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Inventory and Analysis of Plankton in Green River within Mammoth Cave National Park

Justin H. Laughlin
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Justin H. Laughlin entitled "Inventory and Analysis of Plankton in Green River within Mammoth Cave National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

J. Larry Wilson, Major Professor

We have read this thesis and recommend its acceptance:

Richard Strange, Sammy King

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Inventory and Analysis of Plankton in Green River within Mammoth Cave National Park

A Thesis Presented for the Master of Science Degree

The University of Tennessee, Knoxville

Justin H. Laughlin

August 2003

This thesis is dedicated to my family, especially my wife Kathy, for without their support, encouragement, and love this achievement would have been impossible. We are all bound and connected by our love for each other and the world around us, so I offer thanks to you all for making my dreams possible and helping me become the man I am today.

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ABSTRACT

National Park Service biological staff are charged with preserving and protecting all creatures within a park's boundaries. It is only a matter of time before exotic zebra mussels (*Dreissena polymorpha*) invade all eastern waterways including Green River within Mammoth Cave National Park, Kentucky. The National Park Service, in cooperation with University of Tennessee, initiated this inventory of plankton within Mammoth Cave National Park to establish baseline data prior to zebra mussel invasion. During this two year study (2000-2002), 180 plankton samples were collected at three sampling sites which encompassed all major riverine habitat types within the three flow zones (free-flow, transitional, impounded) created by Lock and Dam #6. Duplicate plankton samples were taken on all six occasions at these sites. Each year one sample was collected in June/July (base flow), another in August/September (base flow), and the other in November/December (enhanced flow). Zooplankton were sampled using both vertical (4/site) and horizontal (4/site) tows with 153-micron and 80-micron mesh plankton nets. Samples were fixed in the field with a 10% sugared formalin solution for later examination in the laboratory. A 1.0-L polycarbonate water bottle was used to collect phytoplankton samples at a depth just above the Secchi disk transparency level; samples were fixed in a 1% Lugol's solution and stored in an opaque container for analysis. Water temperature, conductivity, dissolved oxygen, pH, and water transparency were also measured and recorded at each sample site.

Water quality data were similar among sites and the variation among dates was consistent with climatic conditions. Dissolved oxygen ranged from 10.96 (mg/L) in

December 2001 to 6.20 (mg/L) in July 2002. Temperature ranged from 25.9° C in July 2002 to 6.4° C in November 2000. The pH ranged from 8.05 (su) in November 2000 to 5.72 (su) in July 2002. Conductivity ranged from 282 (mS/cm) in November 2000 to 383 (mS/cm) in July 2002. A paucity of zooplankton was observed in Green River while phytoplankton densities were similar to levels measured upstream in Green River Lake. The dominant zooplankton groups were Cladocera (*Bosmina longirostrus*) and Copepoda (*Mesocyclops edax*). Densities of *Bosmina* ranged from 0.01/L in September 2000 to 0.46/L in December 2001; *M. edax* densities ranged from 0.01/L to 0.53/L during the same period. Aquatic insects were collected at densities equal to or greater than the zooplankton during the study, with the family Chironomidae as the dominant aquatic insect taxon collected. Chlorophyta (green algae) was the dominant phytoplankton phylum present during all samples with approximately 97% of the species composition; the genus *Cholorella* comprised over 95% of all cells in every sample. Other filamentous Chlorophyta genera, like *Ulothrix,* contributed minor portions of the population. Also, Cyanophyta (blue-greens) and Chrysophyta (golden-brown algae) were found in relatively low numbers. Only limited evidence of zooplankton reproduction was found at the downstream sample site. We concluded that, during the study period, Green River did not exhibit a true plankton community, potamoplankton, but rather a tachyplankton (transient) community. A digital reference collection of zooplankton and phytoplankton was created to provide baseline data for future studies. A long-term plankton data set should be developed if future mussel propagation projects are to be successful in the river.

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CHAPTER I

INTRODUCTION

Infestation by exotic zebra mussels (*Dreissena polymorpha*) in eastern waterways including Green River within Mammoth Cave National Park (MCNP) is imminent, unless adequate control measured are developed. Since their introduction into the Great Lakes in the late 1980s, via ballast water from Asian ships, the zebra mussel has spread rapidly throughout eastern United States lakes and waterways. Due to their reproductive capability and motility, zebra mussels have detrimental effects on native species in virtually every aquatic habitat. This exotic mussel is a nuisance species because they can out-compete native unionid mussels for space and food resources.

Zebra mussels can filter a large size range of particles allowing them to prey on small zooplankton and compete with zooplankton for phytoplankton. As suspension feeders, they compete directly with native mussels and the primary consumers in aquatic systems, zooplankton. They can produce significant ecological impacts by filtering large volumes of water. For example, an adult can filter more than two liters per day.

The zebra mussel has a free living larval stage, known as a veliger, which is independent of a fish host, so they have an adaptive advantage over native mussels. At about 2 centimeters (cm) in length they are not even half the size of many native mussels. They encrust on any hard surface, even overgrowing other organisms and sometimes forming layers of mussels. Zebra mussels have been know to clog or block intake pipes preventing water flow and were credited with reducing potamoplankton biomass in the Hudson River by approximately 75 to 80 percent (Pace et al. 1998). Zebra mussels have high reproductive rates, with each individual female producing up to 80,000 larva per year. Where they colonize, zebra mussels typically dominate the benthic areas with as many as 40,000 per square meter on rocky substrates.

Colonization by the exotic zebra mussel has been greatly accelerated by human activities. Currently there are too many stressors on the Green River system to sustain the diverse mussel fauna present. The rare diversity of benthic organisms includes six federally listed endangered species, nine state listed endangered species, three threatened species, and nine species of special concern. These figures only account for bivalves and crustaceans from Edmonson County, Kentucky. Birds, fishes, mammals, and plants of the area are not included.

Faced with possibly losing its rich mussel fauna puts this riverine ecosystem at risk of ecological collapse. To date no control method has been found effective to prevent zebra mussels from invading. This tiny invasive bivalve is a cause for concern and the reason a full inventory of the plankton community was undertaken by the National Park Service, Department of the Interior, in cooperation with University of Tennessee to establish baseline data prior to invasion. Once the zebra mussel population is controlled either naturally or artificially, baseline plankton data will be crucial to gauging recovery of the river.

The primary objective of this study was to inventory the present-day plankton assemblages of Green River within MCNP to establish a database which can be used in future research efforts. The study design and accompanying data set will provide a benchmark for comparing species composition and abundance of plankton communities should zebra mussel infestations occur at some future date. A secondary objective of the study was to determine what specific type of plankton community existed in Green River within MCNP during the study period. Ward and Stanford (1983) asserted that true plankton communities, potamoplankton, occur only in the lower reaches of river systems except below dams. We assumed there would be a tachyplankton (transient) community rather than a potamoplankton (sustainable) community due to several factors including: variable hydrogeology, regulated seasonal flows including variable thermal regimes, relatively short retention time which limits zooplankton reproduction except at the downstream site nearest Lock and Dam #6, and the patchiness of plankton communities. A potamoplankton community needs time to complete its life cycle to be sustainable, which, unlike the Green River, is typically found in larger, slower moving rivers.

CHAPTER II

LITERATURE REVIEW

Native burrowing bivalves (Order Unionidae) play an important ecological role in lotic freshwater systems. They can influence ecosystem processes by filter feeding on plankton, bacteria, and particulate organic matter and directly impact benthic processes as they burrow through sediments (Vaughn and Hakenkamp 2001). The major water column processes completed by bivalves are removing particles, excreting nutrients, and bio-depositing feces and pseudofeces. Filter feeding by mussels has the greatest effects on ecological processes when their biomass is large (Vaughn and Hakenkamp 2001). Zebra mussels and other invasive bivalves (*Corbicula*) filter larger volumes of water reducing plankton biomass, increasing water clarity, and, in some cases, effectively causing biological oligotrophication (Vaughn and Hakenkamp 2001).

On the Ohio River, zebra mussels were found to have significant negative impacts on zooplankton, which may alter riverine food webs (Jack and Thorp 2000). In a nine-year study on the Hudson River, Pace et al. (1998) found zebra mussels to significantly reduce large phytoplankton and microzooplankton (small bodied) while allowing macrozooplankton (crustacean) and small phytoplankton to maintain at historic levels. This suggests that size selective feeding by invasive bivalves may not crash the system, but may produce a shift in species composition to groups that were previously nutrient limited or out competed.

Plankton are important components of aquatic ecosystems. They provide the primary and secondary links in the aquatic food web. Although large rivers may have a true plankton community, the potamoplankton, most plankton of rivers are a transient community (tachyplankton), that get washed in from backwater, lake, pond and reservoir drainages (Lind 1985). In freshwater aquatic environments, it is understood that, as water movement slows, there is more time for pelagic organisms to grow and reproduce without being disturbed. Conversely, in shallow fast flowing water bodies, the benthic forms become increasingly important.

Phytoplankton and zooplankton assemblages have been studied extensively in lentic (lake) freshwater environments, but considerably less research has focused on lotic (river) systems (Reynolds 1988; Basu and Pick 1996). There is no consensus as to what factors regulate both phytoplankton and zooplankton biomass in large (greater than fifth order) rivers (Pace et al. 1998). Although, hydrological factors such as discharge or water residence time are thought to be of greater importance to planktonic development in rivers than in lakes (Reynolds 1988). Other possible factors regulating plankton biomass in rivers are physical (light), chemical (nutrients), or biological (predation). There is general agreement among researchers that rivers will have significantly less zooplankton biomass and abundance than lakes with similar water quality due to their longer generation time than phytoplankton. In lotic systems, phytoplankton may be controlled more by nutrient concentrations rather than hydrology because of their higher growth rates (Reynolds 1994; Pace et al. 1998).

Although previous limnologists have made strides in understanding lentic systems, still little is understood or documented about lotic plankton systematics other than they are chaotic and defined by upstream influences. Generally, most river plankton is considered to be allochthonous from tributaries and backwaters (Heller and Katz 1982). Pelagic aquatic communities have temporal and spatial scales that are relative to location in the river continuum and scope of investigation. Planktonic organisms have patchy distribution and exhibit seasonal population variations. Samples can only be examined as a snapshot of the current condition. Rivers are highly dynamic ecosystems and it is generally accepted that the distribution pattern of all biota are governed by interaction between both large and small scale processes (Swan and Palmer 2000).

Limited literature is available dealing specifically with plankton of the Green River. Previous work has documented classical successional patterns present with seasonal bimodal peaks in densities (Heller and Katz 1982). Their study was conducted in the western part of the river near the confluence with the Ohio River. High levels of suspended solids, relatively fast river flows, sedimentation, and pollutants were cited as reasons for low aquatic productivity (Heller and Katz 1982). They also reported diatoms to be the dominant algae, while copepods and rotifers were the dominant zooplankton. Total phytoplankton densities observed were within the normal range of 1.0×10^4 to 101×10^6 cells per liter typically observed in rivers of the United States (Palmer 1964). Zooplankton densities ranged from 0 to 37 individuals per liter depending on the time of day and the month sampled.

A previous plankton study conducted at Green River miles 41 and 82 (GRM 41 and GRM 82) observed zooplankton densities ranging from 0.8 to 13.3 and 2 to 20 organisms per liter, respectively (Geo-Marine, Inc. 1976). These differences reflect the spatial and temporal differences in plankton communities, as well as differences in collection techniques. Heller and Katz (1982) used a timed pump collection technique to collect zooplankton samples, whereas Geo-Marine, Inc. (1976) employed the fixed distance net tow technique, as in this study. The volume of water sampled is much greater using the pump and net collection technique. For example, Heller and Katz (1982) filtered 1,514 liters per sample compared to our 165 liters filtered per sample using the net tow technique.

CHAPTER III

DESCRIPTION OF STUDY AREA

Geography and Geology

The study area was the Green River within the Mammoth Cave National Park. The Green/Tradewater watershed (often combined) is the largest of twelve in the state of Kentucky. The Green River and its associated tributaries drain nearly one-third of the state (Figure 1). Geomorphology plays a major role in the Green River system for many reasons: slope, soil type, land use, and vegetation. The Green River flows directly through Mammoth Cave National Park, which is a 21,450-hectare preserve located in western Kentucky that is extremely rich in biological and physiographic diversity (National Geographic Society 1984). The park has been named by the United Nations as a World Heritage Site and International Biosphere Reserve. MCNP is predominantly in Edmonson County with smaller portions in Hart County and Barren County, Kentucky.

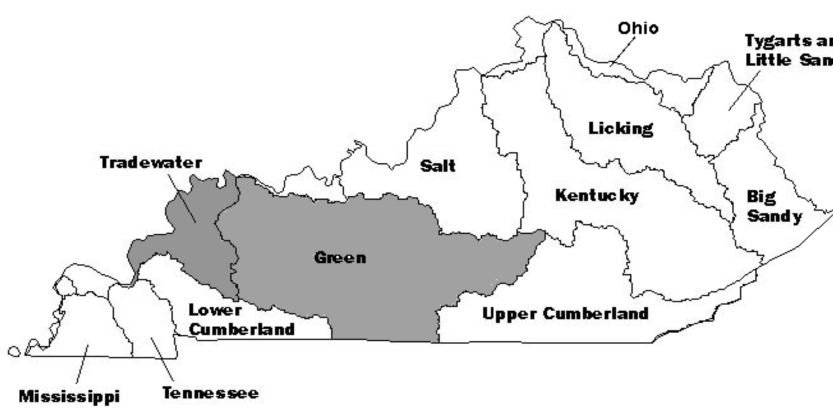

Figure 1. Kentucky watersheds map indicating Green River and Tradewater River basins.

The Mammoth Cave area of western Kentucky is unique because the world's longest known cave system is just below densely vegetated rolling hills and valleys. The forested upland habitats in the Mammoth Cave area are mixed hardwood forests dominated by the oak-hickory component. MCNP is located in the Western Pennyroyal physiographic region which can be described as having karst topography. Karst topography is terrain or a geographic region that has soluble bedrock, such as limestone or sandstone, which leads to the development of numerous sinkholes, caves, and underground streams and rivers (Figure 2). The sinkhole plain extends from Hart County in the northeast to Logan County in the southwest and passes through Mammoth Cave National Park (Kentucky Division of Water 2001).

Due to subterranean drainage, the Mammoth Cave system is ever expanding and creating new passages. Karst areas are known for having numerous seeps and springs contributing to the watershed. This area of western Kentucky is referred to as the largest spring in the state (Kentucky Division of Water 2001). Run-off can enter the subsurface through cracks and caves making karst groundwater highly susceptible to contamination from human activities on the surface. The sinkhole plain does not allow precipitation to naturally filter through vegetation or soil to remove impurities.

Contaminated groundwater can travel long distances in karst aquifers, due to the high velocity from vertical migration. The karst topography results in groundwater and surface water mixing which produces water supplies that are extremely vulnerable to poor land-use practices. Bowling Green, Brownsville, and Munfordville are population centers that all have water supplies from this karst area of western Kentucky.

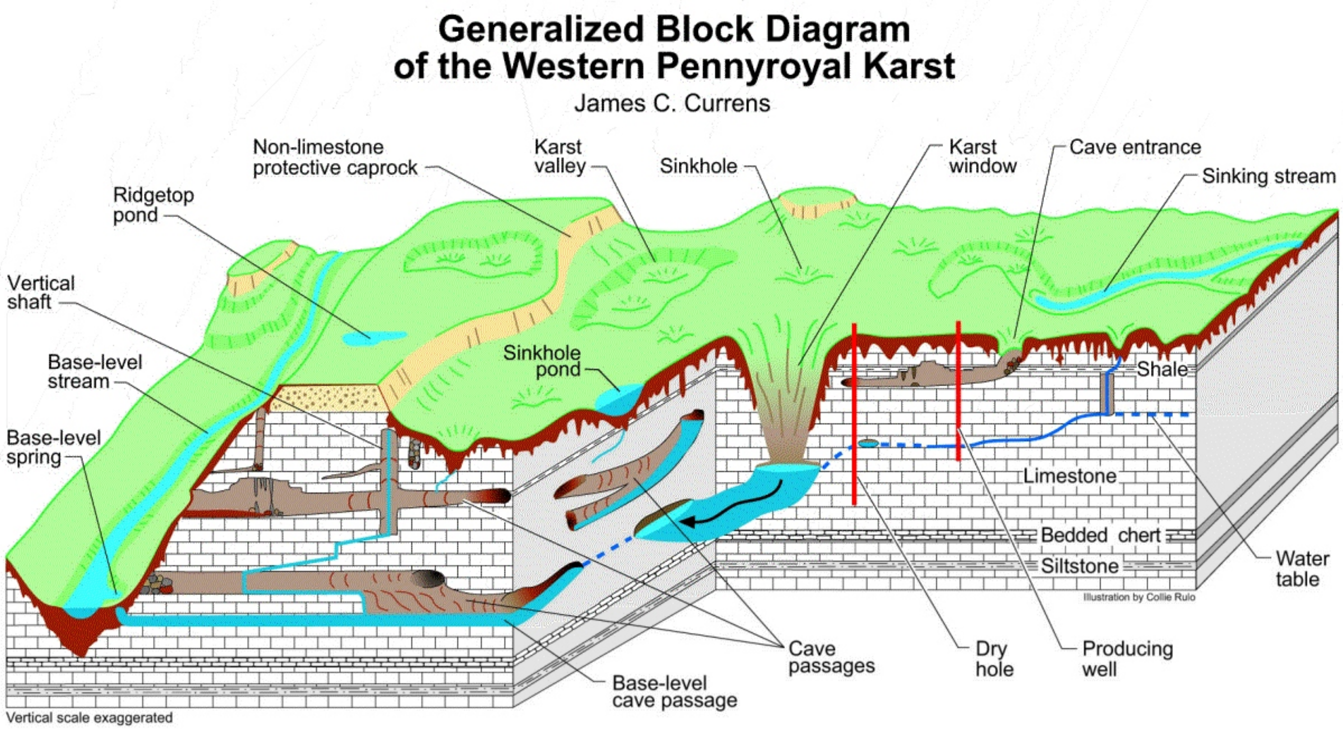

Figure 2. General diagram of limestone honeycomb showing subterranean drainage.

The Green River in MCNP is a 7^{th}-order drainage, the base level lotic environment, and has been designated an “Outstanding Resource Water” by the Kentucky Division of Water and a “Kentucky Wild River” (Miller et al. 1979). The 40-kilometer section of river in MCNP has very wide, undisturbed riparian zones with lush deciduous forests typified by both upland and bottomland species. The river meanders through a gorge of steep limestone bluffs with sandstone caprock and narrow alluvial floodplains. Very few surface tributaries (2^{nd} order or larger) flow into to the Green River in MCNP because of the extensive sinkhole plain south of the river in the Western Pennyroyal province. Water inputs come from nearly 80 subsurface and surface springs and underground streams like Echo River that empty directly into the Green River within MCNP (Figure 3).

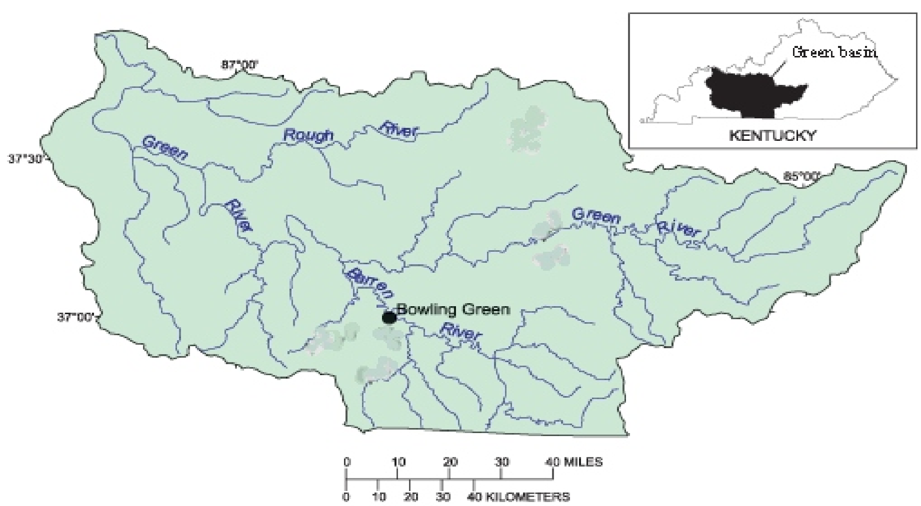

Figure 3. Green River watershed including major tributary inputs.

The Green River basin is divided into two sections, the Upper Green and the Lower Green watersheds. The basin stretches from south-central Kentucky and north-central Tennessee in the southeast, flowing to the northwest until the confluence with the Ohio River near Henderson, KY. MCNP is within the Upper Green watershed which drains nearly 15,222 km^2 in south-central Kentucky and north-central Tennessee. The Upper Green River basin is in the physiographic provinces of the Eastern and Western Pennyroyal, while the Lower Green River basin is mostly in the Western Coal Field province with portions in the Western Pennyroyal and Mississippian Plateau provinces. The headwaters of the river originate south of Danville in the Knobstone Escarpment of the Outer Bluegrass region of Casey and Lincoln counties (Schuster et al. 1996).

From its origin to Greensburg, the river gradient averages 1.0 meter per kilometer. Over the next 96 kilometers, from Greensburg to the last true riffle along the Green River at Cave Island in MCNP, the mean gradient is 0.25 meters per kilometer. The lower section of the river, from slackwater created by the relic structure known as Lock and Dam #6, to the Ohio River, has a mean gradient of 0.08 meters per kilometer. The reach of the river in our study site from Munfordville to Lock and Dam #6 (approximately 71 kilometers) has an average gradient of 0.16 meters per kilometer (Charles 1964). Natural flow conditions have been impeded throughout the system by six lock and dam structures situated in the lower to mid-sections of the river and a major reservoir in the Upper Green drainage basin. From its source, the river flows approximately 280 kilometers before reaching MCNP. The U.S. Army Corps of Engineers built Green River Lake (GRL) dam in 1969, at GRM 305; it impounds approximately 12,950 surface hectares for flood control, water supply, and recreation. GRL dam is a large storage reservoir located approximately 100 river miles upstream of the study area. The flows of Green River within MCNP have been altered by this structure near Greensburg since its construction (Schuster et al. 1996).

Sample Sites

Below the park boundary near Brownsville, a low-head dam, Lock and Dam #6, was erected in 1907 and decommissioned in the 1950s by the U.S. Army Corps of Engineers. This relic structure has been commissioned for removal by the US Army Corps of Engineers. Lock and Dam #6 creates three distinct flow zones within MCNP; these zones are designated as free-flow, transitional, and impounded. For an aquatic invertebrate study, Schuster et al. (1996) used eight sample sites, three of which were chosen to be re-occupied for this study to provide correlative data sets (Figure 4). The restricted flow of the impounded and transitional zones in the park is most apparent during base flow conditions since Lock and Dam #6 is relatively low. The free flowing upper zone is from the park boundary to Site 1 (Lat N37^{o}11.487', Long W86^{o}06.396') near Cave Island. Site 2 (Lat N37^{o}10.131', Long W86^{0}0.893') was located in the transition zone near the downstream point of Sand Cave Island. The furthest downstream in the impounded zone, Site 3 (Lat N37^{o}12.448', Long W86^{o}11.795'), was near the upper end of Crump Island . A Garmin III Plus handheld global positioning system (GPS) unit was used to establish latitude and longitude readings and to accurately relocate sampling sites.

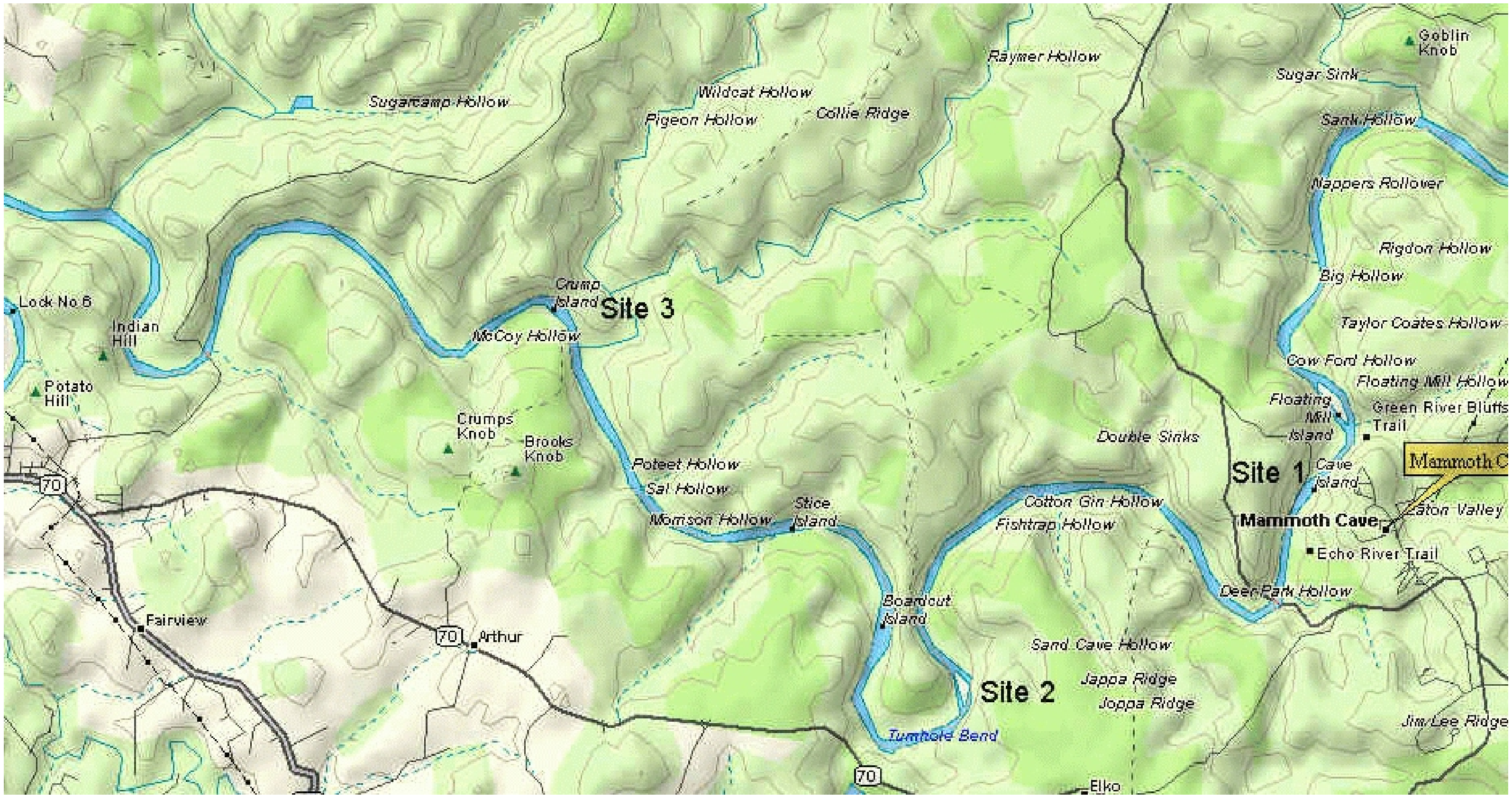

Figure 4. Study area within Mammoth Cave National Park with sample sites labeled.

Hydrology and Land Use

Floodplain development is not extensive in the area due to steep slopes along the river banks. Land use is minimal within the study site, but numerous farms with livestock operations border the river upstream between the Park and Greensburg. The MCNP wastewater treatment plant also discharges directly into the river, possibly contributing periodic nutrient fluxes. The Upper Green River basin has historically had contamination problems due to the lack of municipal sewage treatment facilities, straight-pipe discharges, failed septic systems, and farm-lot runoff. MCNP has two operational ferries that transport automobiles across the river. Green River Ferry is located between Sites 1 and 2, and Houchins Ferry is below the study area. Continued use of these ferries coupled with unstable substrates like gravel and sand could be creating elevated turbidity levels. Schuster et al.(1996) noted that seasonal flooding regimes had a profound effect on stream bed characteristics. Other land uses potentially impacting water quality include surface and subsurface coal mining, gravel mining, oil and gas drilling, road construction, and agriculture (forestry, row cropping, and livestock).

Although the area is spectacular, Green River has been placed on the 2002 list of 303(d) streams in Kentucky as first priority (Kentucky Division of Water 2002). Streams with these designations are those that have one or more properties that violate water quality standards and are not recommended for human contact. They are considered to be impacted by pollution and not fully meeting designated uses such as recreation. The following explanation of the 303(d) listing is taken from the Kentucky Division of Water 2002 List of 303(d) Waters Draft Report:

Clean Water Act, Section 303(d):

"Refers to federal requirements in the Clean Water Act for states to develop a list of waterbodies not supporting designated uses. The Code of Federal Regulations 40 Part 130.7(b)(4) states that listed waters are to be prioritized for total maximum daily load (TMDL) development."

The management of Green River Lake is very important in mimicking natural flood events in winter and providing minimum flows downstream during summer. The flooding regime created by the upstream reservoir generally occurs in two stages: (1) during September and October, resulting in a minor drop of 0.33 meters in GRL, and (2) from mid-October to early December, the drawdown is more severe and achieves a drop in the Green River Lake level of 3.30 meters over a six-week period. The reservoir drawdowns generally affect seasonal discharge patterns in the Green River within the Park, which are subject to weather. Average daily rainfall and discharge data collected at GRL in 2000-2002 are recorded in Appendices A1-A6. During summer, when GRL discharges at base flow, only approximately 25% of the flow reaching MCNP is from GRL (W. Byron, US Army Corps of Engineers, personal communication).

River stage and water quality data are available from the United States Geological Survey (USGS) gauging station at Munfordville, KY. Flow rates are highly variable in regulated systems like the Upper Green and the river stage has been known to fluctuate more than 20 meters in its natural regime (Schuster et al. 1996). Mean annual stream flow at Munfordville between water years 2000-2002 was estimated at 50.9 cubic meters per second (1799 cfs). Average daily stream flow data collected at the USGS gauging station in Munfordville during the study period is recorded in Appendix A7.

CHAPTER IV

METHODS

Field Methods

During the period September 2000 through June 2002, water quality data and plankton samples were collected from the Green River within Mammoth Cave National Park, Kentucky, to evaluate the physical parameters and the planktonic community. A total of six collections were made during the study period during different months to account for seasonal variation in plankton blooms and die-offs. Samples were collected in the river's three distinct zones (free-flow, transitional, and impounded) at three sampling stations previously occupied by Schuster et al. (1996) during an aquatic macro-invertebrate study. A Garmin III Plus GPS unit was used to determine exact location data for each sample site. Each year, two samples were taken during base flow (June through September), and one collection was made during enhanced flow (November or December). The summer samples encompassed the period of maximum densities and the bimodal peaks in typical zooplankton populations. The late fall sample documented plankton abundance and community composition resulting from the drawdown discharges of Green River Lake. All samples were taken from a flat bottom boat which was anchored at each sample site while collections were made.

Sampling protocols were designed to maximize reproducibility. During the study, a total of 180 samples (6 trips x 3 sample sites x 10 samples per site) were collected and returned to the laboratory for analysis. The 10 samples per site included two 1.0-L water bottle samples for phytoplankton; the remaining eight samples were for zooplankton. These included two 10-meter horizontal tows with the 80-micron net, two 10-meter horizontal tows with the 153-micron net, two vertical tows (from river bottom to the surface) with the 80-micron net, and two similar vertical tows with the 153-micron net.

During the summer of 2001, a leak formed under Lock and Dam #6, which lowered the river in MCNP by approximately 1.0 meter. The decreased river level limited access to portions of the study area during the September sample. Since the water level was too low to access to the upstream site, the collection for the upstream site was taken from the Green River Ferry crossing.

In September 2001 and July 2002, additional zooplankton samples were taken at five sites above and below our study area to qualitatively investigate plankton community structure throughout the system. These zooplankton samples were collected at Green River Lake, the tailwaters just below GRL dam, state Highway 88 bridge, and the public access in Munfordville; all of these sites were upstream of the study area. Additional samples were also collected below the study area approximately 150 meters up the Nolin River from the confluence of the Nolin and Green rivers. Samples were collected in a similar manner as those taken in MCNP. All additional sites were sampled using the 80-micron mesh plankton net with both horizontal and vertical tows.

Water Quality

Data were collected on various physical and chemical parameters at each sample site. Water transparency was measured at each site using a 20-centimeter Secchi disk with a 2000-gram weight attached. This measurement coincided with the 10% level of incident surface light and generally with the greatest densities of phytoplankton (Wetzel 1983). Care was taken to keep the Secchi disk on the side of the boat nearest the sun to avoid shadows; on overcast days, this was not a concern. The disk was lowered until out of sight then raised until it became visible again. Where the disk became visible again, the depth (meters) was recorded. The maximum water depth was taken by lowering a 2000-gram weight attached to a rope marked with depth increments to the river bottom. Temperature (C), dissolved oxygen (mg/L), and conductivity (micromoles/L) data were recorded by lowering a YSI Model 85 multiprobe (Yellow Springs Instruments, Yellow Springs, OH) at 1.0-meter intervals from the surface to the river bottom; pH (standard units) was recorded in a similar fashion with a YSI Model 60 meter. Tape was used to mark the cord of the YSI meters to easily measure each group of readings. During enhanced flow collection trips, a 2000-gram weight was added to make the probes hang vertically in the water column.

Zooplankton

Zooplankton were collected using two different size mesh plankton nets (80-um and 153-um mesh nets) to encompass size variation of all major zooplankton groups. Samples were also collected using vertical and horizontal tows to account for phototaxism exhibited by most groups of zooplankton. Each plankton net (Figure 5) had a collection bottle with a hose and clamp attached to the bottom to concentrate the volumes of water sampled. Two 5-meter horizontal hauls were made with each plankton

Figure 5. Plankton nets with 14.5-centimeter openings and collection bottles attached.

net to collect the 10-meter sample at each site. On two occasions, the nets were only pulled 5.0 meters horizontally; therefore, the density calculations were based on the reduced volume sampled.

Horizontal tows were taken within 1.0 meter of the surface, taking care to remove all air bubbles from the net and allowing the lead ring to drop below the surface. Vertical tows were taken on either side of the boat from just above the river bottom to the surface. The river depth at each site was used for calculating the volume of water sampled on vertical tows. During enhanced flow collections, two to five 100-gram weights were attached to the bottom of the collection bottles to reduce downstream drift and accurately sample the vertical water column. Eight total zooplankton samples were collected from each site, with two horizontal tows taken using both nets (four samples) and two vertical tows using both nets (four samples). The samples were transferred to 250-mL opaque plastic collection bottles to prevent any biological activity caused by UV penetration. After collection, approximately 12-15 milliliters (mL) of 10% sugared formalin solution was added to preserve the zooplankton. The sugared formalin had been premixed in the laboratory by mixing approximately 6 grams of sucrose in 250 milliliters of 10% formalin solution (Lind 1985). This solution was used to prevent carapace distortion and loss of brood pouch contents due to ballooning (Haney and Hall 1973). Sample bottles were labeled with date, sample site, mesh size, and direction of tow to assist in comparison of samples in the lab.

Phytoplankton

Grab samples of river water were collected using a vertical 1.0-L polycarbonate water sample bottle (WaterMark ^{R}) to evaluate the phytoplankton community. The water sample bottle was lowered to two-thirds of the Secchi depth, which was usually within 2.0 meters of the surface, where the messenger was dropped, thereby capturing the water column at that point. Samples were transferred to an opaque 1.0-L plastic bottle and preserved by adding 10 milliliters of Lugol's solution. Lugol's solution was used to preserve and stain the cells for later examination (Lind 1985). Samples were transported to the laboratory (usually within 24 hours) and stored in a dark, cool place. This limited any further respiration or decomposition and also allowed the organisms to settle to the bottom of the bottle to facilitate preparation for the identification procedure.

Laboratory Methods

Zooplankton

Zooplankton samples were analyzed using gridded petri dishes filled with approximately 80 milliliters of sample, then systematically viewed across and down with a dissecting microscope. An American Optical Instrument Company dissecting microscope Model 570 was used with a range of magnification of 0.7X to 4.2X. The petri dishes had a total of 36 grids with corresponding letters and numbers to prevent the observer from recounting an organism. All invertebrates were identified to lowest practical taxon using taxonomic keys (Ward and Whipple 1959; Pennak 1978) and recorded. A running tally was taken for each taxon from every sample. Total numbers of organisms were divided by volume sampled (liters) to calculate organisms per liter at each site. The volume sampled was calculated by applying the equation for the volume of a cylinder 10 meters in length to the radius, squared (r^2), of the metal O-ring of the plankton net traveling through the water: $V = r^2 * L$, where r is the radius of the O-ring in centimeters and L is the distance the net was towed (in centimeters). This volumetric measurement (V) was converted to liquid volume by the conversion factor (1 cubic centimeter = 1 milliliter); this value was then multiplied by 0.001 to convert to liters. The total number of each taxa observed was divided by the number of liters to give the density of organisms in number per liter. The volume (liters) sampled in horizontal tows remained consistent at 165 liters for the 10-meter tow (82.5 liters for the 5-meter tow) while the volume sampled in vertical tows varied depending on river depth at each site.

Phytoplankton

Phytoplankton samples were allowed to settle in the laboratory before slides were prepared for viewing. A Fisher Micromaster I compound microscope was used with 4X, 10X, and 40X objectives. A 10X ocular was in place producing total magnification of 40, 100, and 400 times actual size. Due to the large volume sampled (1.0 liter), a three-step sub-sampling process was used for examination. In the first step, half of the sample (500 milliliters) was decanted from the top of the sample bottle using a syphon hose. The decanted sample was visually scanned to ensure no plankton had been removed. The remaining sample containing the organisms was mixed thoroughly and a Henson-Stempel pipette was used to extract a 30-mL sample which was placed in a petri dish. A 1.0-mL pipette was used to sub-sample the petri dish; this sub-sample was placed into a Sedgewick-Rafter counting slide where the phytoplankton was identified, enumerated, and photographed. Three counting slides were prepared from each sample; the plankton organisms enumerated were multiplied by 1000 and divided by three to give number per liter. Numerous taxonomy books were utilized to identify the phytoplankton genera; the most useful were Smith (1950), Prescot (1964), and Dillard (1989).

Photography

A Fisher Digital Microscope Head (MCD) attachment along with associated software (Micron Basic USB 2.0) was added to the compound microscope to facilitate the creation of a digital reference collection for all plankton. The camera attachment had a resolution of 120 dpi. Zooplankton organisms were selected and placed into a drop of glycerine on an isolation slide (Figure 6) and photographed using 100X magnification. If the organisms were too large to capture with the 100X objective either the 40X objective was used or multiple photos were taken showing different halves of the organism with the 100x objective. Phytoplankton were photographed using one or more of several techniques. Images of larger colonies and filaments were captured with samples in the Sedgewick-Rafter counting slide using 40X and 100X magnification. Individual cells or groups of cells were placed on standard glass slides and cover slips applied to photograph cell structure using 400X magnification.

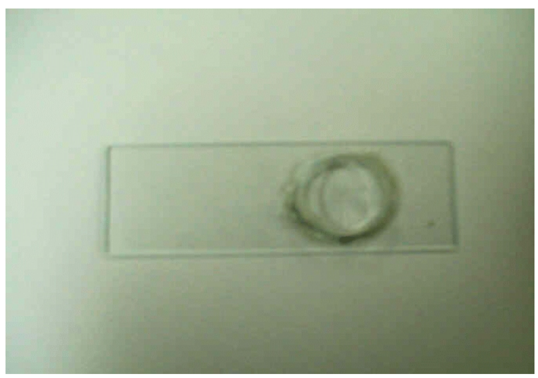

Figure 6. Isolation slide used during photography of zooplankton specimens.

CHAPTER V

RESULTS AND DISCUSSION

Water Quality

Physical parameters and water quality data recorded during the study are presented in Table 1. Water quality data were similar among sites and the variation among dates was consistent with climatic conditions. Dissolved oxygen ranged from 10.96 (mg/L) in December 2001 to 6.20 (mg/L) in July 2002. Temperature ranged from 25.9° C in July 2002 to 6.4° C in November 2000. The pH ranged from 8.05 (su) in November 2000 to 5.72 (su) in July 2002. Conductivity ranged from 282 (mS/cm) in November 2000 to 383 (mS/cm) in July 2002. A leak in Lock and Dam #6 caused the decrease in total depth for the September 2001 sample.

Water quality values obtained are within a range of normal values commonly occurring in temperate rivers (Ruttner 1963; Palmer 1964). A long-term (multiple year periods over several decades) water quality data set for Green River is being maintained by MCNP staff. The study period is not included in this long term data set. Water quality monitoring was reinitiated by the Park in mid-2002 when this study was completed (Joe Meimam, MCNP, personal communication). Water quality values were very similar at each depth measured across sites. This proved there was no stratification and that river waters are constantly mixing and tumbling.

Table 1. Water quality parameters at three sample sites in Green River within Mammoth Cave National Park, 2000-2002

	DO (mg/L)	Temp (C)	pH	Conductivity (mS/cm)
September 2000				
Cave Island: Total depth = 2.2m, Secchi depth = 1.1m				
Surface	10.35	20.3	7.97	346.5
1 meter	10.37	19.4	7.98	345.7
2 meter	10.25	19.3	7.96	345.7
Sand Cave Island: Total depth = 3.0m, Secchi depth = 0.9m				
Surface	9.76	19.5	7.83	347.2
1 meter	9.53	19.3	7.93	347.2
2 meter	9.67	19.3	7.93	347.3
3 meter	9.73	19.3	7.93	347.3
Crump Island: Total depth = 4.5m, Secchi depth = 0.6m				
Surface	9.1	21.1	7.63	371.6
1 meter	9.4	20	7.74	371
2 meter	9.09	19.1	7.71	370
3 meter	8.8	18.9	7.71	369.4
4 meter	8.6	18.9	7.71	368.6
November 2000				
Cave Island: Total depth = 2.5m, Secchi depth = 2.25m				
1 meter	10.75	6.6	8.02	282.5
2 meter	10.78	6.7	8.05	282.7
Sand Cave Island: Total depth = 3.0m, Secchi depth = 2.25m				
Surface	10.71	6.6	7.84	288.1
1 meter	10.7	6.6	7.86	289.5
2 meter	10.69	6.6	7.85	289.5
3 meter	10.64	6.5	7.83	289.6
Crump Island: Total depth = 4.5m, Secchi depth = 2.0m				
Surface	9.83	7.0	7.36	304
1 meter	9.82	6.9	7.6	305.7
2 meter	9.7	6.9	7.71	305.5
3 meter	9.75	6.9	7.72	305.7
4 meter	9.7	6.9	7.69	305.9

Table 1. (continued)

	DO (mg/L)	Temp (C)	pH	Conductivity (mS/cm)
June 2001				
Cave Island: Total depth = 1.5m, Secchi depth = 0.75m				
Surface	6.75	25.5	7.6	347.6
1 meter	7.02	25.6	7.76	347.6
Sand Cave Island: Total depth = 3.0m, Secchi depth = 0.75m				
Surface	6.6	25	7.53	341.9
1 meter	6.37	24.9	7.43	341.8
2 meter	6.3	24.9	7.37	341.6
3 meter	6.23	24.8	7.35	341.7
Crump Island: Total depth = 5m, Secchi depth = 1.5m				
Surface	6.8	24.7	6.62	336.6
1 meter	6.82	24.2	6.7	333.5
2 meter	6.78	24.1	6.7	333.4
3 meter	6.75	24.2	6.27	333.7
4 meter	6.73	24.2	6.19	334.1
5 meter	6.65	24.3	6.19	334
September 2001				
Green River Ferry: Total depth = 0.9m, Secchi depth = 0.75m				
Surface	8.52	26	8.05	379.6
0.75 meter	8.4	25.9	8.03	379.8
Sand Cave Island: Total depth = 2.75m, Secchi depth = 0.5m				
Surface	7.66	24.7	7.59	379.2
1 meter	7.5	24.7	7.6	379.3
2 meter	7.53	24.7	7.61	379.4
Crump Island: Total depth = 3.6m, Secchi depth = 0.5m				
Surface	7.82	25.5	7.9	373.9
1 meter	7.64	24.6	7.85	372.9
2 meter	7.32	24.3	7.75	372.1
3 meter	7.22	24.2	7.69	372.2

Table 1. (continued)

	DO (mg/L)	Temp (C)	pH	Conductivity (mS/cm)
December 2001				
Cave Island: Total depth = 4.0m, Secchi depth = 0.25m				
Surface	10.96	11.1	6.84	286
1 meter	10.92	11	6.72	286.3
2 meter	10.8	11	6.77	286.4
3 meter	10.71	11	6.75	286.4
4 meter	10.36	11	6.7	286.3
Sand Cave Island: Total depth = 4.75m, Secchi depth = 0.25m				
Surface	10.88	11.2	6.83	288.4
1 meter	10.63	11.1	6.82	291.6
2 meter	10.54	11.1	6.81	291.7
3 meter	10.29	11.1	6.71	291.6
4 meter	10.32	11.1	6.75	291.5
Crump Island: Total depth = 4.6m, Secchi depth = 0.35m				
Surface	10.05	11.4	6.75	295.1
1 meter	9.70	11.3	6.75	295.1
2 meter	9.97	11.35	7.36	294.8
3 meter	10.07	11.3	6.93	295.0
4 meter	9.33	11.35	6.92	294.2
July 2002				
Cave Island: Total depth = 2.3m, Secchi depth = 0.70m				
Surface	6.75	24.7	7.35	369.4
1 meter	6.41	24.7	7.29	370.2
2 meter	6.2	24.6	7.2	370.1
Sand Cave Island: Total depth = 3.2m, Secchi depth = 0.50m				
Surface	6.74	25.8	7.52	373.1
1 meter	6.99	25.8	7.27	372.7
2 meter	6.85	25.9	6.94	372.8
3 meter	6.92	25.9	6.53	372.8
Crump Island: Total depth = 4.6m, Secchi depth = 0.60m				
Surface	7.19	25.7	7.52	383.8
1 meter	7.02	25.6	7.18	383.1
2 meter	6.2	25.4	6.79	381
3 meter	6.43	25.1	6.38	378.2
4 meter	6.4	25.1	5.72	377.3

Zooplankton

Zooplankton taxonomy and densities determined from Green River samples within MCNP are reported for each site by sample date in Tables 2-4. Densities are given as an average number of organisms per liter taken from the eight samples collected form each site. The dominant zooplankton groups were Cladocera and Copepoda. Densities of selected cladocerans ranged from 0.01/L in September 2000 to 0.46/L in December 2001. Selected copepod densities ranged from 0.01/L in September 2000 to 0.53/L in December 2001. Various groups of aquatic insects were collected at densities equal to or greater than the zooplankton during the study. The three primary groups of larval insects found were in the orders Diptera, Odonata, and Plecoptera, with Diptera representing the most abundant group. These organisms were often identified from molted carapaces. The 2002 sample (Table 4) seemed to show a greater species richness, although densities remained similar to previous samples.

Bosmina longirostrus was the dominant cladoceran species and *Mesocyclops edax* was the dominant copepod observed. The family Chironomidae was the dominant aquatic insect taxon collected. Densities of these organisms, along with three other taxonomic units most often encountered (*Diaphanosoma, Ceriodaphnia*, Plecoptera), were analyzed using one-way analyses of variance (ANOVA) with SPSS statistical software to determine what differences, if any, existed between dates, sites, and flow regimes. Post Hoc tests were performed to correlate flows to densities, as well as species to site and date.

Table 2. Zooplankton organisms and densities (number/L) collected at three sample sites in Green River, Mammoth Cave National Park, 2000

Month/Organism	Site Cave Is.	 Sand Cave Is.	 Crump Is.
September			
Phylum Anellida			
Class Oligochaeta	0.00	0.00	0.01
Phylum Arthropoda			
Class Arachnoidea			
Hydracarina	0.02	0.00	0.00
Class Crustacea			
Order Cladocera			
Family Bosminidae			
Bosmina longirostris	0.00	0.00	0.01
Family Daphnidae			
Ceriodaphnia sp.	0.03	0.00	0.00
Daphnia sp.	0.01	0.00	0.00
Family Sididae			
Diaphanosoma sp.	0.02	0.02	0.03
Subclass Copepoda			
Order Eucopepoda			
Family Cyclopoidae			
Mesocyclops edax	0.01	0.00	0.08
Subclass Ostracoda (planktonic)	0.00	0.00	0.01
Phylum Insecta			
Order Diptera			
Family Chironomidae	0.05	0.00	0.01
Family Culicideae	0.03	0.00	0.00
Order Plecoptera			
Family Capniidae	0.00	0.02	0.01
November			
Phylum Arthropoda			
Class Arachnoidea			
Hydracarina	0.00	0.00	0.01
Class Crustacea			
Order Cladocera			

Table 2. (continued)

Month/Organism	Cave Is.	Site Sand Cave Is.	Crump Is.
Family Bosminidae			
Bosmina longirostris	0.05	0.03	0.08
Family Daphnidae			
Ceriodaphnia sp.	0.00	0.03	0.01
Daphnia sp.	0.01	0.00	0.00
Family Sididae			
Diaphanosoma sp.	0.00	0.06	0.00
Subclass Copepoda			
Order Eucopepoda			
Eucopepod copepodites	0.00	0.02	0.09
Family Calanoidae (unidentified)	0.03	0.08	0.00
Family Cyclopoidae			
Mesocyclops edax	0.05	0.08	0.05
Subclass Ostracoda (planktonic)	0.00	0.03	0.00
Phylum Rotatoria			
Class Monogononta			
Order Ploima			
Family Asplanchnidae			
Asplanchna sp.	0.01	0.03	0.01
Family Brachionidae			
Keretella sp.	0.00	0.01	0.00
Family Synchaetidae			
Ployarthra sp.	0.00	0.03	0.00
Phylum Insecta			
Order Diptera			
Family Chironomidae	0.02	0.03	0.03
Family Culicidae	0.01	0.02	0.00

Table 3. Zooplankton organisms and densities (number/L) collected at three sample sites in Green River, Mammoth Cave National Park, 2001

Month/Organism	Cave Is.	Site Sand Cave Is.	Crump Is.
June			
Phylum Arthropoda			
Class Arachnoidea			
Hydracarina	0.00	0.00	0.01
Class Crustacea			
Order Cladocera			
Family Bosminidae			
Bosmina longirostris	0.03	0.02	0.04
Family Daphnidae			
Daphnia retrocurva	0.00	0.00	0.01
Family Sididae			
Diaphanosoma sp.	0.01	0.04	0.04
Subclass Copepoda			
Order Eucopepoda			
Eucopepod copepodites	0.00	0.00	0.02
Family Calanoidae (unidentified)	0.00	0.04	0.08
Family Cyclopoidae			
Mesocyclops edax	0.01	0.02	0.05
Subclass Ostracoda (planktonic)	0.00	0.04	0.01
Phylum Nematoda	0.00	0.00	42.39
Phylum Rotatoria			
Class Monogononta			
Order Ploima			
Family Brachionidae			
Keretella sp.	0.00	0.00	0.13
Phylum Insecta			
Order Diptera			
Family Chironomidae	0.06	0.05	0.04
Family Culicidae	0.03	0.04	0.02
Order Hemiptera	0.05	0.00	0.01
Order Odonata	0.03	0.02	0.00
Order Plecoptera			
Family Capniidae	0.05	0.02	0.01

Table 3. (continued)

Month/Organism	Cave Is.	Site Sand Cave Is.	Crump Is.
September			
Phylum Athropoda			
Class Arachnoidea			
Hydracarina	0.00	0.01	0.00
Class Crustacea			
Order Cladocera			
Family Bosminidae			
Bosmina longirostris	0.02	0.01	0.03
Family Daphnidae			
Daphnia retrocurva	0.04	0.00	0.02
Family Sididae			
Diaphanosoma sp.	0.03	0.01	0.11
Subclass Copepoda			
Order Eucopepoda			
Eucopepod copepodites	0.00	0.00	0.01
Family Cyclopoidae			
Mesocyclops edax	0.02	0.01	0.01
Subclass Ostracoda (planktonic)	0.07	0.02	0.02
Phylum Rotatoria			
Class Monogononta			
Order Ploima			
Family Brachionidae			
Keretella sp.	0.00	0.02	0.02
Phylum Insecta			
Order Coleoptera	0.00	0.00	0.01
Order Diptera			
Family Chironomidae	0.03	0.01	0.00
Family Culicidae	0.01	0.02	0.01
Order Hemiptera	0.00	0.02	0.00
Order Odonata	0.00	0.02	0.00
Order Plecoptera			
Family Capniidae	0.09	0.01	0.01

Table 3. (continued)

Month/Organism	Cave Is.	Site Sand Cave Is.	Crump Is.
December			
Phylum Arthropoda			
Class Arachnoidea			
Hydracarina	0.00	0.03	0.00
Class Crustacea			
Order Cladocera			
Family Bosminidae			
Bosmina longirostris	0.32	0.46	0.31
Family Chydoridae (unidentified)	0.12	0.22	0.19
Family Daphnidae			
Ceriodaphnia sp.	0.02	0.07	0.03
Daphnia parvula	0.03	0.00	0.03
Daphnia schodleri	0.03	0.00	0.00
Family Sididae			
Diaphanosoma sp.	0.02	0.00	0.02
Subclass Copepoda			
Order Eucopepoda			
Eucopepod copepodites	0.03	0.05	0.06
Family Calanoidae (unidentified)	0.00	0.04	0.02
Family Cyclopoidae			
Mesocyclops edax	0.53	0.51	0.53
Subclass Ostracoda (planktonic)	0.01	0.01	0.01
Phylum Rotatoria			
Class Monogononta			
Order Ploima			
Family Brachionidae			
Keretella sp.	0.02	0.00	0.01
Family Synchaetidae			
Ployarthra sp.	0.02	0.09	0.01
Phylum Insecta			
Order Diptera			
Family Chironomidae	0.06	0.03	0.02
Family Culicidae	0.02	0.01	0.00
Order Hemiptera	0.03	0.01	0.00
Order Plecoptera			
Family Capniidae	0.02	0.02	0.01

Table 4. Zooplankton organisms and densities (number/L) collected at three sample sites in Green River, Mammoth Cave National Park, 2002

Month/Organism	Cave Is.	Site Sand Cave Is.	Crump Is.
July			
Phylum Arthropoda			
Class Arachnoidea			
Hydracarina	0.02	0.01	0.00
Class Crustacea			
Order Cladocera			
Family Bosminidae			
Bosmina longirostris	0.03	0.02	0.01
Family Chydoridae (unidentified)	0.02	0.02	0.00
Family Daphnidae			
Ceriodaphnia sp.	0.00	0.00	0.01
Daphnia parvula	0.02	0.00	0.01
Family Sididae (unidentified sp.)	0.07	0.00	0.00
Diaphanosoma sp.	0.02	0.02	0.11
Subclass Copepoda			
Order Eucopepoda			
Eucopepod copepodites	0.31	0.01	0.07
Family Cyclopoidae			
Mesocyclops edax	0.06	0.02	0.05
Subclass Ostracoda (planktonic)	0.02	0.01	0.00
Phylum Rotatoria			
Class Monogononta			
Order Ploima			
Family Asplanchnidae			
Asplanchna sp.	0.24	0.08	0.05
Family Brachionidae			
Keretella sp.	0.00	0.04	0.01
Phylum Insecta			
Order Diptera			
Family Chironomidae	0.22	0.09	0.03
Family Culicidae	0.14	0.04	0.02
Family Tabanidae	0.00	0.01	0.00
Order Hemiptera	0.01	0.03	0.01
Order Odonata	0.03	0.01	0.00
Order Plecoptera			
Family Capniidae	0.05	0.04	0.02

Chironomidae, *Diaphanosoma*, and Plecoptera were the groups significantly affected by site (Table 5). The significance value for these organisms is below the alpha level of 0.05, making the site a significant indicator/factor. Cave Island (upstream) was the site where most Chironomidae and Plecoptera were found. This was probably due to the presence of shallow riffles associated with the riverine reach of the study area; these riffles provided interstitial spaces creating suitable habitat for these organisms. *Diaphanosoma* was more abundant at the Crump Island (downstream) site. The reduced flow created by Lock and Dam #6 resulted in a more lentic system that facilitated increased reproduction and favored cladocerans like *Diaphanosoma* (Figure 7). Table 6 shows the analysis of species by date; all the values were below the alpha value of 0.05 indicating that all taxa analyzed were significantly affected by season. *Bosmina longirostris, Ceriodaphnia* and *Mesocylops edax* (Figure 8) all exhibited significant increases in density during the December 2001 sample. Increased plankton densities in winter 2001 were attributed to increased reservoir releases (Appendix A6).

Figure 7. Digital image of *Diaphanosoma* sp.

Table 5. One-way analysis of variance of selected species compared by sample site.

ANOV

		Sum Square	df	Mean	F	Sig.
BOSMI	Between	.01	2	.00	.28	.75
	Within	3.93	14	.02		
	Total	3.94	14			
CERIOD	Between	.00	2	.00	2.75	.06
	Within	.03	14	.00		
	Total	.04	14			
DIAPH	Between	.02	2	.01	4.22	.01
	Within	.32	14	.00		
	Total	.34	14			
CYCLOC	Between	.00	2	.00	.03	.96
	Within	8.01	14	.05		
	Total	8.01	14			
CHIRON	Between	.06	2	.03	7.17	.00
	Within	.65	14	.00		
	Total	.72	14			
PLECOPT	Between	.00	2	.00	5.58	.00
	Within	.11	14	.00		
	Total	.12	14			

Table 6. One-way analysis of variance of selected species compared by sample date

ANOV

		Sum of Squares	df	Mean	F	Sig.
CHIRONO	Between	.209	5	.042	11.21	.000
	Within	.515	138	.004		
	Total	.724	143			
CYCLOCO	Between	5.145	5	1.029	49.48	.000
	Within	2.870	138	.021		
	Total	8.015	143			
DIAPHA	Between	.030	5	.006	2.639	.026
	Within	.315	138	.002		
	Total	.345	143			
CERIODA	Between	.017	5	.003	20.79	.000
	Within	.023	138	.000		
	Total	.040	143			
BOSMIN	Between	2.479	5	.496	46.54	.000
	Within	1.470	138	.011		
	Total	3.949	143			

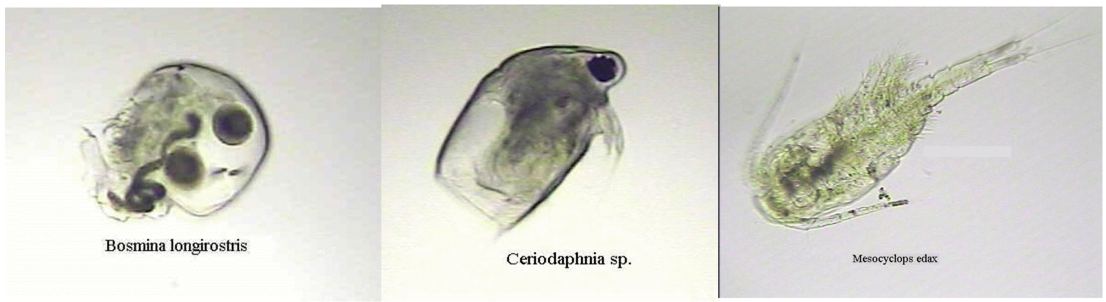

Figure 8. Digital images of *Bosmina longirostris*, *Ceriodaphnia* sp., and *Mesocyclops edax*.

Chironomid densities were significantly greater during the July 2002 sample. Plecoptera densities were similar on June and December 2001 but significantly different between the 2000 samples and other sample dates. The three species pictured above, which increased in the December 2001 sample, were the same species significantly affected by flow regime. Chironomids, *Diaphanosoma* sp., and plecopterans were not significantly affected by flow regime. Figure 9 illustrates the significant increases in *Bosmina* and *Mesocyclops edax* during enhanced flow samples. Conversely, *Diaphanasoma* exhibited a decrease in densities during enhanced flow samples, especially at the Crump Island site. This is evidence of reproduction in the Park, because retention time is greatest in the summer when flows are low. The slower moving water gives plankton an opportunity to complete their life cycle. Additional statistical analysis including post-hoc tests are presented in Appendices B1-B3.

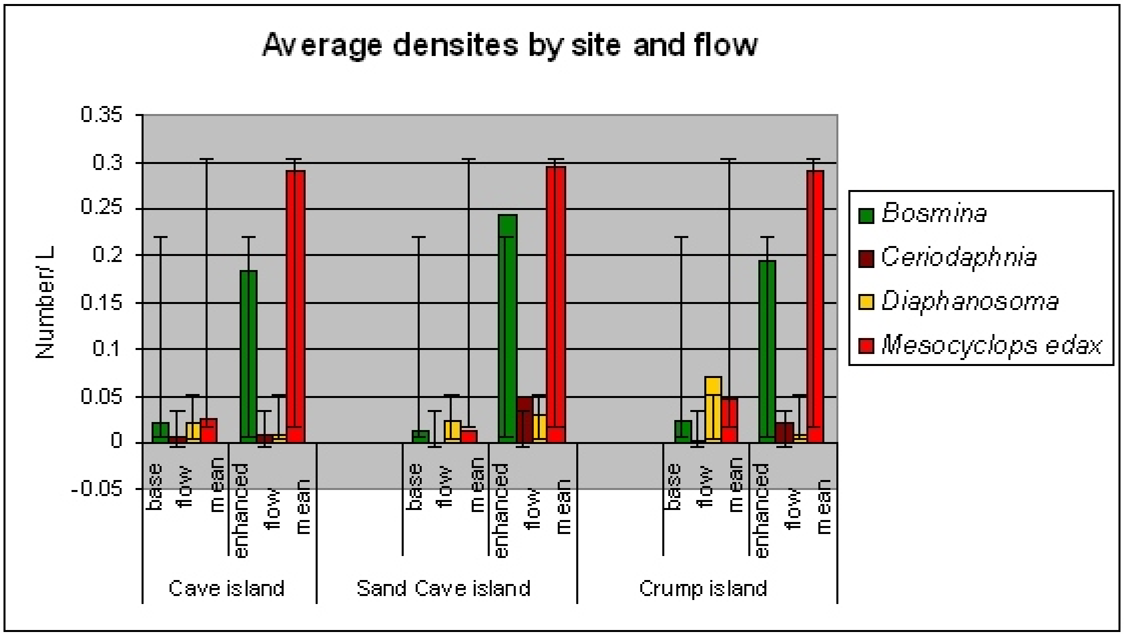

Figure 9. Graph depicting significant changes in densities of selected species at three sites when compared by flow regimes.

Basin Wide Analysis

In September 2001 and July 2002, additional zooplankton samples were collected from sites above and below our study area to investigate community structure throughout the Upper Green River system. Densities of selected common organisms were plotted against mean MCNP data to give some comparisons (Figures 10-11). MCNP data were averaged for all sites in this analysis to facilitate comparison and interpretation. Graphically it appears that these data show decreased numbers of organisms as one moves downstream toward the Park. The slight increase in *Diaphanosoma* from Munfordville to MCNP in 2001 was likely due to Lock and Dam #6 holding back water and creating a more favorable environment for reproduction.

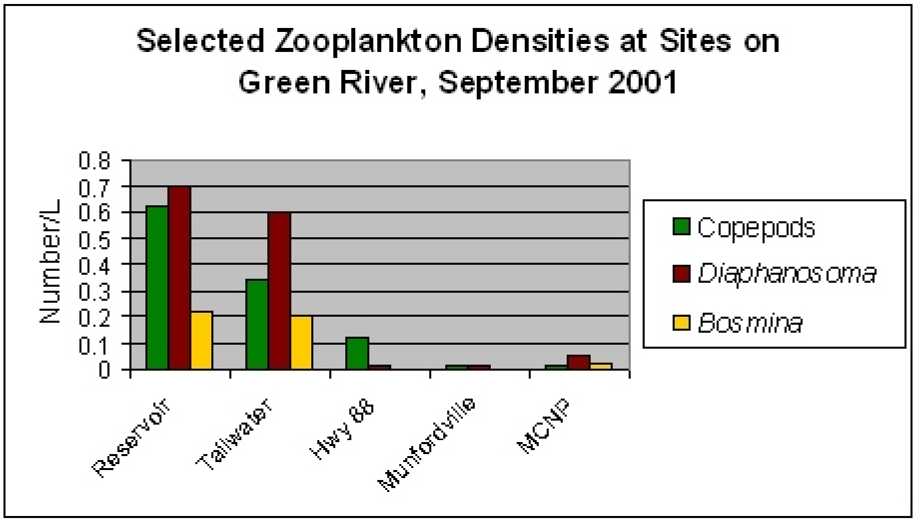

Figure 10. Zooplankton densities collected above the study area at sites along Green River, 2001 including: Green River Lake, Green River Lake tailwaters, Hwy 88 bridge, Munfordville, and within Mammoth Cave National Park.

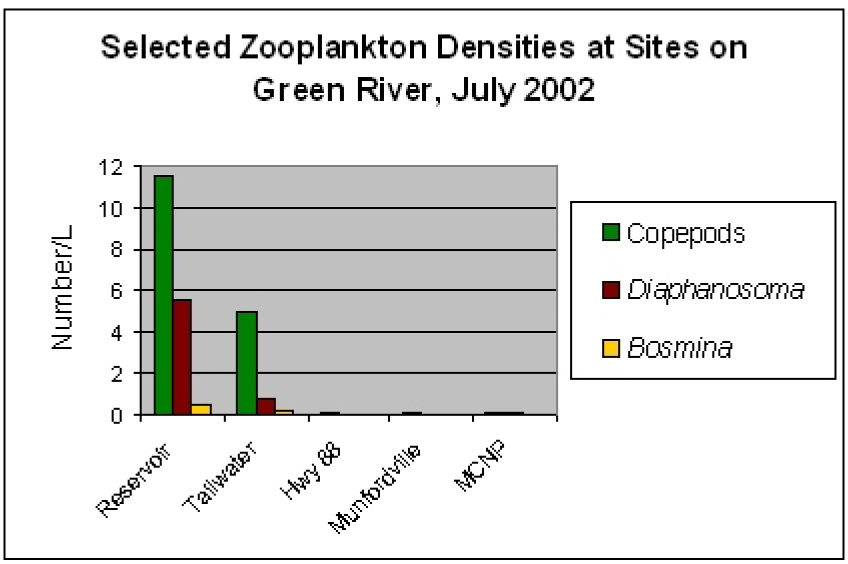

Figure 11. Zooplankton densities collected above the study area at sites along Green River, 2002 including: Green River Lake, Green River Lake tailwaters, Hwy 88 bridge, Munfordville, and within Mammoth Cave National Park.

Additional samples were collected downstream of the study area in the Nolin River within MCNP in June 2001 and July 2002 to gain knowledge of tributary inputs. Nolin River samples contained a much more specious and abundant zooplankton fauna. Six or more cladoceran taxa were routinely found in Nolin River samples whereas Green River samples usually only contained three taxa of cladocerans. Also, both calanoid and cyclopoid copepods were present in Nolin samples, but only cyclopid copepods were found in the majority of Green River samples. Rotifers were found in large numbers in the 2002 sample of Nolin River, but rarely found in significant densities in Green River collections. It is important to note that the sample site on the Nolin River was much closer to the associated upstream dam (Nolin River Dam) than the sites on Green River. Zooplankton results from basin wide samples are presented in Appendices C1 and C2.

Phytoplankton

Phytoplankton taxonomy taken from Green River samples within MCNP are reported for each sample date in Table 7. Chlorophyta (green algae) was the dominant phytoplankton phylum present during all samples with approximately 97% of the species composition. Genus *Cholorella* comprised over 95% of all cells in every sample. Other filamentous Chlorophyta genera, like *Ulothrix,* contributed minor portions of the population. Also, Cyanophyta (blue-greens) and Chrysophyta (golden-brown algae) were found in relatively low numbers. Figures 12 and 13 give the percent occurrence of phytoplankton taken from Green River in summer and winter samples. Although the percentages are no greater, more genera are represented in the summer samples (Figure 11). Densities of cells observed was in the range 1.3×10^3 to 1.6×10^6 which is within

Table 7. Phytoplankton taxonomy and occurrence in Green River within Mammoth Cave National Park, 2000-2002.

Organism	Month/Year					
	9/00	11/00	6/01	9/01	12/01	7/02
Phylum Chlorophyta						
Class Chlorophyceae						
Order Chlorococcales						
Family Oocystaceae						
Chlorella sp.	X	X	X	X	X	X
Treubaria sp.					X	
Family Scenedesmaceae						
Crucigenia sp.					X	
Order Cladophorales						
Family Cladophoraceae						
Rhizoclonium sp.	X	X	X	X		X
Order Ulotrichales						
Family Microsporaceae						
Microspora sp.				X	X	
Family Ulotrichaceae						
Ulothrix sp.	X	X	X	X	X	X
Order Volvocales						
Family Chlamydomonadaceae						
Chlamydomonas sp.			X	X		X
Order Zygnematales						
Family Desmidaceae						
Closterium sp.			X		X	X
Other (unidentified)			X	X		X
Phylum Chrysophyta						
Class Bacillariophyceae						
Order Pennales						
Suborder Achnanthineae						
Family Naviculaceae						
Frustulia sp.					X	
Phylum Cyanophyta						
Class Myxophyceae						
Order Oscillatoriales						
Suborder Nostochineae						
Family Scytonemataceae						
Tolypothrix sp.		X		X		
Family Stigonemataceae						
Stigonema sp.	X	X	X	X		X

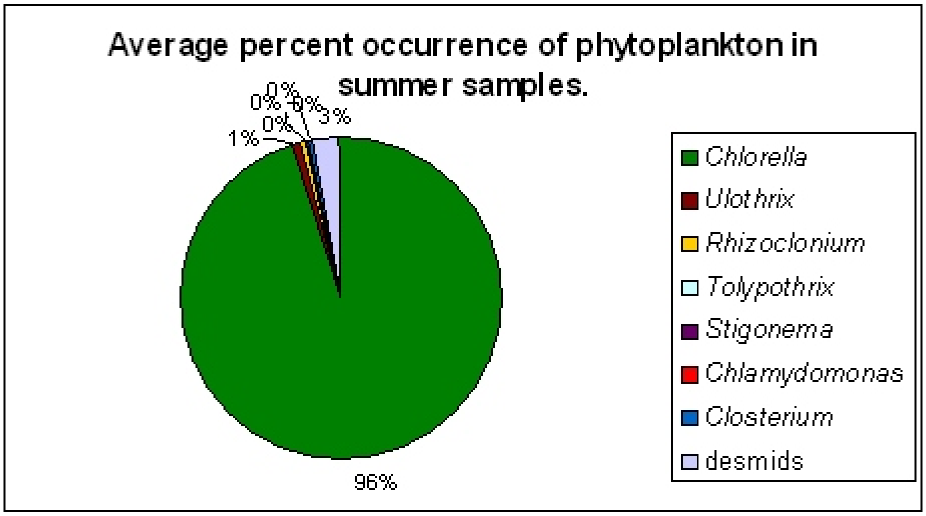

Figure 12. Average percent occurrence of phytoplankton in summer samples.

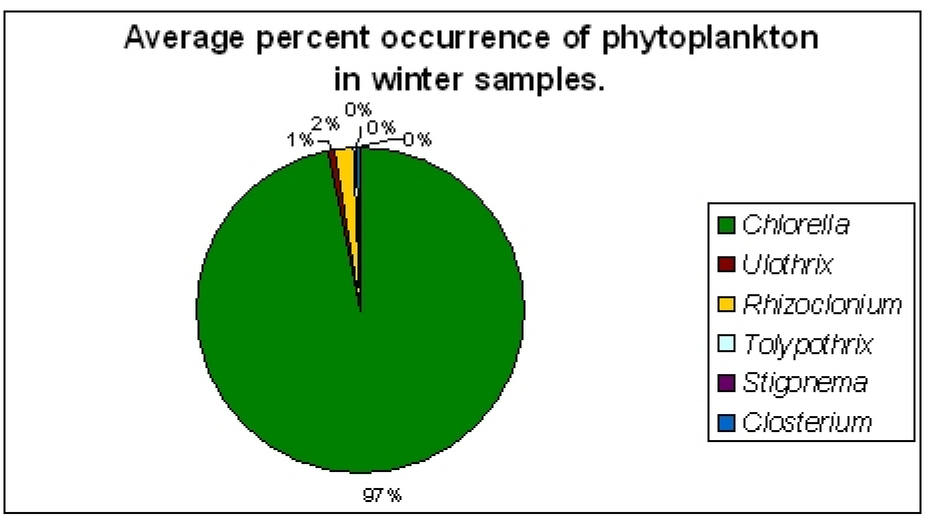

Figure 13. Average percent occurrence of phytoplankton in winter samples.

the normal range (1.0 x 10^4 to 101 x 10^6) for United States rivers, established by Palmer (1964). To provide a relative comparison, phytoplankton data from GRL was obtained. Densities of selected genera were observed in numbers similar to those found in GRL (Lisa Barnese-Walz, US Army Corps of Engineers, personal communication).

A mosaic of variable climatic conditions, water flows, and sample dates have rendered the various results presented above. Numerous factors or variables can affect planktonic growth. Water chemistry, flow, and physiography are three very important variables when dealing with river plankton. Water chemistry analysis was not within the scope of this investigation, so no conclusions can be drawn concerning chemistry and nutrient availability. Nutrient and energy resources in streams are quite variable and often unstable and unpredictable, with both pulsed or episodic inputs and losses resulting from seasonal and hydrologic changes (Elwood et al. 1983). These hydrologic changes are usually averaged through the year by regulation of flow from GRL, but at times the pulse of flow can be profound and create dramatic differences in the nutrient load and biota.

Flow conditions proved to be the most significant factor affecting the plankton community of the Green River. The GRL dam has multiple inlet tubes located at different levels on the intake tower; this multiple level intake operation allows engineers to control water temperature discharged below the dam. Flows, because they are regulated, are a function of season rather than rainfall. The regulated flows created by GRL dam coupled with local physiography produced an oligotrophic, riverine environment. Average weekly stream flows for the weeks sampled are graphically depicted in Figure 14. Notice the

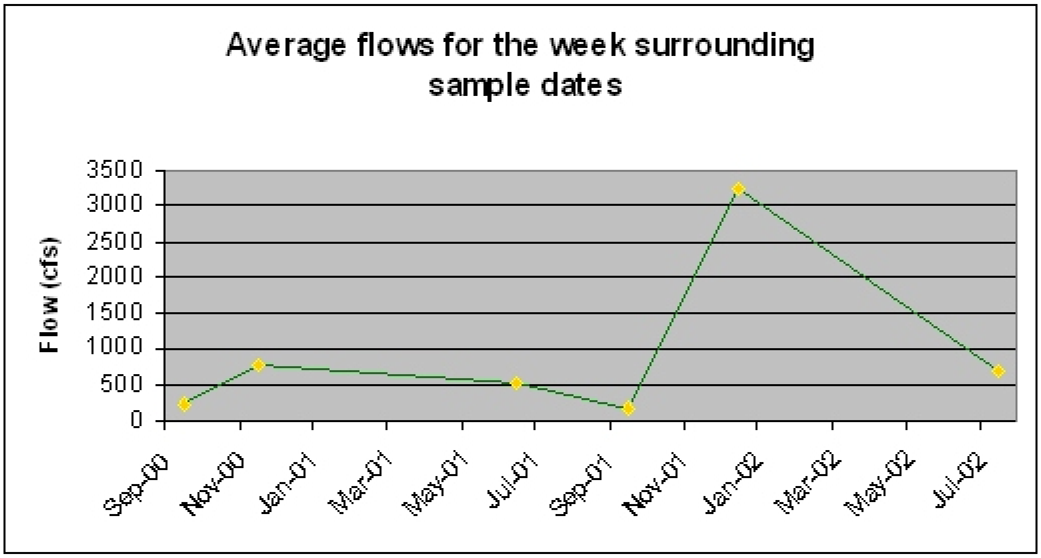

Figure 14. Average flows (cfs) for the week surrounding sample dates.

large difference between the winter 2001 sample and the other samples.

Biologists can only capture a snapshot of plankton communities in rivers because they are constantly in flux, being washed downstream and replaced by less productive water. Floods play an important role in river health. The flood-pulse concept advanced by Junk (1989) is an elemental part of understanding riverine ecosystems. This concept asserts that the major force controlling biota in rivers is lateral exchange between the floodplain and river channel during pulses of discharge, also called the flood-pulse (Junk 1989). Although the focus of this study was on main channel plankton, it is important to note the floodplain contributes organic matter and nutrients that can drive production. During the present study period, flood-pulses were sparse and limited to short bursts because of dry conditions. Local productivity could have been hindered by the loss of connectivity to the flood-plain, which would hinder lateral exchange of nutrients. Also, during minimum flows, the aquatic/terrestrial transition zone was reduced, thereby lowering the possibility of increased productivity.

The river continuum concept (RCC) fostered by Vannote et al. (1980) contradicts the Flood-Pulse concept by asserting rivers are open-ended systems that follow a continuous gradient from headwater to mouth. This concept supports the idea that productivity increases as you move downstream. According to the RCC, producer and consumer communities establish themselves in harmony with the dynamic physical conditions of a given river reach, and downstream communities are fashioned to capitalize on the inefficiencies of upstream processing (Junk 1989). The continuous gradient of rivers is a function of geomorphology and dependent on the river bed or benthos. Anthropogenic effects to rivers, such as dams, totally alter how well this concept can be applied ecologically.

This RCC concept is very applicable when analyzing the Green River study area. Mammoth Cave National Park is on the transitional boundary of the Green River within its river continuum. The river transitions to more of a wider, deeper big river environment within and below the Park boundary. The geomorphological change in the rivers bed and physical characters are exacerbated by the relic Lock and Dam #6. Above the Park, flows are rapid with alternating shallow and deep habitats, but below the Park flows are slowed with deeper, larger pools providing for increased plankton growth.

Anthropogenic effects to rivers, like dams, totally alter how well these concepts can be applied ecologically. The serial discontinuity concept (SDC) is an attempt to gain a broad theoretical perspective of regulated lotic ecosystems. The SDC treats the river as an altering series of lentic and lotic habitats. It is a conceptualized model of hypothesized ramifications resulting from modifying thermal and flow regimes by impoundments. The SDC treats dams as major disruptions in the continuum processes, thereby changing the system below the impoundment. True plankton communities occur only in the lower reaches of river systems except below dams (Ward and Stanford 1983). The plankton community below a dam depends on the water intake level of the dam, but the receiving river's plankton community will be altered by the dam regardless of intake level. In southern storage reservoirs that stratify in summer, upper level water releases cause a spike in nutrients and biomass below the dam creating shifts in community structure, whereas mid and lower level releases are usually nutrient depleted, oxygen deficient, and lack a significant biomass making the river more oligotrophic downstream of the dam.

Climatic conditions play a large role in riverine productivity. The investigation period came on the tail end of a four-year drought experienced by much of the Southeast. Drought conditions coupled with the highly variable topography and groundwater movements of karst watersheds could have lowered productivity in the river during the beginning of this study. The following are excerpts taken from the National Oceanic and Atmospheric Administration (NOAA 2001).

> "The 2001 national drought had its origins in late 1999. At its peak in August 2000 this drought, when compared to other droughts of the 20th Century, was as extensive as the major droughts of the last 40 years, but not as large as the "dust bowl" droughts of the 1930's and 1950's. The duration of the current national drought (about 26 months) falls in between the duration of the 1970's and late 1980's droughts."

> “The drought resulted in record low streamflows, low or dry wells, low reservoirs, and severe stress on crops. Several states declared statewide burning bans, drought alerts were announced for numerous counties, and several communities implemented water use restrictions. The very dry conditions during October led to hundreds of small wildfires in many eastern states from Kentucky and Virginia to South Carolina, and also in Massachusetts.”

As we predicted the Green River does not support a true plankton community, potamoplankton, but rather a transient population (tachyplankton) coming from upstream inputs. The transient nature of tachyplankton make them difficult to study, but with repetition and years of diligent observations, many of their patterns and variations can be understood. Weather conditions were closer to normal in 2002, but the lack of water during the first four sampling periods could possibly be a reason for the paucity of plankton. This project might have been performed at a less than optimum time due to the extended drought in the area, but it did generate a good baseline data set. A digital reference collection of zooplankton and phytoplankton has been created to provide MCNP with baseline data for use in future research activities.

Future research projects dealing with the Green River plankton populations should be designed with greater sample frequency and with greater emphasis placed on flow regimes. Also, in the upstream reaches, benthic algae should be investigated using appropriate methods. A long-term plankton data set should be developed if the National Park Service is interested in future mussel propagation projects in the river.

CHAPTER VI

SUMMARY

During the two year study period (2000-2002), a paucity of plankton was observed in Green River within MCNP. Water quality parameters and water samples were collected at three sites on six dates during the study period. Only samples taken during the winter enhanced flow period (November-December) contained a significantly greater density of zooplankton. Conversely phytoplankton densities were highest during the summer (base flow) sample periods. This is attributed to warmer water temperatures, longer photoperiod, and slower transport downstream due to base flow conditions.

Within MCNP, the Green River transitions from a free flowing oligotrophic river in upstream areas to an impounded mesotrophic larger river in the downstream reaches. This variation in habitats and geomorphology may produce unknown impacts to the plankton communities. It was evident that discharges from GRL were moving zooplankton through the Park with limited reproduction although phytoplankton maintained levels similar to those recorded in GRL. When discharged from a reservoir, the mixed environment of rivers is not as easy for zooplankton to adapt to as phytoplankton. Only limited evidence of zooplankton reproduction was found at the downstream sample site. Therefore, we concluded the Green River does not have a true plankton community, potamoplankton, but rather a tachyplankton (transient) community. This creates the need for a long-term plankton data set, because plankton communities are based on external inputs (rainfall, nutrients, and pollutants) which change with time.

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APPENDICES

Appendix A1. Average daily rainfall totals (inches) collected at Green River Lake, 2000

DAILY RAINFALL (24 HOUR)

(2000)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.13	0.01	0.00	0.00	0.30	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00
4	1.35	0.00	0.00	0.99	0.01	0.00	0.69	0.14	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.05	0.47	0.00	0.00	0.68	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00
8	0.00	0.00	0.00	0.65	0.03	0.00	0.00	0.00	0.19	0.00	0.09	0.00
9	0.15	0.00	0.26	0.00	0.00	0.00	0.00	0.20	0.00	0.00	2.28	0.00
10	0.00	0.00	0.00	0.00	0.11	0.00	0.00	1.01	0.00	0.01	0.50	0.00

11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
12	0.00	0.00	0.42	0.90	0.00	0.00	1.10	0.00	0.00	0.01	0.00	0.00
13	0.08	0.20	0.00	0.00	0.31	0.00	0.00	0.00	0.19	0.00	0.00	0.00
14	0.00	1.19	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	1.16
15	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.01	0.00	0.00	0.00	0.00
16	0.00	0.00	0.15	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.06	0.45
17	0.00	0.00	0.65	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
18	0.30	0.92	0.00	0.05	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.76	0.79	0.26	0.00	2.24	0.64	0.00	0.02	0.01	0.00	0.09
20	0.19	0.10	2.00	0.00	0.60	0.01	0.04	0.00	0.00	0.00	0.00	0.01
21	0.00	0.00	0.00	0.23	0.13	0.01	0.00	0.00	0.13	0.00	0.00	0.00
22	0.00	0.11	0.00	0.04	0.01	0.36	0.00	0.00	0.00	0.32	0.00	0.00
23	0.14	0.00	0.00	0.00	0.22	0.36	0.00	0.00	0.13	0.01	0.00	0.00
24	0.00	0.11	0.00	0.02	2.24	0.00	0.00	0.19	0.17	0.00	0.00	0.00

25	*0.00*	*0.00*	*0.00*	*0.82*	*0.37*	*0.00*	*0.00*	*0.00*	*0.20*	*0.02*	*0.70*	*0.00*
26	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.61*	*0.02*	*0.15*	*0.00*
27	*0.00*	*0.25*	*0.25*	*0.00*	*0.51*	*0.17*	*0.00*	*0.20*	*0.00*	*0.00*	*0.00*	*0.06*
28	*0.00*	*0.00*	*0.00*	*0.00*	*0.47*	*0.15*	*0.00*	*0.01*	*0.02*	*0.00*	*0.00*	*0.00*
29	*0.00*	*0.00*	*0.00*	*0.00*	*0.06*	*0.00*	*1.30*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
30	*0.65*		*0.05*	*0.00*	*0.02*	*0.00*	*1.35*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
31	*0.00*		*0.00*		*0.00*		*0.67*	*0.00*		*0.00*		*0.04*
TOTAL	*2.86*	*3.64*	*4.72*	*4.67*	*5.10*	*3.94*	*6.55*	*2.17*	*1.99*	*1.08*	*4.64*	*1.82*
MAX	*1.35*	*1.19*	*2.00*	*0.99*	*2.24*	*2.24*	*1.35*	*1.01*	*0.61*	*0.68*	*2.28*	*1.16*
MIN	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*

FOR YEAR 2000

TOTAL	*43.18*
MAX	*2.28*
MIN	*0.00*

Appendix A2. Average daily rainfall totals (inches) collected at Green River Lake 2001

DAILY RAINFALL (24 HOUR)

(2001)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.05	0.00	0.00	0.70	0.00	0.36	0.23	0.00	0.03	0.00	0.00	0.00
2	0.03	0.00	0.04	0.00	0.00	0.92	0.20	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	1.21	0.00	0.16	0.00	0.00	0.05	0.00	0.15	0.00
4	0.00	0.00	0.62	0.00	0.00	0.43	0.00	1.06	0.70	0.00	0.00	0.00
5	0.00	0.00	0.45	0.00	0.00	0.88	1.60	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.65	0.00	0.00
7	0.00	0.00	0.00	0.00	0.82	1.00	0.02	0.00	0.00	0.00	0.00	0.67
8	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00	0.00	0.00	0.00	0.75
9	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
10	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.10

11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.06
12	0.07	0.00	0.00	0.02	0.35	0.00	0.00	0.30	0.00	0.11	0.00	0.00
13	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.92
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.26
15	0.00	1.50	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.60	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00
17	0.00	0.78	0.15	0.00	0.00	0.00	0.00	0.04	0.00	0.08	0.00	0.04
18	0.07	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.31
19	0.95	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
20	0.50	0.00	0.00	0.00	1.02	0.00	0.00	0.00	1.13	0.00	0.46	0.04
21	0.04	0.07	0.70	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00
22	0.00	0.39	0.30	0.00	2.64	0.35	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.11	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.50
24	0.00	0.00	0.00	0.12	0.13	0.00	0.00	0.00	0.46	0.01	0.03	0.00

25	0.00	0.94	0.00	0.00	0.13	0.00	0.00	0.00	0.06	0.80	0.38	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.12	0.76	0.08	0.00	0.00	0.34	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.60	0.00
29	0.01		0.00	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.95	0.00
30	0.39		0.00	0.00	0.00	0.03	0.20	0.03	0.00	0.00	1.25	0.00
31	0.00		0.20		0.00		0.00	0.18		0.00		0.00
TOTAL	2.12	5.07	2.83	2.44	6.82	4.25	5.10	2.02	2.86	4.33	4.16	3.80
MAX	0.95	1.50	0.70	1.21	2.64	1.00	1.60	1.06	1.13	2.00	1.25	0.92
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FOR YEAR 2001

TOTAL	45.80
MAX	2.64
MIN	0.00

Appendix A3. Average daily rainfall totals (inches) collected at Green River Lake January - July 2002

DAILY RAINFALL (24 HOUR)

(2002)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL
1	0.00	0.61	0.00	0.70	0.65	0.00	0.00
2	0.00	0.00	0.00	0.00	0.90	0.00	0.00
3	0.00	0.00	0.07	0.09	0.88	0.00	0.00
4	0.00	0.06	0.00	0.00	0.07	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.72	0.00
6	0.08	0.00	0.00	0.00	0.00	0.09	0.08
7	0.19	0.05	0.01	0.00	0.28	0.50	0.00
8	0.00	0.00	0.00	0.00	0.25	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.36	0.03	0.30	0.00	0.04
11	0.00	0.25	0.00	0.00	0.00	0.00	0.07
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.38	1.17	0.00	0.11
14	0.00	0.00	0.00	0.13	0.34	0.45	1.43
15	0.00	0.00	0.00	0.29	0.00	0.00	0.00
16	0.00	0.00	0.59	0.00	0.00	0.00	0.00
17	0.00	0.00	0.48	0.00	0.00	0.04	0.00
18	0.25	0.00	0.73	0.00	2.42	0.00	0.20
19	0.10	0.00	0.03	0.00	0.00	0.00	0.00
20	0.00	0.19	2.33	0.00	0.00	0.20	0.00
21	0.00	0.00	0.56	0.12	0.00	0.00	0.09
22	0.00	0.00	0.00	0.33	0.00	0.00	0.00

23	1.36	0.00	0.00	0.00	0.00	0.00	0.00
24	0.73	0.00	0.00	0.00	0.00	0.00	
25	0.13	0.00	0.00	1.35	0.00	0.12	
26	0.00	0.27	0.92	0.00	0.00	0.00	
27	0.00	0.00	0.18	0.00	0.00	0.10	
28	0.00	0.01	0.00	1.20	0.00	0.21	
29	0.00		0.00	0.00	0.00	0.00	
30	0.08		0.44	0.00	0.00	0.00	
31	0.00		0.57		0.00		
TOTAL	2.92	1.44	7.27	4.62	7.26	2.43	2.02
MAX	1.36	0.61	2.33	1.35	2.42	0.72	1.43
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FOR YEAR 2002

TOTAL	27.96
MAX	2.42
MIN	0.00

Appendix A4. Average daily dam release totals (cfs) for Green River Lake Dam 2000

DAILY OUTFLOWS (24 HOUR CFS)

(2000)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	174.14	437.33	2198.51	90.07	460.39	281.00	170.94	744.38	52.33	51.96	51.51	2164.91
2	174.07	437.32	1165.63	90.12	460.37	169.26	170.89	1030.40	52.32	51.94	51.49	2152.34
3	174.12	437.17	587.84	77.37	460.30	169.25	170.85	538.18	52.32	51.93	108.35	2139.66
4	175.09	437.09	435.98	64.27	460.83	169.24	170.89	764.46	52.31	51.92	165.15	2126.96
5	176.04	436.98	436.02	64.93	960.39	113.36	170.89	1030.52	52.29	51.91	165.06	1364.10
6	537.02	436.81	435.94	131.79	833.16	66.10	171.03	1029.25	52.27	51.91	164.99	580.19
7	807.61	436.60	435.86	167.44	460.48	66.10	171.06	1027.88	52.25	51.89	164.97	416.92
8	878.45	366.87	283.20	168.37	460.31	66.10	171.02	1026.38	52.24	51.87	164.93	358.94
9	805.47	218.20	308.75	450.00	257.64	66.09	170.96	1024.97	52.23	51.84	232.12	300.96
10	804.31	218.23	435.80	568.42	169.09	66.09	170.90	1024.86	52.22	51.82	330.88	300.82

```
  11     803.23  218.24  435.76 1125.64  121.90   66.08  170.87 1023.78
52.21   51.80  330.92  300.71
  12     773.75  218.35  435.89 1723.27   69.73   66.07  170.99 1022.35
52.21   51.79  330.77  300.55
  13     800.95  218.59  436.18 2198.07   52.54   66.06  171.02 1020.88
52.20   51.77  330.58  241.26
  14     460.39  558.08  436.26 2329.34   52.54   66.05  171.04  523.62
52.19   51.75  330.33  198.70
  15     217.71 1273.84  318.11 2325.26   52.53   33.02  171.00  169.08
52.17   51.74  330.05  533.96
  16     217.61 1992.22  218.36 1498.30   52.53   33.03  170.94  108.94
52.14   51.73  329.78  775.39
  17     217.55 2356.95  561.14  852.36   52.53   33.04  170.88   58.91
52.12   51.72  329.50  796.52
  18     217.54 1394.37 1149.03  852.41   52.52   33.05  145.55   52.48
52.10   51.72  329.19 1689.62
  19     137.02  225.48 1583.10  852.36   52.52  134.36  170.83   52.47
52.09   51.71  328.86 2553.78
  20      87.02  227.34  784.37  852.18   52.55  169.87  170.79   52.45
52.07   51.69  533.09 2802.81
  21      87.04  227.97 1420.20  852.20   52.55  169.96  170.72   52.43
52.05   51.68 1644.07 2787.21
  22      87.08 1345.78 3684.02  852.24   52.54  170.37  170.64   52.42
52.04   51.67 2265.57 2770.54
  23      87.11 2656.59 4835.28  852.06   52.61  170.72  170.56   52.41
52.03   51.66 2256.16 2752.31
  24      87.13 3128.87 4810.56  851.98 1360.96  170.79  170.46   52.40
52.03   51.65 2246.74 2734.11
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25	87.14	3860.92	4783.36	1342.87	2687.27	170.80	170.38	52.39	52.03	51.64	2237.80	2716.92
26	87.16	4078.34	4754.06	1661.26	1680.77	170.80	170.29	52.38	52.03	51.63	2228.01	1380.09
27	87.16	4054.88	4144.53	1659.74	851.14	170.87	170.24	52.38	52.02	51.61	2216.03	772.58
28	87.16	4029.70	2879.28	1187.39	852.02	170.93	170.13	52.37	52.00	38.70	2203.66	638.68
29	87.22	2981.46	1625.38	850.94	1323.44	170.96	170.23	52.37	51.99	51.59	2190.98	416.43
30	87.31		762.24	623.02	1197.60	170.97	170.54	52.35	51.97	51.56	2178.33	416.15
31	285.61		225.08		562.73		171.18	52.34		51.54		415.86
AVERAGE	316.01	1341.74	1516.31	907.19	524.79	121.35	169.96	448.47	52.15	51.33	892.33	1287.10
MAX	878.45	4078.34	4835.28	2329.34	2687.27	281.00	171.18	1030.52	52.33	51.96	2265.57	2802.81
MIN	87.02	218.20	218.36	64.27	52.52	33.02	145.55	52.34	51.97	38.70	51.49	198.70

FOR YEAR 2000

AVERAGE 633.43

MAX 4835.28

MIN 33.02

Appendix A5. Average daily dam release totals (cfs) for Green River Lake Dam 2001

DAILY OUTFLOWS (24 HOUR CFS)

(2001)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	415.62	773.06	3356.46	50.97	54.03	200.52	132.75	341.20	92.26	47.89	745.90	1127.84
2	306.95	772.89	2735.77	51.23	54.04	227.84	132.72	341.07	92.23	47.88	747.13	1127.53
3	198.27	772.55	2720.97	51.74	54.04	228.03	132.69	222.63	48.19	96.01	748.30	1126.26
4	138.00	772.09	2157.66	52.72	54.04	228.51	132.78	405.40	48.19	137.98	749.54	1555.63
5	183.22	594.16	1508.87	53.18	54.05	596.55	133.07	1367.00	48.17	138.19	750.84	1879.68
6	198.31	416.64	1864.95	53.44	54.06	859.68	133.19	1669.24	48.16	138.20	752.09	1871.62
7	198.34	416.55	1888.08	53.64	54.09	1635.69	133.23	1192.48	48.15	138.46	753.44	1864.65
8	198.36	416.41	1506.62	53.78	54.13	2296.72	133.23	536.93	48.12	138.74	754.76	1860.80
9	198.39	416.33	1324.50	53.90	54.16	1195.37	133.24	269.53	48.11	220.22	756.10	1864.58
10	198.42	416.86	1194.27	155.37	54.17	627.19	165.44	227.24	48.11	279.02	757.44	1864.20

11 198.43 624.80 609.31 230.28 54.19 392.34 133.25 227.27
48.08 146.25 758.76 1859.55

12 198.47 772.80 68.00 230.47 190.46 177.51 227.39
48.06 47.72 760.10 1853.55

13 198.46 772.61 68.00 299.76 373.94 79.84 133.18 227.43
48.04 47.72 761.44 1852.43

14 198.42 772.79 68.00 349.26 133.92 237.86 133.13 227.40
48.01 47.78 762.76 1860.00

15 138.00 782.30 97.29 349.37 174.76 341.24 133.09 174.00
47.99 47.80 981.97 1863.75

16 183.42 797.84 713.35 349.48 174.72 341.15 133.04 106.71
47.97 47.81 1138.68 1862.40

17 198.60 506.40 775.65 349.48 120.82 340.95 133.00 104.46
47.96 47.82 1139.71 1858.40

18 198.69 1268.01 203.12 349.49 93.36 340.75 132.96 92.50
47.95 47.81 1140.62 1855.22

19 534.67 2869.59 47.42 349.46 93.38 260.45 105.25 92.48
47.97 140.60 1138.57 2504.83

20 1547.64 4520.16 47.62 349.42 93.42 227.61 132.93 92.45
47.99 277.83 1135.57 3023.58

21 2141.45 5233.20 48.37 349.35 93.48 227.55 133.03 92.43
47.98 278.57 1132.21 2492.58

22 2137.08 5186.63 49.09 349.32 243.74 227.46 132.96 92.41
47.98 279.30 1128.83 1818.31

23 2130.31 4254.62 49.53 349.26 1497.55 227.41 132.87 92.38
47.97 280.03 1125.50 1346.90

24 2122.33 2450.41 49.83 349.15 1529.17 227.35 132.85 92.36
47.97 280.56 1122.52 774.52

25	2115.65	1547.98	50.05	349.07	490.67	227.29	132.81	92.35	47.97	280.52	1119.76	987.43
26	1303.99	2253.27	50.22	348.88	231.47	227.19	132.79	92.32	47.95	523.26	1117.21	1199.19
27	416.69	3495.26	50.36	348.73	231.49	227.12	132.84	92.32	47.94	739.74	1115.36	1197.99
28	416.96	3934.78	50.48	348.56	231.49	172.62	132.87	92.30	47.93	740.90	1113.43	1196.57
29	417.12		50.59	348.37	231.47	132.77	133.00	92.28	47.92	742.12	1113.97	708.77
30	624.65		50.69	180.31	231.43	132.75	263.15	92.27	47.90	743.35	1123.24	416.73
31	772.91		50.79		231.42		341.25	92.27		744.59		416.57
AVERAGE	658.96	1707.54	758.26	238.58	235.07	428.84	144.42	295.50	50.97	255.31	948.19	1583.61
MAX	2141.45	5233.20	3356.46	349.49	1529.17	2296.72	341.25	1669.24	92.26	744.59	1140.62	3023.58
MIN	138.00	416.33	47.42	50.97	54.03	79.84	105.25	92.27	47.90	47.72	745.90	416.57

FOR YEAR 2001

AVERAGE 603.10

MAX 5233.20

MIN 47.42

Appendix A6. Average daily dam releases (cfs) for Green River Lake Dam, January-July 2002

DAILY OUTFLOWS (24 HOUR CFS)

(2002)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL
1	369.81	4235.22	417.04	2045.02	3115.05	656.39	48.15
2	301.19	3740.77	416.91	2055.67	2584.92	460.80	48.15
3	301.27	3013.19	416.82	3743.36	2327.00	245.15	48.15
4	301.38	2997.83	416.67	5200.30	2329.52	137.41	48.13
5	301.48	1969.37	416.48	4757.87	2327.38	207.53	48.13
6	363.19	1196.05	416.29	3534.42	2323.48	278.09	48.12
7	416.95	948.20	416.16	2598.14	1921.91	279.17	48.09
8	416.78	771.45	343.95	2326.38	1659.30	279.57	48.07
9	287.29	771.10	300.99	1764.71	1658.52	279.26	48.05
10	208.33	331.43	301.25	1006.73	943.07	278.63	48.04
11	208.46	204.09	301.54	598.35	460.79	277.64	48.03
12	355.64	369.35	301.81	460.96	673.46	276.75	43.83
13	208.94	417.81	221.53	461.15	461.88	277.38	48.25
14	209.13	417.91	151.20	461.46	1154.45	277.80	48.59
15	209.28	418.08	151.36	624.00	2366.16	277.76	241.52
16	331.50	418.12	103.38	744.51	2964.85	277.29	361.36
17	418.66	418.12	67.47	744.74	1832.22	276.70	361.22
18	418.65	418.08	68.64	744.54	472.66	275.76	361.16
19	418.60	418.00	70.29	743.80	1126.11	274.75	361.18
20	418.52	417.99	73.81	742.66	2543.34	210.03	361.17
21	418.56	417.92	250.41	741.32	4109.79	107.02	361.15

22	625.88	417.88	810.60	740.01	4406.89	77.01	360.99
23	663.76	417.79	2916.49	738.47	4921.95	77.01	
24	436.97	417.64	4861.74	740.46	4510.25	60.45	
25	931.80	417.44	3777.57	1242.21	3011.37	48.01	
26	2303.11	417.37	2655.33	2732.35	2029.82	48.00	
27	3516.83	417.25	4009.87	2565.15	2024.42	48.00	
28	4114.46	417.17	5158.50	1322.10	2018.76	48.05	
29	4342.09		4047.14	2885.81	2012.98	48.12	
30	4306.97		2273.33	3806.24	2006.91	48.14	
31	4280.11		2017.05		1350.97		
AVERAGE	1045.34	972.59	1230.70	1762.43	2182.26	213.79	156.34
MAX	4342.09	4235.22	5158.50	5200.30	4921.95	656.39	361.36
MIN	208.33	204.09	67.47	460.96	460.79	48.00	43.83

FOR YEAR 2002

AVERAGE	1123.97
MAX	5200.30
MIN	43.83

Appendix A7. Daily flow measurements (CFS) recorded at USGS gauging station in Munfordville August 2000 - September 2002 with sample dates shaded.

MONTH	DAY	Flow
8	1	1360.00
8	2	1050.00
8	3	1350.00
8	4	1690.00
8	5	1040.00
8	6	1320.00
8	7	1290.00
8	8	1210.00
8	9	1180.00
8	10	4120.00
8	11	5760.00
8	12	2440.00
8	13	1780.00
8	14	1470.00
8	15	1290.00
8	16	817.00
8	17	535.00
8	18	472.00
8	19	397.00
8	20	354.00
8	21	330.00
8	22	313.00
8	23	300.00
8	24	303.00
8	25	302.00
8	26	302.00
8	27	301.00
8	28	299.00
8	29	294.00
8	30	286.00
8	31	275.00
9	1	266.00
9	2	259.00
9	3	254.00
9	4	250.00
9	5	244.00
9	6	240.00
9	7	239.00
9	8	242.00
9	9	242.00
9	10	242.00
9	11	253.00
9	12	322.00
9	13	388.00
9	14	355.00
9	15	296.00
9	16	267.00
9	17	249.00
9	18	239.00
9	19	233.00
9	20	230.00
9	21	226.00
9	22	221.00
9	23	219.00
9	24	222.00
9	25	237.00
9	26	280.00
9	27	314.00
9	28	299.00
9	29	263.00
9	30	258.00
10	1	253.00
10	2	236.00
10	3	225.00
10	4	213.00
10	5	207.00
10	6	205.00
10	7	199.00
10	8	193.00
10	9	190.00
10	10	184.00
10	11	182.00
10	12	182.00
10	13	183.00
10	14	184.00
10	15	186.00
10	16	185.00
10	17	186.00
10	18	185.00
10	19	183.00
10	20	183.00
10	21	182.00
10	22	183.00
10	23	183.00
10	24	183.00
10	25	183.00
10	26	183.00
10	27	185.00
10	28	189.00
10	29	186.00
10	30	186.00
10	31	186.00
11	1	186.00
11	2	205.00
11	3	243.00
11	4	249.00
11	5	246.00
11	6	229.00
11	7	263.00
11	8	275.00
11	9	315.00
11	10	1380.00
11	11	1190.00
11	12	803.00
11	13	617.00
11	14	541.00
11	15	497.00
11	16	475.00
11	17	461.00
11	18	449.00
11	19	440.00
11	20	430.00
11	21	423.00
11	22	864.00
11	23	2440.00
11	24	2520.00
11	25	2610.00
11	26	2670.00
11	27	2650.00
11	28	2650.00
11	29	2600.00
11	30	2540.00
12	1	2500.00
12	2	2480.00
12	3	2460.00
12	4	2450.00
12	5	2430.00
12	6	2100.00
12	7	952.00
12	8	658.00
12	9	489.00
12	10	398.00
12	11	385.00

12	12	382.00	1	30	1240.00	3	20	1090.00
12	13	381.00	1	31	1970.00	3	21	1590.00
12	14	465.00	2	1	2180.00	3	22	2660.00
12	15	1550.00	2	2	1870.00	3	23	1990.00
12	16	1960.00	2	3	1650.00	3	24	1570.00
12	17	15800.00	2	4	1500.00	3	25	1310.00
12	18	12100.00	2	5	1430.00	3	26	1130.00
12	19	5040.00	2	6	1320.00	3	27	1010.00
12	20	4620.00	2	7	984.00	3	28	927.00
12	21	4430.00	2	8	906.00	3	29	861.00
12	22	4070.00	2	9	866.00	3	30	820.00
12	23	3730.00	2	10	949.00	3	31	800.00
12	24	3660.00	2	11	1830.00	4	1	800.00
12	25	3530.00	2	12	1630.00	4	2	1210.00
12	26	3020.00	2	13	1710.00	4	3	3120.00
12	27	1890.00	2	14	1730.00	4	4	7780.00
12	28	1220.00	2	15	5740.00	4	5	4860.00
12	29	1150.00	2	16	10000.00	4	6	3080.00
12	30	1110.00	2	17	13100.00	4	7	2330.00
12	31	1110.00	2	18	10500.00	4	8	1850.00
1	1	1100.00	2	19	5640.00	4	9	1470.00
1	2	1100.00	2	20	6200.00	4	10	1240.00
1	3	709.00	2	21	6800.00	4	11	1080.00
1	4	455.00	2	22	7480.00	4	12	992.00
1	5	454.00	2	23	7890.00	4	13	971.00
1	6	433.00	2	24	7110.00	4	14	927.00
1	7	432.00	2	25	5470.00	4	15	1010.00
1	8	429.00	2	26	6760.00	4	16	1020.00
1	9	426.00	2	27	5550.00	4	17	985.00
1	10	420.00	2	28	5910.00	4	18	909.00
1	11	394.00	3	1	6140.00	4	19	847.00
1	12	392.00	3	2	5480.00	4	20	813.00
1	13	407.00	3	3	4400.00	4	21	794.00
1	14	412.00	3	4	4780.00	4	22	779.00
1	15	575.00	3	5	6660.00	4	23	756.00
1	16	458.00	3	6	5390.00	4	24	735.00
1	17	429.00	3	7	4470.00	4	25	710.00
1	18	422.00	3	8	4150.00	4	26	686.00
1	19	538.00	3	9	3270.00	4	27	668.00
1	20	5330.00	3	10	2860.00	4	28	652.00
1	21	5190.00	3	11	2410.00	4	29	634.00
1	22	4450.00	3	12	2110.00	4	30	617.00
1	23	3890.00	3	13	1300.00	5	1	608.00
1	24	3650.00	3	14	1130.00	5	2	549.00
1	25	3510.00	3	15	1040.00	5	3	405.00
1	26	3320.00	3	16	1050.00	5	4	352.00
1	27	2860.00	3	17	1210.00	5	5	331.00
1	28	1370.00	3	18	2030.00	5	6	316.00
1	29	1120.00	3	19	1380.00	5	7	337.00

5	8	786.00	6	26	326.00	8	14	428.00
5	9	1060.00	6	27	324.00	8	15	360.00
5	10	839.00	6	28	333.00	8	16	327.00
5	11	602.00	6	29	319.00	8	17	301.00
5	12	492.00	6	30	399.00	8	18	265.00
5	13	458.00	7	1	363.00	8	19	219.00
5	14	454.00	7	2	363.00	8	20	212.00
5	15	616.00	7	3	291.00	8	21	194.00
5	16	430.00	7	4	274.00	8	22	189.00
5	17	406.00	7	5	1440.00	8	23	186.00
5	18	412.00	7	6	866.00	8	24	187.00
5	19	398.00	7	7	667.00	8	25	184.00
5	20	361.00	7	8	506.00	8	26	181.00
5	21	567.00	7	9	400.00	8	27	189.00
5	22	1810.00	7	10	334.00	8	28	193.00
5	23	2970.00	7	11	314.00	8	29	188.00
5	24	2080.00	7	12	292.00	8	30	182.00
5	25	2870.00	7	13	269.00	8	31	182.00
5	26	1450.00	7	14	251.00	9	1	177.00
5	27	842.00	7	15	237.00	9	2	176.00
5	28	627.00	7	16	225.00	9	3	175.00
5	29	547.00	7	17	217.00	9	4	175.00
5	30	493.00	7	18	228.00	9	5	174.00
5	31	461.00	7	19	221.00	9	6	172.00
6	1	459.00	7	20	216.00	9	7	171.00
6	2	566.00	7	21	357.00	9	8	168.00
6	3	853.00	7	22	568.00	9	9	168.00
6	4	2710.00	7	23	359.00	9	10	177.00
6	5	10200.00	7	24	294.00	9	11	174.00
6	6	5070.00	7	25	253.00	9	12	172.00
6	7	3560.00	7	26	238.00	9	13	170.00
6	8	3090.00	7	27	321.00	9	14	168.00
6	9	3840.00	7	28	428.00	9	15	163.00
6	10	2410.00	7	29	687.00	9	16	160.00
6	11	1450.00	7	30	716.00	9	17	157.00
6	12	960.00	7	31	622.00	9	18	156.00
6	13	787.00	8	1	451.00	9	19	169.00
6	14	630.00	8	2	474.00	9	20	184.00
6	15	451.00	8	3	480.00	9	21	193.00
6	16	420.00	8	4	565.00	9	22	246.00
6	17	558.00	8	5	1080.00	9	23	219.00
6	18	612.00	8	6	1170.00	9	24	191.00
6	19	554.00	8	7	1940.00	9	25	178.00
6	20	513.00	8	8	1710.00	9	26	167.00
6	21	463.00	8	9	1020.00	9	27	159.00
6	22	376.00	8	10	684.00	9	28	153.00
6	23	354.00	8	11	501.00	9	29	148.00
6	24	342.00	8	12	544.00	9	30	146.00
6	25	333.00	8	13	576.00	10	1	142.00

10	2	139.00	11	20	1260.00	1	8	545.00
10	3	135.00	11	21	1240.00	1	9	703.00
10	4	131.00	11	22	1220.00	1	10	720.00
10	5	133.00	11	23	1210.00	1	11	672.00
10	6	146.00	11	24	1210.00	1	12	631.00
10	7	186.00	11	25	1240.00	1	13	764.00
10	8	198.00	11	26	1210.00	1	14	929.00
10	9	200.00	11	27	1500.00	1	15	762.00
10	10	198.00	11	28	1570.00	1	16	682.00
10	11	199.00	11	29	1970.00	1	17	634.00
10	12	267.00	11	30	6360.00	1	18	650.00
10	13	309.00	12	1	5060.00	1	19	731.00
10	14	277.00	12	2	2890.00	1	20	762.00
10	15	648.00	12	3	2150.00	1	21	804.00
10	16	891.00	12	4	1840.00	1	22	1080.00
10	17	638.00	12	5	1850.00	1	23	4120.00
10	18	419.00	12	6	2460.00	1	24	12800.00
10	19	316.00	12	7	2690.00	1	25	15500.00
10	20	266.00	12	8	3390.00	1	26	8790.00
10	21	239.00	12	9	4730.00	1	27	5800.00
10	22	331.00	12	10	4080.00	1	28	6200.00
10	23	438.00	12	11	3390.00	1	29	6280.00
10	24	443.00	12	12	3040.00	1	30	6310.00
10	25	473.00	12	13	4110.00	1	31	6160.00
10	26	528.00	12	14	7570.00	2	1	6340.00
10	27	677.00	12	15	6140.00	2	2	7470.00
10	28	741.00	12	16	4680.00	2	3	6600.00
10	29	901.00	12	17	3940.00	2	4	5260.00
10	30	896.00	12	18	4250.00	2	5	4820.00
10	31	875.00	12	19	4290.00	2	6	3890.00
11	1	860.00	12	20	4100.00	2	7	2520.00
11	2	852.00	12	21	4550.00	2	8	2280.00
11	3	842.00	12	22	4060.00	2	9	1840.00
11	4	835.00	12	23	3050.00	2	10	1740.00
11	5	826.00	12	24	3160.00	2	11	1650.00
11	6	814.00	12	25	2340.00	2	12	1060.00
11	7	808.00	12	26	2080.00	2	13	887.00
11	8	807.00	12	27	2210.00	2	14	981.00
11	9	805.00	12	28	2110.00	2	15	1030.00
11	10	801.00	12	29	2010.00	2	16	993.00
11	11	796.00	12	30	1770.00	2	17	956.00
11	12	789.00	12	31	1370.00	2	18	926.00
11	13	788.00	1	1	1320.00	2	19	887.00
11	14	788.00	1	2	1120.00	2	20	885.00
11	15	784.00	1	3	780.00	2	21	897.00
11	16	785.00	1	4	680.00	2	22	892.00
11	17	1190.00	1	5	503.00	2	23	870.00
11	18	1240.00	1	6	499.00	2	24	834.00
11	19	1240.00	1	7	488.00	2	25	806.00

2	26	798.00	4	16	2440.00	6	4	994.00
2	27	800.00	4	17	2200.00	6	5	883.00
2	28	811.00	4	18	1960.00	6	6	878.00
3	1	817.00	4	19	1820.00	6	7	1170.00
3	2	799.00	4	20	1720.00	6	8	1020.00
3	3	796.00	4	21	1660.00	6	9	920.00
3	4	797.00	4	22	1610.00	6	10	828.00
3	5	786.00	4	23	1540.00	6	11	754.00
3	6	762.00	4	24	1460.00	6	12	726.00
3	7	750.00	4	25	3550.00	6	13	953.00
3	8	742.00	4	26	4810.00	6	14	1460.00
3	9	741.00	4	27	4330.00	6	15	1420.00
3	10	684.00	4	28	6140.00	6	16	1100.00
3	11	597.00	4	29	5980.00	6	17	929.00
3	12	594.00	4	30	4700.00	6	18	814.00
3	13	596.00	5	1	5910.00	6	19	751.00
3	14	589.00	5	2	5390.00	6	20	706.00
3	15	578.00	5	3	6620.00	6	21	677.00
3	16	599.00	5	4	6270.00	6	22	643.00
3	17	1350.00	5	5	4820.00	6	23	594.00
3	18	4980.00	5	6	4230.00	6	24	580.00
3	19	7880.00	5	7	4060.00	6	25	575.00
3	20	14900.00	5	8	3910.00	6	26	633.00
3	21	21400.00	5	9	3400.00	6	27	693.00
3	22	13300.00	5	10	3130.00	6	28	690.00
3	23	6080.00	5	11	2550.00	6	29	654.00
3	24	5860.00	5	12	1500.00	6	30	598.00
3	25	7690.00	5	13	1800.00	7	1	580.00
3	26	7900.00	5	14	5330.00	7	2	572.00
3	27	10400.00	5	15	4430.00	7	3	564.00
3	28	8690.00	5	16	4140.00	7	4	557.00
3	29	8700.00	5	17	4880.00	7	5	549.00
3	30	8250.00	5	18	14600.00	7	6	541.00
3	31	7020.00	5	19	18900.00	7	7	535.00
4	1	12500.00	5	20	9660.00	7	8	532.00
4	2	9740.00	5	21	5760.00	7	9	530.00
4	3	6460.00	5	22	6510.00	7	10	529.00
4	4	6300.00	5	23	6470.00	7	11	526.00
4	5	7660.00	5	24	6550.00	7	12	523.00
4	6	7100.00	5	25	6450.00	7	13	523.00
4	7	5730.00	5	26	4680.00	7	14	1050.00
4	8	4390.00	5	27	3290.00	7	15	1090.00
4	9	3820.00	5	28	3030.00	7	16	578.00
4	10	3340.00	5	29	2920.00	7	17	450.00
4	11	2330.00	5	30	2830.00	7	18	526.00
4	12	1850.00	5	31	2750.00	7	19	587.00
4	13	1640.00	6	1	2380.00	7	20	613.00
4	14	2020.00	6	2	1480.00	7	21	563.00
4	15	2130.00	6	3	1050.00	7	22	534.00

7	23	563.00
7	24	584.00
7	25	575.00
7	26	602.00
7	27	623.00
7	28	618.00
7	29	610.00
7	30	593.00
7	31	576.00
8	1	568.00
8	2	555.00
8	3	550.00
8	4	541.00
8	5	530.00
8	6	514.00
8	7	491.00
8	8	466.00
8	9	444.00
8	10	432.00
8	11	425.00
8	12	419.00
8	13	409.00
8	14	403.00
8	15	398.00
8	16	390.00
8	17	385.00
8	18	380.00
8	19	372.00
8	20	367.00
8	21	363.00
8	22	359.00
8	23	355.00
8	24	350.00
8	25	342.00
8	26	337.00
8	27	332.00
8	28	326.00
8	29	323.00
8	30	320.00
8	31	315.00
9	1	309.00
9	2	305.00
9	3	301.00
9	4	297.00
9	5	290.00
9	6	286.00
9	7	282.00
9	8	278.00
9	9	274.00
9	10	269.00
9	11	264.00
9	12	258.00
9	13	254.00
9	14	250.00
9	15	248.00
9	16	244.00
9	17	241.00
9	18	239.00
9	19	242.00
9	20	244.00
9	21	247.00
9	22	327.00
9	23	374.00
9	24	279.00
9	25	231.00
9	26	273.00
9	27	3680.00
9	28	5830.00
9	29	2690.00
9	30	1470.00

Appendix B1. Statistical analysis output from SPSS: Comparison of Organisms by Site

```
ONEWAY
  chironom cyclocop diaphan ceriodap bosmina BY site
  /STATISTICS DESCRIPTIVES
  /MISSING ANALYSIS
  /POSTHOC = TUKEY ALPHA(.05).
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Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
CHIRONOM	cave I	48	.0623	.10996	.01587	.0304	.0942	.00	.64
	sand cave I	48	.0235	.03823	.00552	.0124	.0346	.00	.13
	crump I	48	.0119	.02090	.00302	.0058	.0179	.00	.10
	Total	144	.0326	.07117	.00593	.0208	.0443	.00	.64
CYCLOCOP	cave I	48	.1006	.24192	.03492	.0304	.1709	.00	1.30
	sand cave I	48	.0904	.21657	.03126	.0275	.1533	.00	.88
	crump I	48	.1021	.25499	.03680	.0280	.1761	.00	1.51
	Total	144	.0977	.23675	.01973	.0587	.1367	.00	1.51
DIAPHAN	cave I	48	.0038	.00914	.00132	.0011	.0064	.00	.04
	sand cave I	48	.0096	.02052	.00296	.0036	.0155	.00	.11
	crump I	48	.0308	.08018	.01157	.0076	.0541	.00	.44
	Total	144	.0147	.04915	.00410	.0066	.0228	.00	.44
CERIODAP	cave I	48	.0023	.00722	.00104	.0002	.0044	.00	.03
	sand cave I	48	.0100	.02467	.00356	.0028	.0172	.00	.12
	crump I	48	.0046	.01254	.00181	.0009	.0082	.00	.07
	Total	144	.0056	.01671	.00139	.0029	.0084	.00	.12
BOSMINA	cave I	48	.0579	.16620	.02399	.0097	.1062	.00	1.03
	sand cave I	48	.0829	.19888	.02871	.0252	.1407	.00	.97
	crump I	48	.0658	.12847	.01854	.0285	.1031	.00	.62
	Total	144	.0689	.16617	.01385	.0415	.0963	.00	1.03

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
CHIRONOM	Between Groups	.067	2	.033	7.171	.001
	Within Groups	.657	141	.005		
	Total	.724	143			
CYCLOCOP	Between Groups	.004	2	.002	.034	.966
	Within Groups	8.011	141	.057		
	Total	8.015	143			
DIAPHAN	Between Groups	.020	2	.010	4.220	.017
	Within Groups	.326	141	.002		
	Total	.345	143			
CERIODAP	Between Groups	.002	2	.001	2.759	.067
	Within Groups	.038	141	.000		
	Total	.040	143			
BOSMINA	Between Groups	.016	2	.008	.281	.756
	Within Groups	3.933	141	.028		
	Total	3.949	143			

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
CHIRONOM	cave I	sand cave I	.0387*	.01394	.017	.0057	.0718
		crump I	.0504*	.01394	.001	.0174	.0834
	sand cave I	cave I	-.0387*	.01394	.017	-.0718	-.0057
		crump I	.0117	.01394	.681	-.0214	.0447
	crump I	cave I	-.0504*	.01394	.001	-.0834	-.0174
		sand cave I	-.0117	.01394	.681	-.0447	.0214
CYCLOCOP	cave I	sand cave I	.0102	.04866	.976	-.1050	.1255
		crump I	-.0015	.04866	1.000	-.1167	.1138
	sand cave I	cave I	-.0102	.04866	.976	-.1255	.1050
		crump I	-.0117	.04866	.969	-.1269	.1036
	crump I	cave I	.0015	.04866	1.000	-.1138	.1167
		sand cave I	.0117	.04866	.969	-.1036	.1269
DIAPHAN	cave I	sand cave I	-.0058	.00981	.823	-.0291	.0174
		crump I	-.0271*	.00981	.018	-.0503	-.0038
	sand cave I	cave I	.0058	.00981	.823	-.0174	.0291
		crump I	-.0213	.00981	.081	-.0445	.0020
	crump I	cave I	.0271*	.00981	.018	.0038	.0503
		sand cave I	.0213	.00981	.081	-.0020	.0445
CERIODAP	cave I	sand cave I	-.0077	.00337	.061	-.0157	.0003
		crump I	-.0023	.00337	.776	-.0103	.0057
	sand cave I	cave I	.0077	.00337	.061	-.0003	.0157
		crump I	.0054	.00337	.246	-.0026	.0134
	crump I	cave I	.0023	.00337	.776	-.0057	.0103
		sand cave I	-.0054	.00337	.246	-.0134	.0026
BOSMINA	cave I	sand cave I	-.0250	.03409	.744	-.1058	.0558
		crump I	-.0079	.03409	.971	-.0887	.0728
	sand cave I	cave I	.0250	.03409	.744	-.0558	.1058
		crump I	.0171	.03409	.871	-.0637	.0978
	crump I	cave I	.0079	.03409	.971	-.0728	.0887
		sand cave I	-.0171	.03409	.871	-.0978	.0637

*. The mean difference is significant at the .05 level.

CHIRONOM

Tukey HSD[a]

SITE	N	Subset for alpha = .05	
		1	2
crump I	48	.0119	
sand cave I	48	.0235	
cave I	48		.0623
Sig.		.681	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 48.000.

CYCLOCOP

Tukey HSD[a]

SITE	N	Subset for alpha = .05
		1
sand cave l	48	.0904
cave l	48	.1006
crump l	48	.1021
Sig.		.969

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 48.000.

DIAPHAN

Tukey HSD[a]

SITE	N	Subset for alpha = .05	
		1	2
cave l	48	.0038	
sand cave l	48	.0096	.0096
crump l	48		.0308
Sig.		.823	.081

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 48.000.

CERIODAP

Tukey HSD[a]

SITE	N	Subset for alpha = .05
		1
cave l	48	.0023
crump l	48	.0046
sand cave l	48	.0100
Sig.		.061

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 48.000.

BOSMINA

Tukey HSD[a]

SITE	N	Subset for alpha = .05 1
cave l	48	.0579
crump l	48	.0658
sand cave l	48	.0829
Sig.		.744

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 48.000.

Appendix B2. Statistical analysis output from SPSS: Comparison of Organisms by Date

```
ONEWAY
  chironom cyclocop diaphan ceriodap bosmina BY date
  /STATISTICS DESCRIPTIVES
  /MISSING ANALYSIS
  /POSTHOC = TUKEY
ALPHA(.05).
```

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
CHIRONOM	9/19/00	24	.0113	.02401	.00490	.0011	.0214	.00	.11
	11/20/00	24	.0050	.00978	.00200	.0009	.0091	.00	.03
	6/18/01	24	.0225	.03220	.00657	.0089	.0361	.00	.10
	9/5/01	24	.0079	.01956	.00399	-.0003	.0162	.00	.07
	12/3/01	24	.0338	.03998	.00816	.0169	.0506	.00	.18
	7/12/02	24	.1150	.13676	.02792	.0572	.1728	.01	.64
	Total	144	.0326	.07117	.00593	.0208	.0443	.00	.64
CYCLOCOP	9/19/00	24	.0038	.01637	.00334	-.0032	.0107	.00	.08
	11/20/00	24	.0183	.03345	.00683	.0042	.0325	.00	.12
	6/18/01	24	.0042	.01139	.00232	-.0006	.0090	.00	.05
	9/5/01	24	.0042	.00881	.00180	.0004	.0079	.00	.04
	12/3/01	24	.5196	.34806	.07105	.3726	.6666	.15	1.51
	7/12/02	24	.0363	.04509	.00920	.0172	.0553	.00	.18
	Total	144	.0977	.23675	.01973	.0587	.1367	.00	1.51
DIAPHAN	9/19/00	24	.0033	.00816	.00167	-.0001	.0068	.00	.03
	11/20/00	24	.0079	.02467	.00504	-.0025	.0183	.00	.11
	6/18/01	24	.0054	.01474	.00301	-.0008	.0116	.00	.06
	9/5/01	24	.0346	.09358	.01910	-.0049	.0741	.00	.44
	12/3/01	24	.0017	.00565	.00115	-.0007	.0041	.00	.02
	7/12/02	24	.0354	.06345	.01295	.0086	.0622	.00	.26
	Total	144	.0147	.04915	.00410	.0066	.0228	.00	.44
CERIODAP	9/19/00	24	.0013	.00612	.00125	-.0013	.0038	.00	.03
	11/20/00	24	.0017	.00637	.00130	-.0010	.0044	.00	.03
	6/18/01	24	.0000	.00000	.00000	.0000	.0000	.00	.00
	9/5/01	24	.0000	.00000	.00000	.0000	.0000	.00	.00
	12/3/01	24	.0300	.03007	.00614	.0173	.0427	.00	.12
	7/12/02	24	.0008	.00282	.00058	-.0004	.0020	.00	.01
	Total	144	.0056	.01671	.00139	.0029	.0084	.00	.12
BOSMINA	9/19/00	24	.0008	.00282	.00058	-.0004	.0020	.00	.01
	11/20/00	24	.0271	.03689	.00753	.0115	.0427	.00	.12
	6/18/01	24	.0125	.02592	.00529	.0016	.0234	.00	.10
	9/5/01	24	.0067	.01404	.00287	.0007	.0126	.00	.05
	12/3/01	24	.3617	.24819	.05066	.2569	.4665	.14	1.03
	7/12/02	24	.0046	.00833	.00170	.0011	.0081	.00	.03
	Total	144	.0689	.16617	.01385	.0415	.0963	.00	1.03

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
CHIRONOM	Between Groups	.209	5	.042	11.214	.000
	Within Groups	.515	138	.004		
	Total	.724	143			
CYCLOCOP	Between Groups	5.145	5	1.029	49.485	.000
	Within Groups	2.870	138	.021		
	Total	8.015	143			
DIAPHAN	Between Groups	.030	5	.006	2.639	.026
	Within Groups	.315	138	.002		
	Total	.345	143			
CERIODAP	Between Groups	.017	5	.003	20.797	.000
	Within Groups	.023	138	.000		
	Total	.040	143			
BOSMINA	Between Groups	2.479	5	.496	46.548	.000
	Within Groups	1.470	138	.011		
	Total	3.949	143			

Multiple Comparisons
Tukey HSD

Dependent Variable	*(I) DATE*	*(J) DATE*	*Mean Difference (I-J)*	*Std. Error*	*Sig.*	*95% Confidence Interval Lower Bound*	*Upper Bound*
CHIRONOM	*9/19/00*	*11/20/00*	*.0063*	*.01764*	*.999*	*-.0447*	*.0572*
		6/18/01	*-.0113*	*.01764*	*.988*	*-.0622*	*.0397*
		9/5/01	*.0033*	*.01764*	*1.000*	*-.0476*	*.0543*
		12/3/01	*-.0225*	*.01764*	*.798*	*-.0735*	*.0285*
		7/12/02	*-.1037*	*.01764*	*.000*	*-.1547*	*-.0528*
	11/20/00	*9/19/00*	*-.0063*	*.01764*	*.999*	*-.0572*	*.0447*
		6/18/01	*-.0175*	*.01764*	*.920*	*-.0685*	*.0335*
		9/5/01	*-.0029*	*.01764*	*1.000*	*-.0539*	*.0481*
		12/3/01	*-.0288*	*.01764*	*.580*	*-.0797*	*.0222*
		7/12/02	*-.1100*	*.01764*	*.000*	*-.1610*	*-.0590*
	6/18/01	*9/19/00*	*.0113*	*.01764*	*.988*	*-.0397*	*.0622*
		11/20/00	*.0175*	*.01764*	*.920*	*-.0335*	*.0685*
		9/5/01	*.0146*	*.01764*	*.962*	*-.0364*	*.0656*
		12/3/01	*-.0113*	*.01764*	*.988*	*-.0622*	*.0397*
		7/12/02	*-.0925*	*.01764*	*.000*	*-.1435*	*-.0415*
	9/5/01	*9/19/00*	*-.0033*	*.01764*	*1.000*	*-.0543*	*.0476*
		11/20/00	*.0029*	*.01764*	*1.000*	*-.0481*	*.0539*
		6/18/01	*-.0146*	*.01764*	*.962*	*-.0656*	*.0364*
		12/3/01	*-.0258*	*.01764*	*.687*	*-.0768*	*.0251*

		7/12/02	-.1071	.01764	.000	-.1581	-.0561
	12/3/01	9/19/00	.0225	.01764	.798	-.0285	.0735
		11/20/00	.0288	.01764	.580	-.0222	.0797
		6/18/01	.0113	.01764	.988	-.0397	.0622
		9/5/01	.0258	.01764	.687	-.0251	.0768
		7/12/02	-.0812	.01764	.000	-.1322	-.0303
	7/12/02	9/19/00	.1037	.01764	.000	.0528	.1547
		11/20/00	.1100	.01764	.000	.0590	.1610
		6/18/01	.0925	.01764	.000	.0415	.1435
		9/5/01	.1071	.01764	.000	.0561	.1581
		12/3/01	.0812	.01764	.000	.0303	.1322
CYCLOCOP	9/19/00	11/20/00	-.0146	.04163	.999	-.1349	.1057
		6/18/01	-.0004	.04163	1.000	-.1207	.1199
		9/5/01	-.0004	.04163	1.000	-.1207	.1199
		12/3/01	-.5158	.04163	.000	-.6361	-.3955
		7/12/02	-.0325	.04163	.970	-.1528	.0878
	11/20/00	9/19/00	.0146	.04163	.999	-.1057	.1349
		6/18/01	.0142	.04163	.999	-.1061	.1345
		9/5/01	.0142	.04163	.999	-.1061	.1345
		12/3/01	-.5013	.04163	.000	-.6216	-.3809
		7/12/02	-.0179	.04163	.998	-.1382	.1024
	6/18/01	9/19/00	.0004	.04163	1.000	-.1199	.1207
		11/20/00	-.0142	.04163	.999	-.1345	.1061
		9/5/01	.0000	.04163	1.000	-.1203	.1203
		12/3/01	-.5154	.04163	.000	-.6357	-.3951
		7/12/02	-.0321	.04163	.972	-.1524	.0882
	9/5/01	9/19/00	.0004	.04163	1.000	-.1199	.1207
		11/20/00	-.0142	.04163	.999	-.1345	.1061
		6/18/01	.0000	.04163	1.000	-.1203	.1203
		12/3/01	-.5154	.04163	.000	-.6357	-.3951
		7/12/02	-.0321	.04163	.972	-.1524	.0882
	12/3/01	9/19/00	.5158	.04163	.000	.3955	.6361
		11/20/00	.5013	.04163	.000	.3809	.6216
		6/18/01	.5154	.04163	.000	.3951	.6357
		9/5/01	.5154	.04163	.000	.3951	.6357
		7/12/02	.4833	.04163	.000	.3630	.6036
	7/12/02	9/19/00	.0325	.04163	.970	-.0878	.1528
		11/20/00	.0179	.04163	.998	-.1024	.1382
		6/18/01	.0321	.04163	.972	-.0882	.1524
		9/5/01	.0321	.04163	.972	-.0882	.1524
		12/3/01	-.4833	.04163	.000	-.6036	-.3630
DIAPHAN	9/19/00	11/20/00	-.0046	.01380	.999	-.0445	.0353
		6/18/01	-.0021	.01380	1.000	-.0420	.0378
		9/5/01	-.0313	.01380	.216	-.0711	.0086
		12/3/01	.0017	.01380	1.000	-.0382	.0415
		7/12/02	-.0321	.01380	.191	-.0720	.0078
	11/20/00	9/19/00	.0046	.01380	.999	-.0353	.0445
		6/18/01	.0025	.01380	1.000	-.0374	.0424
		9/5/01	-.0267	.01380	.387	-.0665	.0132
		12/3/01	.0063	.01380	.998	-.0336	.0461
		7/12/02	-.0275	.01380	.352	-.0674	.0124
	6/18/01	9/19/00	.0021	.01380	1.000	-.0378	.0420
		11/20/00	-.0025	.01380	1.000	-.0424	.0374

		9/5/01	-.0292	.01380	.286	-.0690	.0107
		12/3/01	.0038	.01380	1.000	-.0361	.0436
		7/12/02	-.0300	.01380	.257	-.0699	.0099
	9/5/01	9/19/00	.0313	.01380	.216	-.0086	.0711
		11/20/00	.0267	.01380	.387	-.0132	.0665
		6/18/01	.0292	.01380	.286	-.0107	.0690
		12/3/01	.0329	.01380	.169	-.0070	.0728
		7/12/02	-.0008	.01380	1.000	-.0407	.0390
	12/3/01	9/19/00	-.0017	.01380	1.000	-.0415	.0382
		11/20/00	-.0063	.01380	.998	-.0461	.0336
		6/18/01	-.0038	.01380	1.000	-.0436	.0361
		9/5/01	-.0329	.01380	.169	-.0728	.0070
		7/12/02	-.0338	.01380	.148	-.0736	.0061
	7/12/02	9/19/00	.0321	.01380	.191	-.0078	.0720
		11/20/00	.0275	.01380	.352	-.0124	.0674
		6/18/01	.0300	.01380	.257	-.0099	.0699
		9/5/01	.0008	.01380	1.000	-.0390	.0407
		12/3/01	.0338	.01380	.148	-.0061	.0736
CERIODAP	9/19/00	11/20/00	-.0004	.00371	1.000	-.0111	.0103
		6/18/01	.0013	.00371	.999	-.0095	.0120
		9/5/01	.0013	.00371	.999	-.0095	.0120
		12/3/01	-.0288	.00371	.000	-.0395	-.0180
		7/12/02	.0004	.00371	1.000	-.0103	.0111
	11/20/00	9/19/00	.0004	.00371	1.000	-.0103	.0111
		6/18/01	.0017	.00371	.998	-.0091	.0124
		9/5/01	.0017	.00371	.998	-.0091	.0124
		12/3/01	-.0283	.00371	.000	-.0391	-.0176
		7/12/02	.0008	.00371	1.000	-.0099	.0116
	6/18/01	9/19/00	-.0013	.00371	.999	-.0120	.0095
		11/20/00	-.0017	.00371	.998	-.0124	.0091
		9/5/01	.0000	.00371	1.000	-.0107	.0107
		12/3/01	-.0300	.00371	.000	-.0407	-.0193
		7/12/02	-.0008	.00371	1.000	-.0116	.0099
	9/5/01	9/19/00	-.0013	.00371	.999	-.0120	.0095
		11/20/00	-.0017	.00371	.998	-.0124	.0091
		6/18/01	.0000	.00371	1.000	-.0107	.0107
		12/3/01	-.0300	.00371	.000	-.0407	-.0193
		7/12/02	-.0008	.00371	1.000	-.0116	.0099
	12/3/01	9/19/00	.0288	.00371	.000	.0180	.0395
		11/20/00	.0283	.00371	.000	.0176	.0391
		6/18/01	.0300	.00371	.000	.0193	.0407
		9/5/01	.0300	.00371	.000	.0193	.0407
		7/12/02	.0292	.00371	.000	.0184	.0399
	7/12/02	9/19/00	-.0004	.00371	1.000	-.0111	.0103
		11/20/00	-.0008	.00371	1.000	-.0116	.0099
		6/18/01	.0008	.00371	1.000	-.0099	.0116
		9/5/01	.0008	.00371	1.000	-.0099	.0116
		12/3/01	-.0292	.00371	.000	-.0399	-.0184
BOSMINA	9/19/00	11/20/00	-.0263	.02979	.950	-.1124	.0599
		6/18/01	-.0117	.02979	.999	-.0978	.0744
		9/5/01	-.0058	.02979	1.000	-.0919	.0803
		12/3/01	-.3608	.02979	.000	-.4469	-.2747
		7/12/02	-.0037	.02979	1.000	-.0899	.0824

11/20/00	*9/19/00*	*.0263*	*.02979*	*.950*	*-.0599*	*.1124*
	6/18/01	*.0146*	*.02979*	*.996*	*-.0715*	*.1007*
	9/5/01	*.0204*	*.02979*	*.983*	*-.0657*	*.1065*
	12/3/01	*-.3346*	*.02979*	*.000*	*-.4207*	*-.2485*
	7/12/02	*.0225*	*.02979*	*.974*	*-.0636*	*.1086*
6/18/01	*9/19/00*	*.0117*	*.02979*	*.999*	*-.0744*	*.0978*
	11/20/00	*-.0146*	*.02979*	*.996*	*-.1007*	*.0715*
	9/5/01	*.0058*	*.02979*	*1.000*	*-.0803*	*.0919*
	12/3/01	*-.3492*	*.02979*	*.000*	*-.4353*	*-.2631*
	7/12/02	*.0079*	*.02979*	*1.000*	*-.0782*	*.0940*
9/5/01	*9/19/00*	*.0058*	*.02979*	*1.000*	*-.0803*	*.0919*
	11/20/00	*-.0204*	*.02979*	*.983*	*-.1065*	*.0657*
	6/18/01	*-.0058*	*.02979*	*1.000*	*-.0919*	*.0803*
	12/3/01	*-.3550*	*.02979*	*.000*	*-.4411*	*-.2689*
	7/12/02	*.0021*	*.02979*	*1.000*	*-.0840*	*.0882*
12/3/01	*9/19/00*	*.3608*	*.02979*	*.000*	*.2747*	*.4469*
	11/20/00	*.3346*	*.02979*	*.000*	*.2485*	*.4207*
	6/18/01	*.3492*	*.02979*	*.000*	*.2631*	*.4353*
	9/5/01	*.3550*	*.02979*	*.000*	*.2689*	*.4411*
	7/12/02	*.3571*	*.02979*	*.000*	*.2710*	*.4432*
7/12/02	*9/19/00*	*.0037*	*.02979*	*1.000*	*-.0824*	*.0899*
	11/20/00	*-.0225*	*.02979*	*.974*	*-.1086*	*.0636*
	6/18/01	*-.0079*	*.02979*	*1.000*	*-.0940*	*.0782*
	9/5/01	*-.0021*	*.02979*	*1.000*	*-.0882*	*.0840*
	12/3/01	*-.3571*	*.02979*	*.000*	*-.4432*	*-.2710*

* *The mean difference is significant at the .05 level.*

CHIRONOM

Tukey HSD[a]

DATE	N	Subset for alpha = .05	
		1	2
11/20/00	24	.0050	
9/5/01	24	.0079	
9/19/00	24	.0113	
6/18/01	24	.0225	
12/3/01	24	.0338	
7/12/02	24		.1150
Sig.		.580	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24.000.

BOSMINA

Tukey HSD[a]

DATE	N	Subset for alpha = .05	
		1	2
9/19/00	24	.0008	
7/12/02	24	.0046	
9/5/01	24	.0067	
6/18/01	24	.0125	
11/20/00	24	.0271	
12/3/01	24		.3617
Sig.		.950	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24.000.

CYCLOCOP

Tukey HSD[a]

DATE	N	Subset for alpha = .05	
		1	2
9/19/00	24	.0038	
9/5/01	24	.0042	
6/18/01	24	.0042	
11/20/00	24	.0183	
7/12/02	24	.0363	
12/3/01	24		.5196
Sig.		.970	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24.000.

DIAPHAN

Tukey HSD[a]

DATE	N	Subset for alpha = .05
		1
12/3/01	24	.0017
9/19/00	24	.0033
6/18/01	24	.0054
11/20/00	24	.0079
9/5/01	24	.0346
7/12/02	24	.0354
Sig.		.148

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24.000.

CERIODAP

Tukey HSD[a]

DATE	N	Subset for alpha = .05	
		1	2
6/18/01	24	.0000	
9/5/01	24	.0000	
7/12/02	24	.0008	
9/19/00	24	.0013	
11/20/00	24	.0017	
12/3/01	24		.0300
Sig.		.998	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 24.000.

Appendix B3. Statistical analysis output from SPSS: Comparison of Organisms by Flow

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```
ONEWAY
  plecopte chironom cyclocop diaphan ceriodap bosmina BY flow
  /PLOT MEANS
  /MISSING ANALYSIS
  /POSTHOC = TUKEY ALPHA(.05).
```

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
PLECOPTE	Between Groups	.003	1	.003	3.902	.050
	Within Groups	.119	142	.001		
	Total	.122	143			
CHIRONOM	Between Groups	.013	1	.013	2.501	.116
	Within Groups	.712	142	.005		
	Total	.724	143			
CYCLOCOP	Between Groups	2.112	1	2.112	50.790	.000
	Within Groups	5.903	142	.042		
	Total	8.015	143			
DIAPHAN	Between Groups	.007	1	.007	2.980	.086
	Within Groups	.338	142	.002		
	Total	.345	143			
CERIODAP	Between Groups	.008	1	.008	32.843	.000
	Within Groups	.032	142	.000		
	Total	.040	143			
BOSMINA	Between Groups	1.134	1	1.134	57.195	.000
	Within Groups	2.815	142	.020		
	Total	3.949	143			

Appendix C1. Zooplankton taxonomy and densities (number/L) collected at sites above Mammoth Cave National Park, September 2001 and July 2002

	Site			
Month/Organism	Reservoir	Tailwaters	Hwy 88	Munfordville
September				
Phylum Arthropoda				
Class Crustacea				
Order Cladocera				
Family Bosminidae				
Bosmina longirostris	0.22	0.20	0.00	0.00
Family Daphnidae				
Daphnia sp.	0.01	0.00	0.00	0.00
Daphnia schodleri	0.02	0.00	0.00	0.00
Family Sididae				
Diaphanosoma sp.	0.71	0.61	0.01	0.01
Subclass Copepoda				
Order Eucopepoda				
Eucopepod copepodites	0.01	0.00	0.01	0.00
Family Calanoidae (unid.)	0.29	0.38	0.11	0.00
Family Cyclopoidae				
Mesocyclops edax	0.96	0.30	0.13	0.01
Subclass Ostracoda (planktonic)	0.01	0.00	0.00	0.00
Phylum Nematoda	0.12	0.00	0.00	0.00
Phylum Rotatoria				
Class Monogononta				
Order Ploima				
Family Brachionidae				
Keretella sp.	0.01	0.01	0.00	0.00
Phylum Insecta				
Order Diptera				
Family Chironomidae	0.01	0.01	0.00	0.00
Family Culicidae	0.02	0.02	0.01	0.02
Order Hemiptera	0.00	0.00	0.01	0.00
Order Plecoptera	0.00	0.07	0.00	0.00

Appendix C1. (continued)

Month/Organism	Site Reservoir	Tailwaters	Hwy 88	Munfordville
July				
Phylum Arthropoda				
Class Arachnoidea				
Hydracarina	0.00	0.00	0.01	0.01
Class Crustacea				
Order Cladocera				
Family Bosminidae				
Bosmina longirostris	0.53	0.22	0.00	0.01
Family Daphnidae				
Ceriodaphnia sp.	0.00	0.00	0.00	0.01
Daphnia parvula	0.09	0.00	0.00	0.00
Daphnia retrocurva	0.43	0.11	0.00	0.01
Daphnia schodleri	0.00	0.24	0.00	0.00
Family Sididae				
Diaphanosoma sp.	5.55	0.75	0.00	0.00
Subclass Copepoda				
Order Eucopepoda				
Eucopepod copepodites	15.61	1.24	0.05	0.02
Family Calanoidae (unid.)	12.30	6.98	0.13	0.00
Family Cyclopoidae				
Mesocyclops edax	10.76	2.82	0.04	0.05
Subclass Ostracoda (planktonic)	0.00	0.05	0.00	0.08
Phylum Rotatoria				
Class Monogononta				
Order Ploima				
Family Asplanchnidae				
Asplanchna sp.	4.53	0.00	0.00	0.00
Family Brachionidae				
Keretella sp.	1.82	0.10	0.05	0.02
Phylum Insecta				
Order Diptera				
Family Chironomidae	0.07	0.21	0.36	0.06
Family Culicidae	0.00	0.00	0.08	0.01
Order Ephemeroptera	0.00	0.00	0.08	0.01
Order Plecoptera	0.00	0.00	0.10	0.04

Appendix C2. Zooplankton taxonomy and densities (number/L) collected in Nolin River within Mammoth Cave National Park, June 2001 and July 2002

Month/Organism	Site 100-meters upstream of confluence
June	
Phylum Arthropoda	
Class Arachnoidea	
Hydracarina	0.01
Class Crustacea	
Order Cladocera	
Family Bosminidae	
Bosmina longirostris	0.04
Family Daphnidae	
Ceriodaphnia sp.	0.30
Daphnia lumholtzi	0.20
Daphnia parvula	0.03
Daphnia retrocurva	0.04
Family Sididae	
Diaphanosoma sp.	0.07
Subclass Copepoda	
Order Eucopepoda	
Eucopepod copepodites	0.41
Family Calanoidae (unidentified)	2.47
Family Cyclopoidae	
Mesocyclops edax	2.72
Phylum Rotatoria	
Class Monogononta	
Order Ploima	
Family Asplanchnidae	
Asplanchna sp.	0.19
Phylum Insecta	
Order Diptera	
Family Chironomidae	0.03
Order Plecoptera	0.01

Appendix C2. (continued)

Month/Organism	Site 100-meters upstream of confluence
July	
Phylum Arthropoda	
Class Crustacea	
Order Cladocera	
Family Bosminidae	
Bosmina longirostris	0.87
Family Chydoridae	0.28
Family Daphnidae	
Ceriodaphnia sp.	3.24
Daphnia ambigua	0.07
Daphnia parvula	0.16
Daphnia schodleri	0.01
Family Sididae	
Diaphanosoma sp.	1.18
Sida sp.	0.33
Subclass Copepoda	
Order Eucopepoda	
Eucopepod copepodites	2.78
Family Calanoidae (unidentified)	0.05
Family Cyclopoidae	
Mesocyclops edax	1.46
Subclass Ostracoda (planktonic)	0.01
Phylum Rotatoria	
Class Monogononta	
Order Ploima	
Family Asplanchnidae	
Asplanchna sp.	0.92
Family Brachionidae	
Keretella sp.	1.43
Family Synchaetidae	
Ployarthra sp.	1.42
Phylum Insecta	
Order Diptera	
Family Chironomidae	0.06

Vita

Justin H. Laughlin was born in Jackson, MS, on 16 August 1976. He was raised in Brandon and Pearl and graduated from St. Joseph High School in Jackson, May 1994. He received a B.S. degree in Forestry from Mississippi State University in May 2000 after completing a co-op program with Mississippi State Cooperative Extension Service. After graduation, he spent six months as an aquaculture technician in North Carolina before returning to graduate school. He spent 2001 through 2003 working as a graduate assistant and fisheries technician at the University of Tennessee, Knoxville. He received his M.S. in Wildlife and Fisheries Science in August 2003, and is currently contracting with TVA as an aquatic biologist.