found in headwaters and was most prevalent immediately downstream of the dam. *B. occidentalis* became more abundant downstream as the stream regained thermal variability. These results indicate that the reservoir influenced distribution of invertebrates by dampening temperature fluctuations, particularly immediately downstream of the impoundment. As distance from the impoundment increased, the stream began to recover from the effects of the reservoir by assuming its natural temperature regime.

In addition to alterations in temperature regime, changes in flow patterns often accompany the operation of a reservoir. Depending on the type of operation, releases of the reservoir may cause reduced flow, seasonal flow constancy, increased flow or short-term flow fluctuations. Gore (1978) concluded that almost all macroinvertebrate species have distinct and preferred ranges of velocity, water depth and other hydraulic conditions. Therefore, altered flow regime may modify composition of the mayfly fauna by eliminating favorable flow habitat. Short-term flow fluctuations are typical downstream of peaking hydropower dams. There are a limited number of species that can survive extreme daily variations of flow and velocity. Mayflies may be adversely affected by a rapid rise and fall of water level, because many of them occupy shallow margins of streams, where rapid changes in water level may cause drift and stranding (Brittain and Eikeland 1988). Thus, lower invertebrate diversity is often a result of short-term fluctuations. Many species of invertebrates are only capable of existing within some specific range of velocities. Minimal flows or exceedingly high flows may be detrimental to the organism, depending on the species. For example, both of the caddisflies, *A. grandis* and *B. occidentalis*, seemed to require some threshold velocities in order to filter feed efficiently (Voelz and Ward 1996).

The effect of flow fluctuations downstream of hydroelectric dams has been the focus of several studies. Populations of *Ephemerella inermis* Eaton, *Rhithrogena* species and *Baetis* species increased significantly after the flow regime was modified from short-term fluctuations to a relatively stabilized flow in the Skagit River, Washington (Gislason 1985). Downstream of Dworshak Dam, Idaho, reduced variability in flow resulted in high densities of aquatic mosses, which trapped food particles, apparently facilitating an increase in *Ephemerella infrequens* McDunnough (Brusven 1984). Trotsky and Gregory (1974) attributed the increased numbers of *Paraleptophlebia* in a regulated Maine river that experienced high and low flows to mobility of the species. While *Paraleptophlebia* became more abundant, heptageniids were reduced, particularly by low flows. The reduction of high seasonal discharges resulted in growth of algae on the Strawberry River, Utah. Enhanced algal growth caused an increase in *Baetis* spp. and *Paraleptophlebia,* apparently increasing their available food source (Mattingly 1987). Physical characteristics of the streambed also influence diversity, density and distribution of benthic invertebrates (Petts and Greenwood 1985). Sedimentation or scouring may substantially change the structure and composition of the benthic community. After construction of a dam on the Huntington River, Utah, species of *Cinygmula* were able to tolerate the increased sediments produced during construction (Winget 1984), while *Rhithrogena robusta* Doddsi, another heptageniid, was eliminated downstream of the dam because of increased sedimentation and algal growth. The reduced number of two other species was considered to be due to scour by high flows on the small nymphal forms that were present during summer months. Other studies have also shown that highly variable discharge may result in erosive effects downstream of impoundments

(Petts 1984). This erosion causes fine particles of sediment to be washed out and generally reduces invertebrate diversity.

In impounded rivers, alterations in flow adversely affect many species of invertebrates. In the case of mayflies, their abundance may not be changed downstream of the impoundment. However, species diversity is typically reduced (Brittain and Saltveit 1989). Growth of algae and macrophytes may be enhanced downstream of dams with stabilized discharges that eliminate scouring flows. This increases the availability of an important food resource. Algal growth may additionally provide a trap for seston and refuge from predation and other environmental hazards. While some mayflies may be able to take advantage of increased periphyton abundance, other mayflies may be excluded by its presence. Species that use friction pads or suckers for attachment usually require rocks with clean surfaces. Therefore, the survival of several genera of Heptageniidae, for instance, may be precluded. In flow regimes of high discharge, heptageniids may be the dominant invertebrates downstream of dams (Radford and Hartland-Rowe 1971).

Changes in temperature and flow regime seem to be major factors that influence community structure of mayflies in regulated river systems. Sudden flow fluctuations seem to have the most dramatic effect, as many mayflies become stranded or catastrophically enter the drift. When discharge is low or reduced, mayfly species that typically exist in lentic zones become more dominant in the community structure. Alterations in discharge and temperature inevitably modify the composition of the mayfly fauna, even if total numbers do not change.

Altered discharge in lotic systems invariably affects parameters such as water depth, water velocity, and substrate. Brusven (1984) examined distributions and abundance of benthic insects subjected to releases from a reservoir in the Clearwater River, Idaho. Insect densities were lowest in deeper pools. Margins of the stream typically support a relatively high density of invertebrates. The regulated flow regime that resulted in the rise and fall of water level in these shallow, marginal zones in the Clearwater River may have caused a significant reduction in the number of insects. When relating densities with increasing depth, caddisflies, stoneflies, and mayflies all followed the general pattern of decreasing densities with increasing depth. However, midges increased in density with increasing depth. The greatest species richness, excluding the Chironomidae, was found in shallow areas that were near the shore.

Effective management of a regulated river requires assessment of the cross-sectional and the longitudinal distribution of invertebrates. In the Clearwater River, stable, shallow-water zones, particularly riffles, are essential components of the system if species diversity and abundance are to be maintained (Brusven 1984). Riffles provided necessary heterogeneity of both the microenvironment and the macroenvironment. When midges were included in the assessment, shallow, marginal areas downstream of the dam on the Clearwater River had densities nearly twice those further downstream. In contrast, when midges were excluded, the reach immediately downstream of the dam was relatively impoverished. This indicates the importance of close examination of community structure.

Evaluating impacts of regulated flow on insects should encompass several aspects. These include functional roles of organisms that dominate the community and the resilience of those organisms to variations in flow regime. The total number of organisms in the community may indeed be a useful indicator. However, it is not necessarily the most descriptive index for determining system integrity. For example, in the Clearwater River, certain species preferentially occupied various reaches. The mayfly, *Ephemerella infrequens*, attained its maximum density immediately downstream of the dam, in a reach that was completely subjected to the impact of regulated flows. This species is a collector- gatherer (Brusven 1984). It was able to take advantage of the abundance of aquatic moss that serves as a trap for fine particulate organic matter and facilitates production of algae on its filaments. The collector-filtering caddisfly, *Cheumatopsyche* sp., was enhanced farther downstream, but was uncommon in the tailwaters near the dam. Brusven (1984) attributed these differences to the abilities of the species to occupy areas where they can optimally acquire food. A more detailed evaluation of Chironimidae, by subfamily, seemed to suggest that they, too, were preferentially distributed throughout the river. Orthocladinae comprised only 34% of the midge community upstream of the dam, while it was by far the dominant midge (99%) in the dam tailwaters. Upstream of the dam and farther downstream, Chironominae was the dominant midge subfamily. Brusven (1984) indicated that the ability of the species or community to withstand anthropogenic occurrences, such as altered flows, determined the degree of its perpetuation. Characteristics of species related to life cycles, migration, fecundity, functional status and diel behavior influenced resilience.

Drift is related to diel behavior for many insects. Drift is the primary means by which insects move downstream (Waters 1972). Pearson and Franklin (1968) indicated that catastrophic drift may occur with a rapid rise of water level because of regulated flows. Gore (1977) found that massive drift could also be initiated with the decline of flows below a critical threshold discharge.

Many aquatic insects complete their life cycle as winged adults that are capable of dispersal. Adult insects fly upstream to lay eggs in order to compensate for the downstream drift of immature stages (Muller 1954). After successful oviposition by migrating adults, the environment must still meet minimal standards in order to insure hatching and survival of young.

To optimize the effectiveness of management, streams that have been disturbed by regulation must be evaluated to assess their potential for recolonization. Several aspects of the perturbation should be considered. These include length of the impacted reach, modes of dispersal, distance from colonization, time required for recolonization, and ability of mitigation to balance economic considerations with ecological integrity of the system (Allan 1995).

In the southeastern United States, Hudson and Nichols (1986) conducted a study on the Savannah River downstream of a hydropower station to determine the impact of regulation on the benthic community. Invertebrate diversity in tailwaters of the dam was generally reduced, compared with that upstream of the reservoir and further downstream. The reduced diversity was a result of widespread physical, biological and chemical changes induced by reservoir discharges that vary considerably in flow and are reduced in temperature. The reach downstream of the dam was subjected to large fluctuations in flow and modified water temperature. Invertebrate diversity in the tailwater of the dam on the Savannah River was compared with that of other tailwaters and natural streams. There were 206 taxa found in the tailwaters of the Hartwell Dam on the Savannah River. The majority of the insects that were collected at the site, located one kilometer downstream of the dam, were Diptera. Chironomidae, Oligochaeta, Turbellaria and Amphipoda were more common near the dam, while Plecoptera, Ephemeroptera, and Ceratopogonidae were dominant farther downstream. Although Oligochaeta, Chironomidae, and Amphipoda were common directly downstream of the dam, larger invertebrates dominated the community as distance from the dam increased. Other studies in various tailwaters have reported fewer than 100 species; however, there were over 200 species in the Hartwell tailwater. The lack of identification of small forms to species level, especially in the case of the Chironomidae and Oligochaeta, may result in an underestimation of species diversity in other tailwaters. Organisms in tailwaters usually have small forms that are adapted to high flows, altered substrates and temperatures of regulated streams. Daily flow fluctuations may limit survival of many aquatic insects, but some species may develop the capacity to adapt to regular water level fluctuations (Brittain and Saltveit 1989).

Since most large rivers have been modified or regulated in some way, very few areas within them meet the standards of natural conditions necessary to be used as controls. Comparisons of the invertebrate diversity of the Hartwell tailwater were made with that of two small streams in South Carolina and Quebec and with that of the Missouri River. Comparisons were made with the small streams because diversities in the tailwaters of reservoirs are compared with those from streams in the headwaters when characteristics of the river before impoundment are unknown. Results suggest that the smaller streams may naturally contain more diversity and prohibit comparison with the larger river downstream. The operation of the Hartwell reservoir resulted in decreased turbidity and increased input of seston to the tailwater. Consequently, growth of algae and macrophytes was widespread within the 12.5 kilometer reach downstream of the dam. Although there were large fluctuations in discharge, existing invertebrate fauna seemed to be adapted to these variations.

Voelz and Ward (1991) studied biotic responses along a regulated stream to determine whether there was some degree of predictability in species diversity and abundance downstream. They found that total invertebrate abundance was high within a 1.4 kilometer reach downstream of the dam. Farther downstream, the densities of macroinvertebrates decreased substantially. Species diversity increased with increasing distance from the dam on the Colorado River. Immediately downstream of the dam, chironomids, baetid mayflies, and simuliids were common. Trichopera and Plecoptera increased further downstream while Diptera decreased. Higher temperature maxima and increased diversity of food resources were observed further downstream from the impoundment. Tailwaters of the dam had a somewhat comparable composition to the headwaters of the river. Farther downstream, there were fewer dominant species. Abundance of periphyton directly downstream of the dam was considered to be a result of abiotic factors, such as water clarity and increased nutrients, and biotic factors, such as lack of grazers. Dense growth of algae and bryophytes may impede the ability of some invertebrates to acquire habitat.

According to the River Continuum Concept, organisms are distributed from headwaters to the mouth of a stream according to their ability to consume the available food (Vannote *et al.* 1980). Therefore, shredders are primarily found in the headwaters, where leaf litter accumulates. Both collector-gatherers and collector-filterers exist in all segments of the stream, where detritus is available, but are primarily the only invertebrates in the lower reaches except predators. Grazers are mainly found in the intermediate sections, while predators exist in low numbers along the entire stream. The conditions immediately downstream of the dam on the Colorado River did not seem to follow the predictions of the River Continuum Concept, because this reach of the river did not completely assume the characteristics of a headwater stream (Voelz and Ward 1991). It has been predicted that cold-water releases from reservoirs and widening of the river downstream of the impoundment will cause the area just downstream of the dam to mimic a stream in the headwaters (Stanford and Ward 1984). As the regulated river becomes more distant from the reservoir, it begins to regain the character of an unimpounded stream. In contrast to the River Continuum Concept, sites directly downstream of the impoundment on the Colorado River consisted of a relatively high abundance of filter feeders, instead of shredders. This abundance of collector-gatherers and collector-filterers may be a result of the large amount of organic seston released from the reservoir. Seston would not be a substantial part of the headwater stream, by comparison. This further exemplifies the unique character of regulated rivers and their lack of complete resemblance to free-flowing systems.

If the character of a tailwater of an impoundment partially resembles the headwater of an unregulated stream and returns to its pre-impoundment qualities with increasing distance from the dam, then rivers with a series of impoundments offer a more unique perspective on regulation. Stanford and Ward (1984) studied effects of a series of dams on invertebrates in the Gunnison River. They observed a downstream shift of community structure. Farther downstream, the biotic community resembled a community in an upstream reach before impoundment. In the discontinuity of a regulated river, upstream characteristics of a free-flowing system are extended downstream, in part, by hypolimnial releases. In a river system with a series of dams, the biotic integrity may not be able to fully recover downstream before the continuum is again interrupted by another impoundment. This may result in a less diverse, more uniform community structure of macroinvertebrates throughout the entire impacted reach of the river. Although in a more natural stream, the composition of the invertebrate community may change substantially downstream, one may not expect to observe a significant longitudinal change in community composition along a river impacted by a series of dams, because the number of species that can exist in the tailwater of an impoundment is limited.

The effects of impoundment on macroinvertebrates are complex. It is difficult, if not impossible, to define the consequences of regulation as completely separate entities. Factors such as discharge, temperature and food availability seem to be interrelated. In addition to impoundment, most rivers are subjected to other impacts of urbanization.

With so many factors to consider, the issue of management becomes increasingly difficult and increasingly important.

Although there has been progress regarding the study of invertebrates downstream of a single impoundment, relatively little is known about the cumulative impacts of impoundments on invertebrates, particularly in the southeastern United States. A plan to study the middle Chattahoochee River watershed was implemented by the Columbus (Georgia) Water Works. Along with evaluation of physical and chemical characteristics of storm events on urban streams in Columbus and the mainstem Chattahoochee, a background survey of stream biota in the entire catchment of the middle Chatahoochee River was initiated. This included a series of studies designed to assess the composition of benthic communities over a period of several years, as well as an evaluation of changes in land use (agriculture, silviculture, and urbanization) and CSO (combined sewer overflow) treatment on the integrity of tributary and mainstem fluvial ecosystems. The study was divided into several independent investigations. The objective of this investigation was to identify the species composition of benthic invertebrates in a large, urbanized river to determine the extent to which they have been affected by a cumulative system of low- and high-head reservoirs.

STUDY SITE

The middle reach of the Chattahoochee River defines part of the border between the states of Alabama and Georgia. The middle Chattahoochee River is impounded over approximately 56 kilometers of its course. There are no substantial free flowing reaches on the river. There are seven dams between West Point Dam and Eagle-Phenix Dam. Located upstream of the remaining dams on the middle reach of the river, West Point has the largest peaking hydropower facility in the region (Willoughby 1999). The dams immediately downstream of West Point are Langdale and Riverview, two low-head dams used for flood control. Farther downstream, Bartlett's Ferry Dam operates as another power-generating facility. Approximately 6.4 kilometers downstream from Bartlett's Ferry Dam is Goat Rock Dam, followed by Oliver and North Highlands Dams, both used for peaking hydropower. The remaining dams on this reach of the river are City Mills Dam and Eagle-Phenix Dam, two small dams that are within 3.4 kilometers and are primarily diversion structures for offstream power generation. The depth of the middle reach of the river channel varies from approximately 0.3 meters during periods of low flow to 3.0 meters during peak power generation. The shoreline around much of the middle Chattahoochee River is rocky, steep and forested to the edge of the bank.

Between October 1998 and October 1999, sites downstream of West Point Dam, Bartlett's Ferry Dam, Goat Rock Dam, and Eagle-Phenix Dam were sampled for macroinvertebrates, as were two non-impounded sites farther downstream (Figure 1).

Invertebrates were collected within 200 meters downstream of the dams except at West Point.

Access to the site downstream of West Point was obtained at Riverview, Alabama, approximately 12 kilometers from the dam. The substrate at the site consisted of large cobble, sand and silt. The surrounding land was largely residential. At low flow conditions, the river channel was only partially inundated with depths as low as 0.6 meters. When power was being generated, the river channel was completely inundated and was as deep as 3.0 meters. The discharge at West Point ranged from 20 to 1300 m^3/s (USGS).

The site downstream of Bartlett's Ferry Dam was located on Lee County (Alabama) Road 334, which was accessed via Lee County Road 379. The site was surrounded by land that was largely undeveloped and forested. River channel substrate was gravel, sand and silt. Releases for power generation at Bartlett's Ferry Dam resulted in highly variable discharges in the tailwaters. When power was being generated, the elevation of the water was observed to increase as much as 1.0 meter in a period of fifteen minutes.

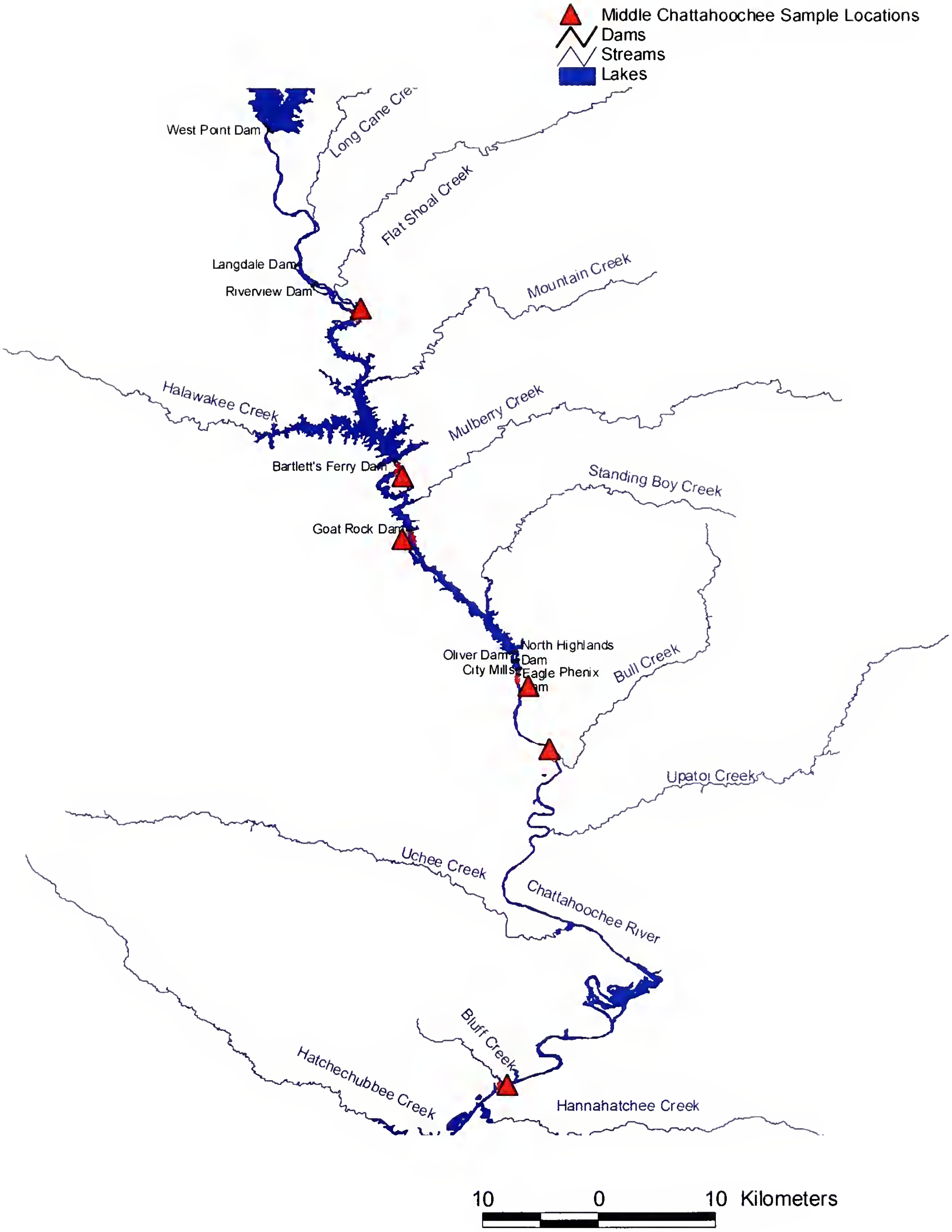
The tailwater of Goat Rock Dam was located near Lee County Road 249, which intersected Lee County Road 379. The substrate of the river was predominantly silt, sand

and gravel with scattered woody debris. The land around the site was largely undeveloped and forested. The surface elevation fluctuated 1.5 to 2.0 meters on a daily basis.

Access to the site downstream of Eagle-Phenix was obtained at Rotary Park on Victory Drive in Columbus, Georgia. In the tailwater of the dam, the substrate included boulders, large cobble and sand. At low flows, there were many small islands with water depth being as low as 0.3 meters. The elevation of the water fluctuated up to 1 meter daily. The discharge ranged from 57 to 1900 m^3/s (USGS).

The two non-impounded sites that were sampled along the river were its confluences with Bull Creek and Bluff Creek. The Bull Creek confluence was 16 kilometers downstream of Eagle-Phenix Dam. The substrate consisted mainly of sand and silt. The depth of the water ranged from 1.2 to 3.0 meters. The land surrounding Bull Creek was relatively developed and residential. The Bluff Creek confluence was approximately 24 kilometers from the Bull Creek confluence. The Bluff Creek confluence was located near Alabama State Highway 165. The substrate was largely composed of sand and silt. The land surrounding the site was residential. The depth of the water was 1.8- 2.7 meters.

Figure 1: Sampling sites on the middle Chattahoochee River.


Middle Chattahoochee Sample Locations
Dams
Streams
Lakes
West Point Dam
Long Cane Cre
Flat Shoal Creek
Langdale Dam
Riverview Dam
Mountain Creek
Halawakee Creek
Mulberry Creek
Bartlett's Ferry Dam
Standing Boy Creek
Goat Rock Dam
North Highlands Dam
Oliver Dam
City Mills
Eagle Phenix Dam
Bull Creek
Upatoi Creek
Uchee Creek
Chattahoochee River
Bluff Creek
Hatchechubbee Creek
Hannahatchee Creek
10
0
10
Kilometers

MATERIALS AND METHODS

When sampling, date, sample reference number, site and names of collectors were recorded. Sampling occurred quarterly from October 1998 through October 1999. At each sampling site, a D-frame net was used to sample substrate and aquatic vegetation along margins of the river. Three to four samples were collected at each site. Upon collection, samples were placed into double strength zip-lock bags and preserved in 70% ethanol. In the laboratory, samples were hand sorted from the mud and debris. Macroinvertebrates were identified to the lowest possible taxonomic level using various taxonomic keys (Edmunds *et al.* 1976; Pennak 1978; Burch 1982; Thorp and Covich 1991; Epler 1995). Chironomids were mounted and identified to the lowest possible taxonomic level on microscopic slides using CMC-10 mounting medium (Epler 1995). Species composition at each site was compared using cluster analysis based on the coefficient of Jaccard (Krebs 1999). The most taxonomically similar sites cluster together.

Relative abundance was calculated for each site from the original data. Simpson's Index, which emphasizes changes in the more dominant taxa of a community, was used as a measure of species diversity for each site and season (Krebs 1999). The Hilsenhoff Biotic Index was calculated to estimate organic loading and the degree of physical disturbance. Tolerance values, ranging from 0 (intolerant) to 10 (very tolerant), were assigned to macroinvertebrates (Barbour *et al.* 1999). Values are expected to increase with increased organic pollution or physical disturbance. The biotic index is the mean tolerance value for all individuals collected from a particular site.

Water chemistry was sampled from September 1998 through the fall of 1999 by Wet Weather Engineering and Technology and provided to this project for analysis. Water samples were analyzed for oxygen-demanding substances, indicator bacteria, and trace metals. *In situ* probes were used to measure pH, dissolved oxygen, oxidation-reduction potential, specific conductivity, turbidity, and temperature.

RESULTS

A total of 45 taxa was collected between October 1998 and October 1999 (Tables 3-9). Chironomid larvae accounted for 78% of the total number of macroinvertebrates. The maximum abundance of macroinvertebrates was collected in the Goat Rock tailwater. Simpson's index of diversity ranged from a mean of 0.275 at the Bull Creek confluence to 0.807 in the West Point tailwater (Table 1). Composite diversity values indicate that Goat Rock had a higher richness than Bartlett's Ferry, while Bartlett's Ferry had the higher degree of evenness (Figure 4). The biotic index ranged from a mean of 6.76 at Bartlett's Ferry to 7.14 at the confluence of Bluff Creek and at Goat Rock (Table 2). According to the general guide outlined by Hilsenhoff (1987), these values indicate that the water quality of the middle Chattahoochee River was fairly poor, based on the degree of organic pollution.

Corbicula fluminea, the Asian clam, accounted for 69% of the non-chironomid macroinvertebrate fauna. *C. fluminea* was most dominant in the tailwater of Eagle-Phenix and at the confluence of Bull Creek, where it comprised 94% and 100%, respectively, of the non-chironomid community (Figure 2). Remaining invertebrates were collected sporadically and in small numbers. Species of Odonata and Ephemeroptera were the most abundant large invertebrates collected.

Within the Chironomidae, subfamily Chironominae was dominant, in terms of both relative abundance and number of taxa, followed by the Orthocladiinae. In many instances, the most accurate identification was at the generic level. The most abundant genera were *Dicrotendipes* and *Cricotopus/Orthocladius*, which were often found on vegetation. *Dicrotendipes neomodestus* and the *Cricotopus/Orthocladius* species complex represented 13% of the chironomids, while they accounted for 16% at Bartlett's Ferry, 29% at Goat Rock, 88% at Eagle-Phenix, 50% at the Bull Creek confluence and 27% at the Bluff Creek confluence (Figure 3).

Cluster analysis indicated that the invertebrates were generally distributed according to proximity of sites (Figure 5). Identical taxa were normally found at sites that were adjacent. *Stictochironomus devinctus* and *Chironomus decorus*, which were collected only at sites that were not in close proximity, were exceptions.

The numbers of invertebrates were generally highest in July. *Ablabesmyia* (*Karelia*) species and *C. decorus* were only collected in July. *S. devinctus* was collected in March and July.

The concentrations of the various chemical constituents did not indicate that Georgia water quality standards for aquatic life were violated, although, in some cases, particularly with copper, the in-stream criterion was lower than laboratory detection limits. Values for oxidation-reduction potential, ammonia-nitrogen, and iron were higher at the Bluff Creek confluence than at other macroinvertebrate sampling sites evaluated for those constituents (Table 10). Chemical oxygen demand (COD) was two times higher at the Bluff Creek confluence.

Figure 2: Distribution of macroinvertebrates by site. WPt indicates West Point; BF, Bartlett's Ferry; GR, Goat Rock; E-Ph, Eagle-Phenix; BC, Bull Creek; BlC, Bluff Creek.

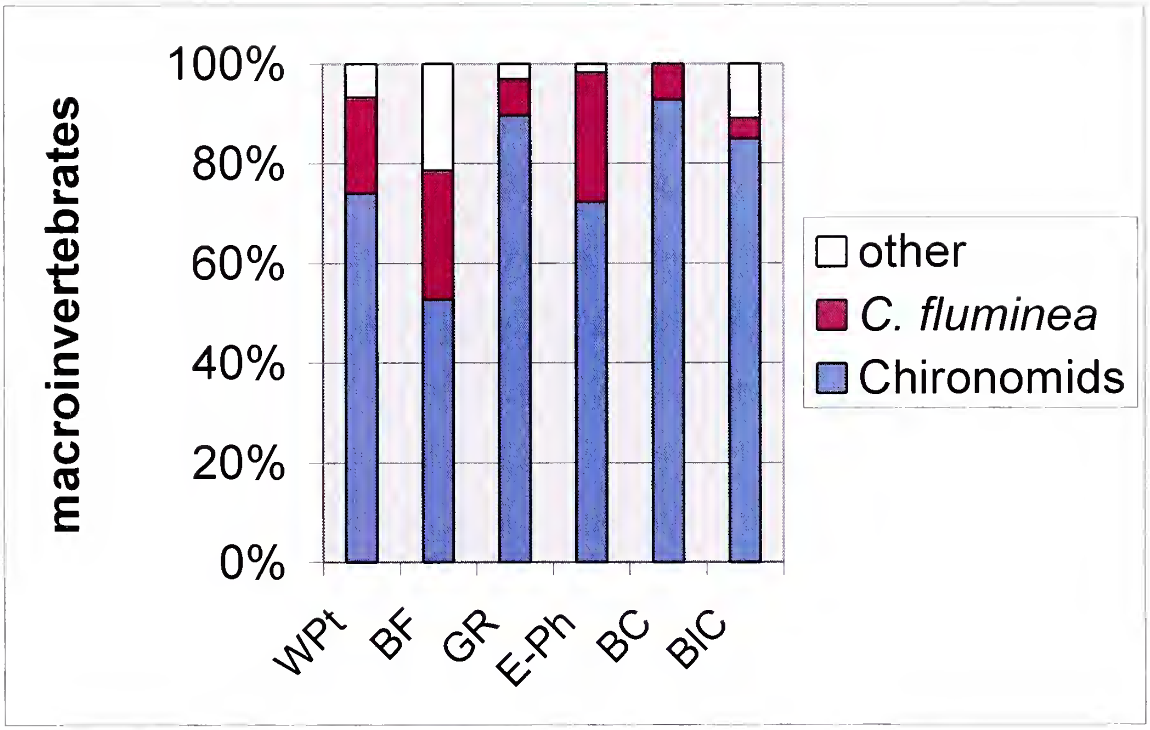

macroinvertebrates
100%
80%
60%
40%
20%
0%
WPt
BF
GR
E-Ph
BC
BlC
other
C. fluminea
Chironomids

Figure 3: Relative abundance of *D. neomodestus* and *Cricotopus/Orthocladius* species complex among chironomids at each site. WPt indicates West Point; BF, Bartlett's Ferry; GR, Goat Rock; E-Ph, Eagle-Phenix; BC, Bull Creek; BlC, Bluff Creek.

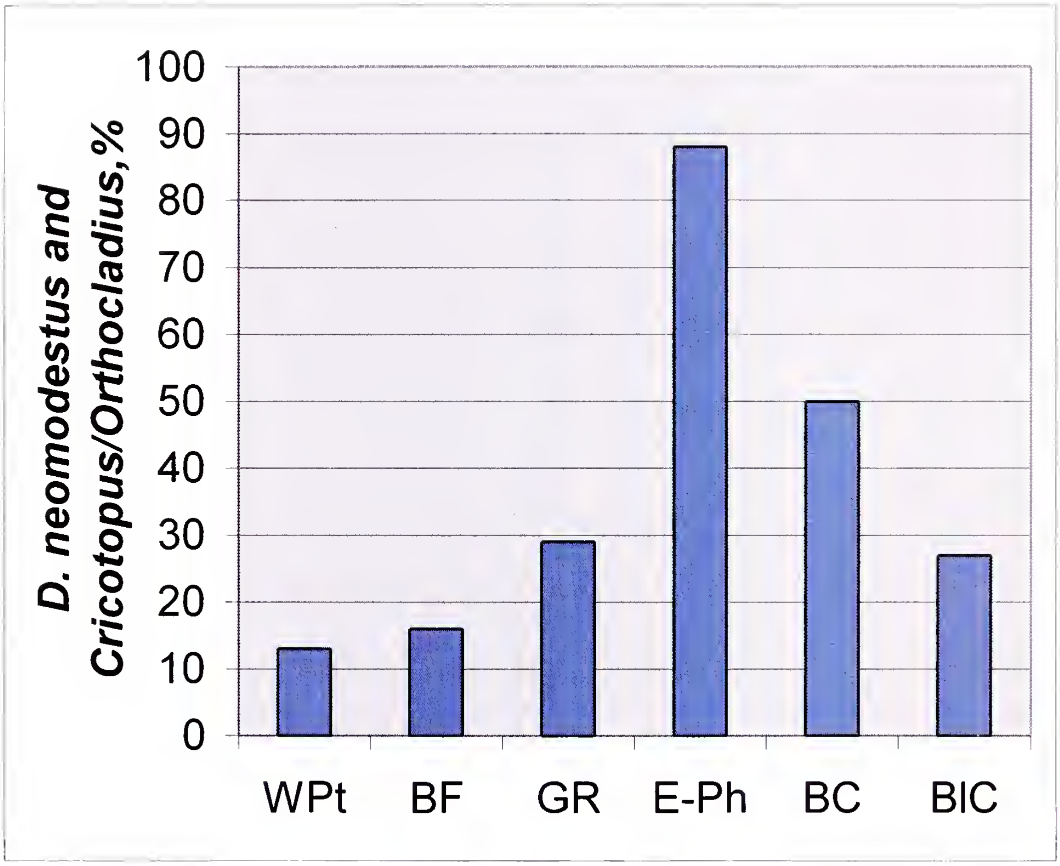

D. neomodestus and Cricotopus/Orthocladius,%
100
90
80
70
60
50
40
30
20
10
0
WPt
BF
GR
E-Ph
BC
BIC

Table 1: Biological Diversity (Evenness) Values. WPt indicates West Point; BF, Bartlett's Ferry; GR, Goat Rock; E-Ph, Eagle-Phenix; BC, Bull Creek; BlC, Bluff Creek.

	Oct-98	Mar-99	Jul-99	Oct-99	mean
WPt	0.836 (0.637)	0.880 (0.701)	0.779 (0.396)	0.732 (0.292)	0.807 (0.507)
BF	0.598 (0.408)	0.716 (0.667)	0.830 (0.520)	0.634 (0.246)	0.695 (0.460)
GR	0.738 (0.421)	0.711 (0.557)	0.823 (0.310)	0.803 (0.347)	0.769 (0.409)
E-Ph	0.629 (0.242)	0.833 (0.889)	0.628 (0.266)	0	0.523 (0.349)
BC	0.513 (0.204)	0	0.587 (0.300)	0	0.275 (0.126)
BIC	0.950 (0.848)	0.790 (0.460)	0.712 (0.720)	0.481 (0.461)	0.733 (0.622)
mean	0.712 (0.460)	0.655 (0.546)	0.726 (0.419)	0.440 (0.224)	

Table 2: Biotic Index Values. WPt indicates West Point; BF, Bartlett's Ferry; GR, Goat Rock; E-Ph, Eagle-Phenix; BC, Bull Creek; BlC, Bluff Creek.

	Oct-98	Mar-99	Jul-99	Oct-99	mean
WPt	6.65	6.84	7.02	6.72	6.81
BF	8.53	7.09	5.58	5.84	6.76
GR	7.56	7.55	5.75	7.70	7.14
E-Ph	6.80	7.35	7.60	6.30	7.01
BC	5.58	7.20	7.69	8.00	7.12
BIC	6.77	6.98	6.75	8.06	7.14
mean	6.98	7.17	6.73	7.10	

Figure 4: Comparison of composite values of Simpson's index of diversity (D) and Simpson's measure of evenness ($E_{1/D}$). WPt indicates West Point; BF, Bartlett's Ferry; GR, Goat Rock; E-Ph, Eagle-Phenix; BC, Bull Creek; BlC, Bluff Creek.

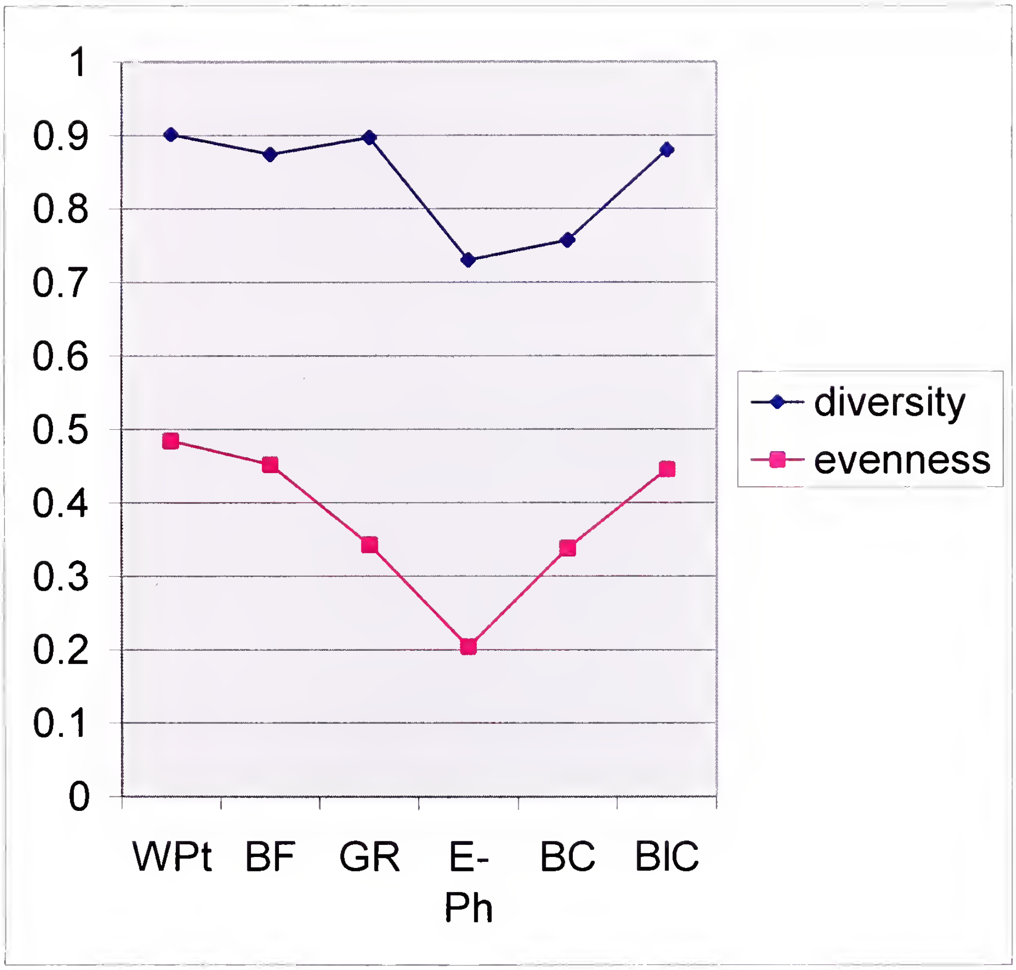

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
WPt
BF
GR
E-Ph
BC
BIC
diversity
evenness

Figure 5: Dendogram resulting from cluster analysis of macroinvertebrate community data, based on the coefficient of Jaccard. WPt indicates West Point; BF, Bartlett's Ferry; GR, Goat Rock; E-Ph, Eagle-Phenix; BC, Bull Creek; BlC, Bluff Creek.

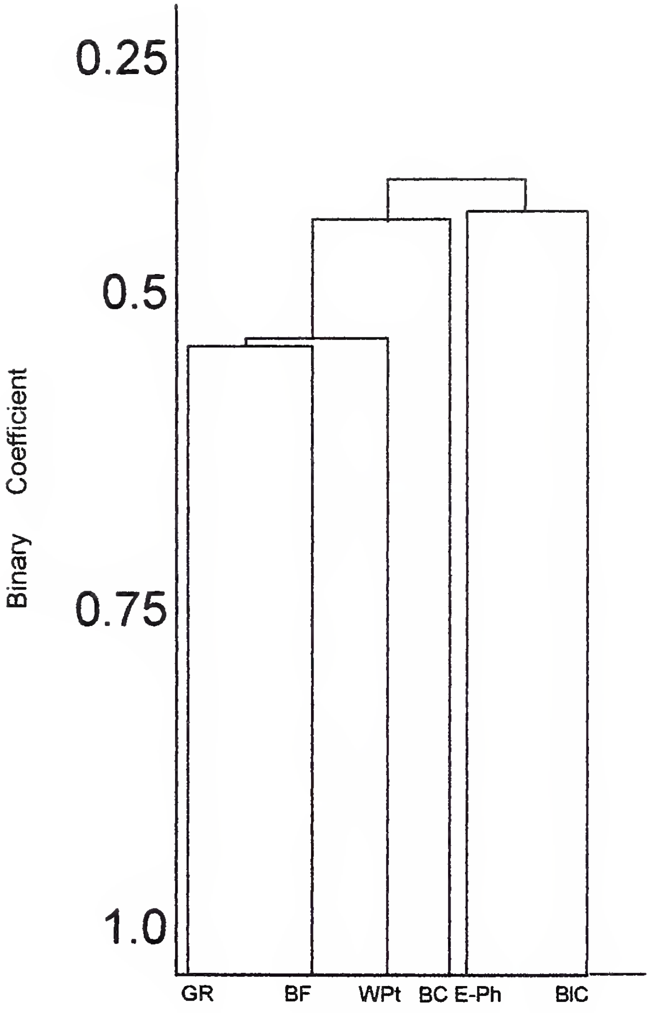

0.25
0.5
0.75
1.0
Binary Coefficient
GR
BF
WPt
BC
E-Ph
BIC

Table 3: Composite list of macroinvertebrates of the middle Chattahoochee River.

Taxa

- Phylum Annelida
  - Order Arynchobdellida
    - Family Hirudinae
- Phylum Nematoda
  - Order Rhabditidae
    - Family Rhabditidae
- Phylum Nemertea
  - Family Hoplonemertea
    - *Prostoma graecense*
- Phylum Mollusca
  - Class Gastropoda
    - Order Limnophila
      - Family Physidae
        - *Physella* (Costatella) *hendersoni*
    - Order Mesogastropoda
      - Family Pleuroceridae
        - *Elimia boykiniana boykiniana*
  - Class Pelecypoda
    - Order Bivalvia
      - Family Corbiculiidae
        - *Corbicula fluminea*
- Phylum Arthropoda
  - Class Crustacea
    - Order Isopoda
      - Family Asellidae
        - *Caecidotea militaris*
    - Order Amphipoda
      - Family Hyalellidae
        - *Hyalella azteca*
  - Class Insecta
    - Order Trichoptera
      - Family Leptoceridae
        - *Setodes* sp.
      - Family Polycentropodidae
        - *Cyrnellus* sp.
    - Order Odonata
      - Family Libellulidae
        - *Libellula* sp.
      - Family Gomphidae
        - *Progomphus obscurus*
    - Order Ephemeroptera

Table 3 (continued): Composite list of macroinvertebrates of the middle Chattahoochee River.

Taxa

- Family Baetidae
    - *Baetis* sp.
- Family Heptageniidae
    - *Heptagenia* sp.
- Family Leptophlebiidae
    - *Leptophlebia* sp.
- Family Ephemeridae
    - *Hexagenia* sp.

- Order Diptera
    - Family Tipulidae
        - *Tipula (Yamatotipula) furca* (Walker)
    - Family Chaoboridae
        - *Chaoborus americanus*
    - Family Chironomidae
        - *Ablabesmyia* (Karelia) sp.
        - *A. mallochi*
        - *Asheum beckae*
        - *Chironomus decorus* gr.
        - *Cladotanytarsus* sp.
        - *Clinotanypus* sp.
        - *Coelotanypus* sp.
        - *Cricotopus/Orthocladius* sp.
        - *Cryptochironomus* sp.
        - *Cryptotendipes* sp.
        - *Dicrotendipes neomodestus*
        - *Endochironomus* sp.
        - *Glyptotendipes meriodonalis*
        - *Harnischia* complex B
        - *Paratrichocladius* sp.
        - *Phaenopsectra* sp.
        - *Polypedilum convictum* gr.
        - *Polypedilum halterale* gr.
        - *Procladius* sp.
        - *Pseudochironomus* sp.
        - *Rheotanytarsus* sp.
        - *Robackia demeijerei*
        - *Stictochironomus devinctus*
        - *Stilocladius* sp.
        - *Tanypus neopunctipennis*
        - *T. punctipennis*
        - *Tanytarsus* sp.

Table 4: List of macroinvertebrates collected in the tailwater of West Point Dam.

Order	Family	Genus	Species	Oct-98	Mar-99	Jul-99	Oct-99
Amphipoda	Hyalellidae	*Hyalella*	*azteca*	4	0	0	1
Bivalvia	Corbiculiidae	*Corbicula*	*fluminea*	14	9	4	21
Diptera	Chaoboridae	*Chaoborus*	*americanus*	2	0	0	0
Diptera	Chironomidae	*Ablabesmyia* (Karelia)	sp.	0	0	0	2
Diptera	Chironomidae	*Asheum*	*beckae*	15	0	0	0
Diptera	Chironomidae	Cladotanytarsus	sp.	0	0	1	0
Diptera	Chironomidae	*Cricotopus/Orthocladius*	sp.	9	6	0	0
Diptera	Chironomidae	*Cryptochironomus*	sp.	0	3	8	6
Diptera	Chironomidae	*Cryptotendipes*	sp.	0	6	7	1
Diptera	Chironomidae	*Dicrotendipes*	*neomodestus*	2	0	7	2
Diptera	Chironomidae	*Glyptotendipes*	*meriodonalis*	20	0	0	0
Diptera	Chironomidae	*Polypedilum*	*halterale* gr.	0	6	3	2
Diptera	Chironomidae	*Procladius*	sp.	0	2	14	1
Diptera	Chironomidae	*Pseudochironomus*	sp.	0	0	6	1
Diptera	Chironomidae	*Rheotanytarsus*	sp.	1	0	0	0
Diptera	Chironomidae	*Stictochironomus*	sp.	0	3	2	0
Diptera	Chironomidae	*Stilocladius*	sp.	0	2	3	1
Diptera	Chironomidae	*Tanytarsus*	sp.	0	1	41	3
Mesogastropoda	Pleuroceridae	*Elimia*	*boykiniana boykiniana*	9	0	0	1
Odonata	Gomphidae	*Progomphus*	*obscurus*	0	1	0	0
				76	39	96	42

Table 5: List of macroinvertebrates collected in the tailwater of Bartlett's Ferry Dam.

Order	Family	Genus	Species	Oct-98	Mar-99	Jul-99	Oct-99
Amphipoda	Hyalellidae	*Hyalella*	*azteca*	34	0	0	0
Arhynchobdellida	Hirudinae			1	0	0	0
Bivalvia	Corbiculiidae	*Corbicula*	*fluminea*	9	20	5	88
Diptera	Chironomidae	*Ablabesmyia* (Karelia)	sp.	0	0	0	1
Diptera	Chironomidae	*Cladotanytarsus*	sp.	0	0	39	0
Diptera	Chironomidae	*Cricotopus/Orthocladius*	sp.	0	11	4	7
Diptera	Chironomidae	*Cryptochironomus*	sp.	0	0	2	3
Diptera	Chironomidae	*Cryptotendipes*	sp.	0	0	1	2
Diptera	Chironomidae	*Dicrotendipes*	*neomodestus*	1	0	16	1
Diptera	Chironomidae	*Paratrichocladius*	sp.	0	6	0	0
Diptera	Chironomidae	*Polypedilum*	*halterale* gr.	0	1	11	0
Diptera	Chironomidae	*Pseudochironomus*	sp.	0	0	11	50
Diptera	Chironomidae	*Stilocladius*	sp.	0	0	36	1
Diptera	Chironomidae	*Tanytarsus*	sp.	0	0	35	10
Ephemeroptera	Leptophlebiidae	*Leptophlebia*	sp.	0	0	0	1
Isopoda	Asellidae	*Caecidotea*	*militaris*	51	0	0	0
Limnophila	Physidae	*Physella* (Costatella)	*hendersoni*	0	7	0	4
Mesogastropoda	Pleuroceridae	*Elimia*	*boykiniana boykiniana*	0	0	2	0
Trichoptera	Polycentropodidae	*Cyrnellus*	sp.	1	0	0	0
				97	45	162	168

Table 6: List of macroinvertebrates collected in the tailwater of Goat Rock Dam.

Order	Family	Genus	Species	Oct-98	Mar-99	Jul-99	Oct-99
Amphipoda	Hyalellidae	*Hyalella*	*azteca*	0	0	2	1
Bivalvia	Corbiculiidae	*Corbicula*	*fluminea*	35	7	13	8
Diptera	Chironomidae	*Ablabesmyia* (Karelia)	sp.	0	0	0	3
Diptera	Chironomidae	*Ablabesmyia*	*mallochi*	2	6	16	0
Diptera	Chironomidae	*Chironomus*	*decorus* gr.	80	0	0	3
Diptera	Chironomidae	*Cladotanytarsus*	sp.	0	0	60	0
Diptera	Chironomidae	*Clinotanypus*	sp.	0	0	0	3
Diptera	Chironomidae	*Cricotopus/Orthocladius*	sp.	105	13	5	0
Diptera	Chironomidae	*Cryptochironomus*	sp.	2	0	17	13
Diptera	Chironomidae	*Cryptotendipes*	sp.	0	0	8	0
Diptera	Chironomidae	*Dicrotendipes*	*neomodestus*	2	32	26	37
Diptera	Chironomidae	*Glyptotendipes*	*meriodonalis*	4	0	0	0
Diptera	Chironomidae	*Paratrichocladius*	sp.	0	1	0	0
Diptera	Chironomidae	*Polypedilum*	*halterale* gr.	0	0	51	0
Diptera	Chironomidae	*Procladius*	sp.	0	0	0	2
Diptera	Chironomidae	*Pseudochironomus*	sp.	0	0	11	0
Diptera	Chironomidae	*Stilocladius*	sp.	0	0	116	8
Diptera	Chironomidae	*Tanypus*	*neopunctipennis*	0	0	0	3
Diptera	Chironomidae	*Tanytarsus*	sp.	107	8	8	0
Ephemeroptera	Baetidae	*Baetis*	sp.	0	0	5	0
Ephemeroptera	Ephemerellidae	*Ephemerella*	sp.	0	0	0	3
Ephemeroptera	Heptageneidae	*Heptagenia*	sp.	0	0	1	0
Ephemeroptera	Leptophlebiidae	*Leptophlebia*	sp.	0	0	0	3
Limnophila	Physidae	*Physella* (Costatella)	hendersoni	0	0	1	4
Mesogastropoda	Pleuroceridae	*Elimia*	*boykiniana boykiniana*	0	0	2	0
Odonata	Libellulidae	*Libellula*	sp.	1	0	0	1
Rhabditida	Rhabditidae			0	0	2	0
Trichoptera	Leptoceridae	*Setodes*	sp.	0	0	1	0
				338	67	345	92

Table 7: List of macroinvertebrates collected in the tailwater of Eagle-Phenix Dam.

Order	Family	Genus	Species	Oct-98	Mar-99	Jul-99	Oct-99
Bivalvia	Corbiculiidae	*Corbicula*	*fluminea*	76	2	7	2
Diptera	Chironomidae	*Ablabesmyia*	*mallochi*	1	0	1	0
Diptera	Chironomidae	*Cricotopus/Orthocladius*	sp.	40	0	60	0
Diptera	Chironomidae	*Cryptochironomus*	sp.	1	0	1	0
Diptera	Chironomidae	*Cryptotendipes*	sp.		0	1	0
Diptera	Chironomidae	*Dicrotendipes*	*neomodestus*	17	0	96	0
Diptera	Chironomidae	*Phaenopsectra*	sp.	1	0	0	0
Diptera	Chironomidae	*Polypedilum*	*convictum* gr.	1	0	0	0
Diptera	Chironomidae	*Polypedilum*	*halterale* gr.	0	0	9	0
Diptera	Chironomidae	*Pseudochironomus*	sp.	0	0	3	0
Diptera	Chironomidae	*Rheotanytarsus*	sp.	2	0	0	0
Diptera	Chironomidae	*Robackia*	*demeijerei*	1	0	0	0
Diptera	Chironomidae	*Tanypus*	*punctipennis*	1	0	0	0
Diptera	Chironomidae	*Tanytarsus*	sp.	0	0	6	0
Diptera	Tipulidae	*Tipula (Yamatotipula)*	*furca* (Walker)	0	1	0	0
Limnophila	Physidae	*Physella* (Costatella)	*hendersoni*	0	1	0	0
Odonata	Gomphidae	*Progomphus*	*obscurus*	2	0	0	0
	Hoplonemertea	*Prostoma*	*graecense*	0	0	2	0
				143	4	186	2

Table 8: List of macroinvertebrates collected at the confluence of Bull Creek.

Order	Family	Genus	Species	Oct-98	Mar-99	Jul-99	Oct-99
Bivalvia	Corbiculiidae	*Corbicula*	*fluminea*	6	0	19	0
Diptera	Chironomidae	*Ablabesmyia* (Karelia)	sp.	0	0	0	1
Diptera	Chironomidae	*Cladotanytarsus*	sp.	0	0	1	0
Diptera	Chironomidae	*Cricotopus/Orthocladius*	sp.	2	0	31	0
Diptera	Chironomidae	*Cryptochironomus*	sp.	3	0	4	0
Diptera	Chironomidae	*Cryptotendipes*	sp.	1	0	0	0
Diptera	Chironomidae	*Dicrotendipes*	*neomodestus*	1	0	127	0
Diptera	Chironomidae	*Harnischia* complex B		1	0	0	0
Diptera	Chironomidae	*Polypedilum*	*halterale* gr.	14	1	18	0
Diptera	Chironomidae	*Robackia*	*demeijerei*	2	0	0	0
Diptera	Chironomidae	*Stilocladius*	sp.	93	0	6	0
Diptera	Chironomidae	*Tanytarsus*	sp.	13	0	1	0
				136	1	207	1

Table 9: List of macroinvertebrates collected at the confluence of Bluff Creek.

Order	Family	Genus	Species	Oct-98	Mar-99	Jul-99	Oct-99
Arhynchobdellida	Hirudinae			0	0	1	0
Bivalvia	Corbiculiidae	*Corbicula*	*fluminea*	2	1	0	0
Diptera	Chironomidae	*Ablabesmyia*	*mallochi*	2	0	0	0
Diptera	Chironomidae	*Chironomus*	*decorus* gr.	0	0	0	1
Diptera	Chironomidae	*Coelotanypus*	sp.	1	0	0	0
Diptera	Chironomidae	*Cricotopus/Orthocladius*	sp.	0	1	0	0
Diptera	Chironomidae	*Cryptochironomus*	sp.	3	3	3	0
Diptera	Chironomidae	*Dicrotendipes*	*neomodestus*	0	1	0	15
Diptera	Chironomidae	*Endochironomus*	sp.	1	0	0	0
Diptera	Chironomidae	*Polypedilum*	*convictum* gr.	1	2	0	0
Diptera	Chironomidae	*Polypedilum*	*halterale* gr.	2	11	0	3
Diptera	Chironomidae	*Pseudochironomus*	sp.	1	0	0	0
Diptera	Chironomidae	*Stictochironomus*	*devinctus*	0	1	6	0
Diptera	Chironomidae	*Stilocladius*	sp.	1	0	0	0
Diptera	Chironomidae	*Tanytarsus*	sp.	1	0	0	2
Ephemeroptera	Ephemeridae	*Hexagenia*	sp.	1	3	0	0
Limnophila	Physidae	*Physella* (Costatella)	*hendersoni*	0	2	0	0
Rhabditida	Rhabditidae			0	0	2	0
				16	25	12	21

DISCUSSION

Discharge patterns are among the parameters altered by impoundments, resulting in the disruption of the structure of the macroinvertebrate community downstream (Petts 1984). The operation of a reservoir often results in short-term flow fluctuations, which may preclude the existence of species adapted to more stabilized flows. While many species are unable to exist within a fluctuating flow regime, a few species may be able to flourish in this environment (Radford and Hartland-Rowe 1971).

Corbicula fluminea reached high densities in tailwaters of impoundments. It was the most abundant non-chironomid sampled. The heavy, ridged shell and an ability to burrow rapidly may contribute to the adaptability of *C. fluminea* to high flows and unstable substrate, allowing it to flourish under conditions of altered flow. The remaining taxa of the non-chironomid macroinvertebrate fauna were collected sporadically and in relatively small numbers.

Cluster analysis generally revealed that sites in close proximity were more taxonomically similar. In contrast to this pattern, the two most distant sites, the West Point tailwater and the Bluff Creek confluence, were somewhat similar in terms of relative abundance of chironomids. At least two factors contributed to their taxonomic similarity. First, the relative abundance of *Dicrotendipes neomodestus* and the *Cricotopus/Orthocladius* species complex was similar at these two sites. Second, they were the only sites at which *Stictochironomus devinctus* was collected.

D. neomodestus and the *Cricotopus/Orthocladius* species complex steadily increased in relative abundance from the West Point tailwater downstream to the Eagle-Phenix tailwater, where they accounted for 88% of Chironomidae. Downstream of the Eagle-Phenix tailwater, percent composition of *D. neomodestus* and the *Cricotopus/Orthocladius* species complex decreased with increasing distance from the dam. Hudson and Nichols (1986) also documented an abundance of *Dicrotendipes* and *Cricotopus/Orthocladius* in the Hartwell tailwater of the Savannah River. These two genera are apparently able to withstand the effects of frequent fluctuations in flow.

Historical streamflow values provided by the United States Geological Survey and Georgia Power indicate that releases of West Point Dam fluctuated significantly less over time than releases of Eagle-Phenix Dam (Figure 6). West Point Dam, which was upstream of the other sites, was a large hydropower peaking facility. The impoundments downstream of West Point accommodated the discharges from West Point as well as their own respective discharges. For example, Bartlett's Ferry Dam regulated releases for its generation of power, but released flows from West Point as well. Thus, flow fluctuations became progressively more variable downstream with each subsequent impoundment.

A negative relationship appeared to exist between fluctuation in flow and chironomid diversity. The number of fluctuations of discharge was compared for releases of West Point, Bartlett's Ferry, Oliver, and Eagle-Phenix Dams. The mode of hourly average flow rates downstream of each of these four dams was calculated to estimate baseline values from July 1998 through September 1998. Figure 7 displays the number of fluctuations that depart more than 2.83 m^3/s from values of baseline flow. Relative abundance of *D. neomodestus* and the *Cricotopus/Orthocladius* species complex steadily increased from the tailwater of West Point Dam downstream to the tailwater of Eagle-Phenix Dam, as did the number of fluctuations of discharge.

The results demonstrated that the composition of the chironomid community was altered extensively with each additional impoundment. Many taxa seemed to be intolerant of the highly regulated conditions that existed downstream of the series of dams. *S. devinctus* was collected in the West Point tailwater, but was only found again 100 kilometers downstream. It is possible that *S. devinctus* was unable to tolerate the increasing flow variability found within the continuum of impoundments. While most taxa were eliminated by the regulated regime, *D. neomodestus* and the *Cricotopus/Orthocladius* species complex were apparently capable of exploiting its conditions.

The cumulative effect of variable discharges from a series of dams may enhance unnaturally rapid fluctuations in flow. Since most lotic species can survive only within a specific range of water depth and velocity, the highly variable flow in the Eagle-Phenix tailwater may be the reason that two taxa dominated the community there. Downstream of the Eagle-Phenix tailwater, *D. neomodestus* and the *Cricotopus/Orthocladius* species complex became less dominant, perhaps as the river began to regain a more even flow regime.

Although effects of rapid flow fluctuation were attenuated, the impact of organic pollution was a significant factor at the Bluff Creek confluence, where values for a number of constituents were highest. The Goat Rock tailwater and the Bluff Creek confluence had equally poor rankings of water quality, according to the biotic index, indicating that these sites were composed of fairly pollution-tolerant macroinvertebrates. Biochemical oxygen demand (BOD) at the Bluff Creek confluence was on the order of a few milligrams per liter, typical of relatively unpolluted waters (Reeve 1994). By contrast, COD was twice as high at the confluence of Bluff Creek than at other sites, suggesting that oxygen was being depleted by means other than biological activity. Increased COD may implicate industrial wastes as a source of pollution (Reeve 1994). While the Bluff Creek confluence occupied an intermediate position in terms of macroinvetebrate diversity among sampling sites, the biotic index values indicate that macroinvertebrates were exposed to a significant amount of disturbance, which could be the result of organic loading, sediment loading, or habitat degradation (Barbour *et al.* 1999).

Evaluation of the water chemistry did not indicate any detectable improvement or decline of water quality as a result of regulation. In an effort to yield more conclusive results, more long-term monitoring of wet weather events will be necessary. Detailed, contemporaneous sampling at multiple sites should occur, including the chemical analysis of bottom material. Duda *et al.* (1982) suggested that bottom material provides a better indication of pollution than constituents in the water column.

Species richness was highest at Goat Rock. The diversity index reflects this abundance of taxa. As a result of its high diversity index values, casual examination of the community at Goat Rock might have led to the conclusion that environmental disturbance was somewhat reduced there. However, Goat Rock did not rank as highly when evenness was the criterion. The discrepancy that exists between evenness and diversity at Goat Rock may be explained by recognizing that individuals of several taxa were present at very high densities, while only one or two individuals represented many other taxa. This was not the case at other sites, where evenness and diversity were more closely linked. For example, West Point and the Bluff Creek confluence exhibited relatively high species richness with low densities in all taxa. Thus, both evenness and diversity remained relatively high at these sites, where there was no disproportionate population explosion within any taxon or group of taxa.

The maximum densities at Goat Rock may be related to its poor ranking in the biotic index. Lenat *et al.* (1980) concluded that organic pollution results in an increase in total numbers of organisms, because the pollutant may serve as a direct or indirect source of food. The biotic index values were not the only indication that Goat Rock may have been impacted by a significant amount of organic loading. During the fall of 1998, *C. decorus* accounted for nearly 25% of the sample collected at Goat Rock. *C. decorus* is most often associated with polluted habitation (Epler 1995). The Bluff Creek confluence, which presented several indications of poor water quality, was the only other site where *C. decorus* was collected. Generally, a given taxa was either found throughout the entire reach or at sites that were in close proximity. It is unusual that *C. decorus* was found only at two disjunct sites.

Unimpacted waters are normally expected to be inhabited by many species that coexist at low densities (Lenat *et al.* 1980). Natural environmental pressure will prohibit any taxon or group of taxa from dominating the community, providing the opportunity for less competitive taxa to survive (Primack 1998). The natural flow regime may be conceptualized as the environmental pressure exerted on the community at the Bluff Creek confluence, where the effects of regulation were attenuated because of the increased distance from the dam. Intense modification of the flow regime occurred in the Eagle-Phenix tailwater, where the absence of pressure by a natural flow regime allowed two taxa to overwhelmingly dominate the community. This is a simplified explanation of the dynamics that may have affected the invertebrate communities, because it does not address the interaction of other factors, such as altered thermal regime and pollution, which may have acted in synergy with altered flow. Organic loading was observed as an environmental factor. However, the extent to which it affected the biota is unclear, as is the exact relationship between organic loading and altered flow. It is likely, but not certain, that organic loading and altered flow may have combined, in some instances, to exhibit an offsetting effect on the macroinvertebrate fauna.

This discussion is limited by the presentation of only two components, organic loading and altered flow regime. It is a simplistic approach to this analysis, in part, because these two factors have been presented primarily as independent units. It remains difficult to effectively quantify their interaction. Conclusive assessments of the combined impact of organic pollution and impoundments were unattainable, partially because other factors that have not been excluded as impacts remain to be evaluated. For example, Lenat *et al.* (1980) suggested that toxic substances may have a very different effect on the biota than organic loading by decreasing densities of invertebrates. Thermal regime and nutrient availability from the reservoir are potential factors that may have acted synergistically, neutrally, or counteractively (Ward and Stanford 1983). The possibility that unidentified factors may have played a significant role in impacting the macroinvertebrate community restricts the ability to effectively quantify interactions and limits general predictions within the framework of this study as well as for any broader context.

The flow regime of the regulated river is a result of the function of the reservoir and the operating characteristics of the impounding structure. Regulated rivers differ significantly in the changes that they cause within macroinvertebrate communities, depending on the type of reservoir. Differences between lotic ecosystems are compounded when a chain of reservoirs, each operating for its own specific function or combination of functions, exists along the continuum. Each of these serially impounded systems represents a unique environment that imposes its own set of properties upon the ecosystem. As a result of the function of each reservoir, the impacts of a series of impoundments may be cumulative, offsetting or neutral (Ward and Stanford 1983). Given this additional impediment, the ability to design a framework that interprets research on rivers with multiple reservoirs becomes increasingly complex.

Although careful consideration must be given to the individuality of each lotic ecosystem separated by a series of impoundments, the results of this study indicate that some general occurrences may become manifest as a result of anthropogenic environmental stress. For example, the apparent disjunct distribution of two taxa, *C. decorus* and *S. devinctus*, was attributed to significant organic loading and intense regulation, respectively. Notably, the disappearance and subsequent reappearance of a species down the continuum, within a given reach, perhaps should not be immediately interpreted as a consequence of environmental disturbance. However, disjunct distribution down a particular reach warrants further investigation that may indicate stress.

Results of this study exemplified the importance of evaluating taxonomic composition. High values of diversity may not always reflect ecological integrity. In some cases, species richness may primarily be the result of the presence of many tolerant taxa. Graphical analysis indicates that evenness seemed to be a more accurate measurement of the impacts of altered flow than diversity.

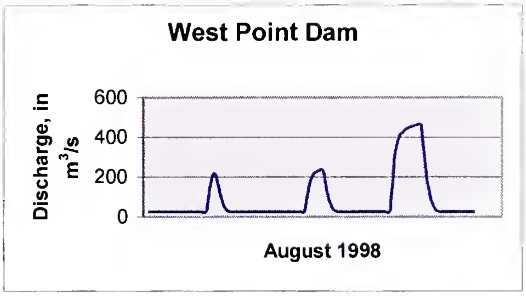
At least two factors, impoundment and waste discharges, impacted macroinvertebrate communities of the middle Chattahoochee River. In a highly regulated river surrounded by an urban area, it is difficult to quantify environmental causes of degraded aquatic communities as discrete entities. Each source of environmental disturbance may potentially create a multitude of alterations to the dynamics of natural systems.

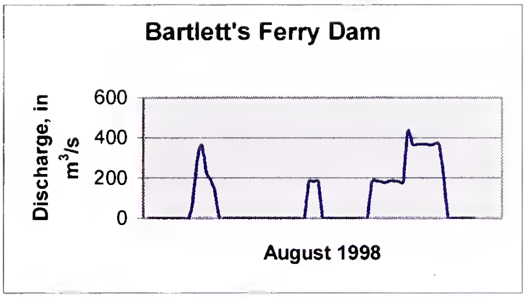
Significant reduction of the anthropogenic influence on the Chattahoochee River is imperative if populations of aquatic life are to be protected. Alternatively, a reduction in the frequency of fluvial surges may provide a more predictable, and consequently, a more hospitable environment for the enhancement of species richness (Petts 1984). The rates of stage change appeared to be more detrimental to community structure than the magnitude of discharge. Increased stability in flow may have improved the degree of species richness in the Chattahoochee River. In contrast, excessively stable flows may preclude the survival of many species (Petts 1984). It is clear that conditions supporting the maximum number of species provide some intermediate degree of stability in flow. The challenge for the management of highly regulated ecosystems will be to quantify the optimum that exists between flow constancy and flow variability. Once the optimal level of flow variability is identified, it may be established as a reference for regulated systems.

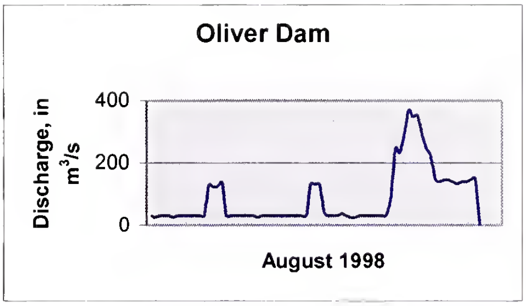
Given the unique characteristics of each regulated river, Richter *et al.* (1997) proposed a management method in which the natural hydrological variability of a river is determined by evaluating hydrographs of the years prior to impoundment. According to the authors, this method was developed in response to the limitations of many previous instream flow models, which do not consider the entire range of hydrologic parameters and often fail to include many characteristics of flow, such as frequency and rates of change. The authors prefer the Range of Variability Approach (RVA) because it is comprehensive, in that it is based on a suite of thirty-two hydrologic parameters. Management targets for the flow regime are defined using the range of parameters that typify the natural flow regime, which is characterized by streamflow records that represent unregulated conditions. In the event that insufficient pre-impoundment streamflow data exist for a particular river, the RVA recommends the use of estimates of streamflow data under unregulated conditions. The estimates may be obtained by data based on simulation modes or by reference streams for which long-term streamflow data exists. The management targets, whether derived from estimates of streamflow data or from actual pre-impoundment hydrographs of the stream, are established as temporary guidelines for managers. After the targets have been implemented as minimum and maximum flow requirements, the biota is continually monitored to assess the degree to which the integrity of the ecosystem is enhanced. The results of long-term ecological research dictate the revision of management targets.

The RVA was developed as a preliminary guide for the management of regulated rivers in the face of a lack of certainty of the standards necessary to attain a more natural flow regime. Thus, implementation of the RVA may serve as an initial step in the process of reducing the adverse effects imposed by the intense regulation of the middle Chattahoochee River. However, the objectives of the RVA are based on the restoration of a flow regime with natural variability, which, by definition, directly contrasts the principles of regulation. It is difficult to conceptualize a system in which it is not economically restrictive to operate a dam, or more specifically, a series of dams, which meet management targets that characterize the natural flow regime. The revitalization of the biodiversity of the middle Chattahoochee River will primarily depend on the public's perception of the long-term ecological risks associated with the highly altered flow regime. Continuous ecological research that yields conclusive results will be necessary to effectively demonstrate the cause-effect relationship between loss of ecosystem integrity and a modified flow regime. Ideally, these findings will result in the prescription of instream flow targets that accurately reflect a natural flow regime and in an increase in public awareness that translates into the implementation of those management targets.

Figure 6: Average hourly flow rates for releases of four middle Chattahoochee River dams for August 28 through September 1, 1998. The hydrographs represent typical discharge patterns that demonstrate increased variation of flow proceeding downstream. Baseline values of streamflow fluctuated least frequently at West Point Dam (USGS) and most frequently at Eagle-Phenix Dam (USGS). (Streamflow data at Bartlett's Ferry Dam and Oliver Dam were provided by GA Power.)


West Point Dam
Discharge, in m^3/s
600
400
200
0
August 1998


Bartlett's Ferry Dam
Discharge, in m^3/s
600
400
200
0
August 1998


Oliver Dam
Discharge, in m^3/s
400
200
0
August 1998

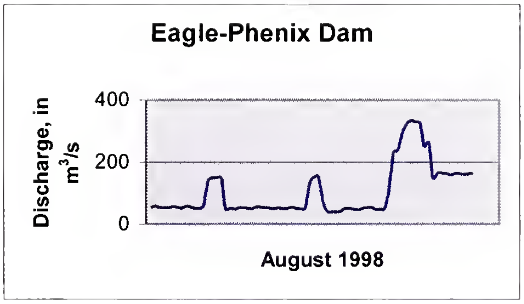
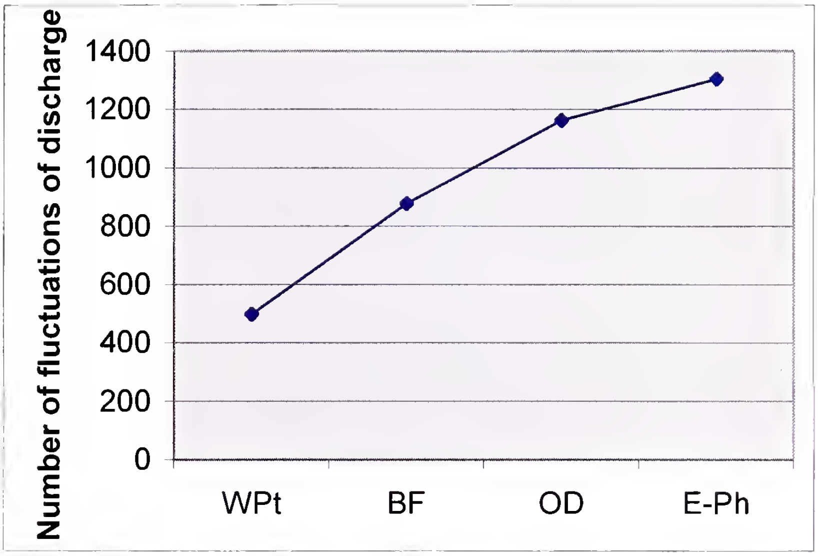

Eagle-Phenix Dam
Discharge, in m^3/s
400
200
0
August 1998

Figure 7: Relative abundance of *D. neomodestus* and the *Cricotopus/ Orthocladius* species complex steadily increased from the tailwater of West Point Dam downstream to the tailwater of Eagle-Phenix Dam, as did the number of fluctuations of discharge.


Number of fluctuations of discharge
0
200
400
600
800
1000
1200
1400
WPt
BF
OD
E-Ph

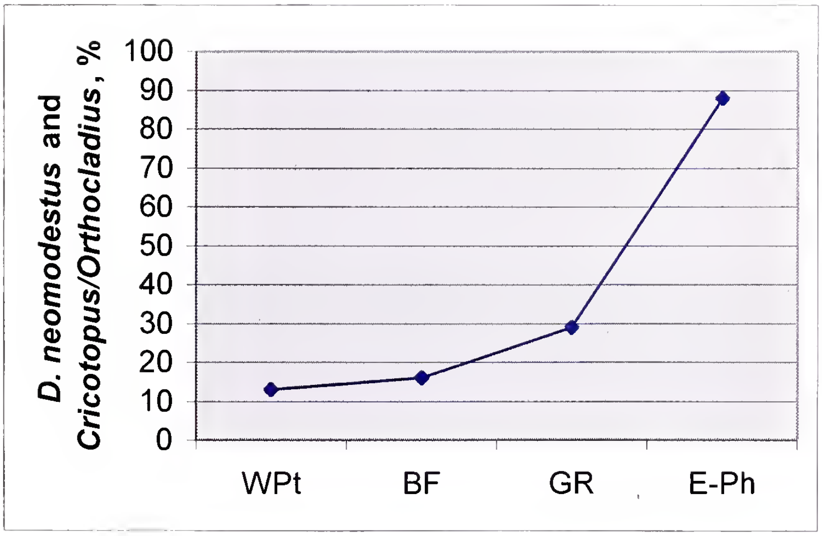

D. neomodestus and *Cricotopus/Orthocladius*, %
0
10
20
30
40
50
60
70
80
90
100
WPt
BF
GR
E-Ph

Table 10: Mean concentrations of physical, chemical and microbial constituents at three sites. (WWETCO)

Constituent	units	Eagle-Phenix	Bartlett's Ferry	Bluff Creek
DO	mg/L	8.5	8.0	8.6
pH	--	7.2	8.1	7.0
Temp	C	21.6	27.2	27.0
Turbidity	NTU	5.7	3.1	11.4
Sp Conductivity	mS/cm	0.09	0.11	0.11
ORP	mV	382	315	494
BOD	mg/L	2.1	2.1	2.7
chromium	mg/L	<0.01	<0.01	<0.01
copper	mg/L	0.02	<0.01	<0.01
iron	mg/L	0.27	0.19	0.42
lead	mg/L	<0.01	<0.01	<0.01
nickel	mg/L	<0.01	<0.01	<0.01
zinc	mg/L	<0.02	<0.02	<0.02
total phosphorus	mg/L	<0.3	<0.3	<0.3
ammonia	mg/L	0.08	0.08	0.12
TOC	mg/L	3.3	3.3	3.0
COD	mg/L	20.6	20.6	44.7
TSS	mg/L	77.8	77.8	11.4
fecal coliform	col/100 mL	1488	1488	367
E. coli	col/100 mL	20	20	178

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