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A Review of Research on the Kentucky River Ecosystem: Biota and Human Impacts

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Prepared for:
The Kentucky River Authority

By:
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Under Contract with:
The Kentucky Water Resources Research Institute

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TABLE OF CONTENTS

LIST OF FIGURES

PAGE

LIST OF TABLES **PAGE**

1.0. EXECUTIVE SUMMARY

1.1. Objective.

- The objective of this report is to supply relevant information for developing a dynamic model that will help characterize biological impacts during low flow periods in the mainstem of the Kentucky River.

1.2. Initial assessment of past and current conditions in the Kentucky River Basin.

- A thorough review of the existing data and literature for the basin provided some insight into the current conditions of the biological communities in the Kentucky River Basin and how they have been effected by changes in water quality, quantity, and flow regime.

  - ♦ The 1990 Environmental Science and Engineering investigation provided the most current biological survey information on fish and aquatic invertebrates as well as historical data on mussels and algae relative to species abundance, species diversity, and predicted outcomes from flow changes.
  - ♦ Additional information was obtained from the numerous National Water Quality Assessment Program studies on the Kentucky River Basin dating back to 1986 and continuing through 1990.

1.3. Water quality.

- The primary sources of pollution to the river are siltation from agricultural runoff and nutrient enrichment from waste water treatment plant effluents and agricultural runoff, but other sources of pollution including pesticides, metals contamination, and brine intrusion from oil and gas wells combine to affect the organisms of the river ecosystem (Haag and Porter, 1995).

  - ♦ During periods of low flow, the river is reduced to a series of pools which are subject to stratification and subsequent DO depletion and surface water temperature elevation (ESE, 1991).
  - ♦ The influx of toxic organic compounds such as atrazine and butylate herbicides and organochlorine insecticides to the river is of growing concern because of the bioaccumulation phenomenon that occurs in living organisms (Smoot et al., 1991). In areas where there were no detectable organic compound concentrations in the water column, tissue analysis from organisms such as fish and mussels contained significant levels of various organic compounds. Bottom dwelling organisms are especially susceptible to toxic organics adsorbed to sediments.

- The macrobenthic invertebrate community has responded to alteration of water quality and physical habitat by changing composition to include mostly pollution tolerant species and by decreases in diversity, evenness, and abundance.

- The most recent survey of mussels in the study area was completed in 1975.

    - ♦ All of the species present are considered facultative; they can live in polluted waters.
    - ♦ More recently, researchers have concluded that reduced velocities, increased sedimentation, and other water quality changes would eliminate all populations over time.

- Studies dating back to 1954 indicate that the fish assemblage has been and still is dominated by species considered facultative. Facultative species are approximately 63.5% of the total species collected.

    - ♦ Littoral fish species dominate the upstream samples where more nearshore structure exists. The lower pools that consist mostly of open water areas and less nearshore structure are dominated by benthic or pelagic fish species.
    - ♦ Increased sedimentation, increased discharges from municipalities and industries, and increased organic and inorganic inputs to the river continue to significantly affect the population of fish of the river.

- Phytoplankton densities and potential for nuisance algal growths in the river are positively correlated to nutrient enrichment. Diversity of phytoplankton decreases as nutrient concentrations increase.

2.0. INTRODUCTION.

The Kentucky River is an important resource. Residents of the basin area, which consists of approximately 7000 square miles and includes about 3500 miles of streams, depend on the river for water supply, recreation, and transportation (**Figure 1**). The river and many streams that make up the drainage basin are equally important as habitat for aquatic species as well as terrestrial species that occupy the riparian zones along the water edge. Slightly more than 50% of the basin is forested, with the remaining land used mostly for agriculture, logging, coal mining, and oil and gas production (Smoot et. al., 1991).

Increasing pressure from humans has resulted in water issues that relate to the quantity and quality of water in the river. The quantity issues include too much water during high flow periods, too little water during low flow periods, and availability for recreation. The quality issues include sediment load, presence of nutrients, depletion of oxygen, the presence of bacteria and viruses, the presence of organic and inorganic compounds, and radioactivity. Some of the headwater tributary streams continue to support a diverse aquatic community, but these communities are impaired in other streams including the mainstem of the Kentucky River.

For continued best management of the water resources in the basin, relevlant information must be available to assist managers in water supply planning, water quality management, and protection of the natural system. Information in this report should be incorporated in the overall data base for the basin and utilized for developing accurate models for predicting water quality and quantity impacts on the biological communities of the river. Some susceptible communities include decomposers, benthic organisms, and pelagic organisms. Decomposers live in the sediments of the riverbed and are vital for breaking down organic material and releasing nutrients into the water column where they are utilized by other organisms. Benthic organisms such as some mussels, invertebrates, fish, and algae also live on and among the river sediments. These organisms provide an important link between the decomposers and the pelagic or open water organisms. (**Figure 2**).

Land uses in the basin contribute both direct and indirect stressors to the biological community (**Table 1**). If the stressors reach critical levels, they may negatively impact the biota of the river. The object of this report was to use a conceptual model of a river ecosystem to identify some of the critical values for temperature and dissolved oxygen in relation to fish and for dissolved oxygen in relation to macroinvertebrates for developing a dynamic model of the Kentucky River Ecosystem. The bibliography contains sources of information concerning other stressors and their influence on biological organisms.

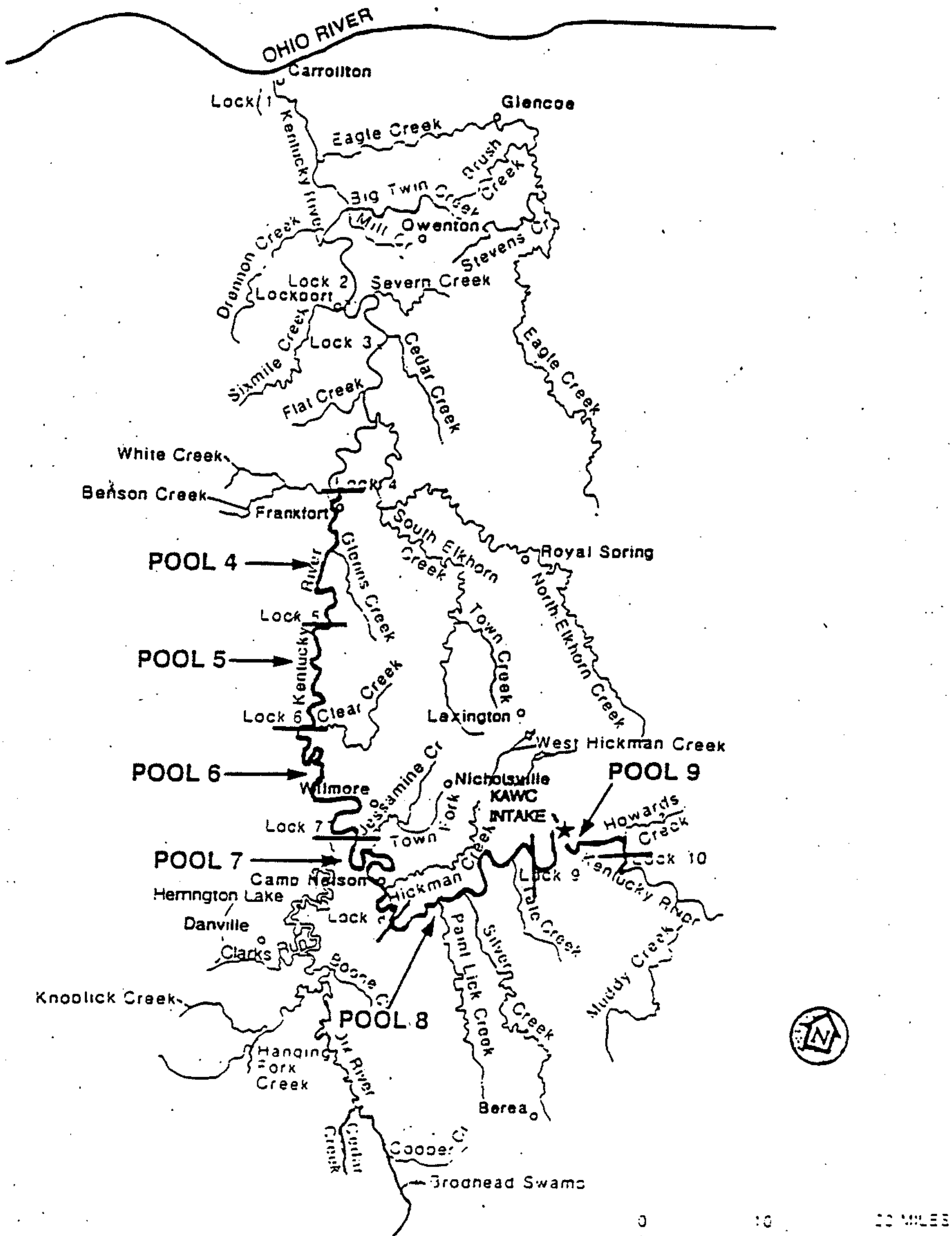
OHIO RIVER
Carrollton
Lock 1
Glencoe
Eagle Creek
Kentucky River
Big Twin Creek
Brush Creek
Mill Cr
Owenton
Drennon Creek
Stevens Cr
Lock 2
Lockport
Severn Creek
Sixmile Creek
Lock 3
Cedar Creek
Eagle Creek
Flat Creek
White Creek
Benson Creek
Lock 4
Frankfort
POOL 4
Glenns Creek
South Elkhorn Creek
Royal Spring
North Elkhorn Creek
Lock 5
Town Creek
POOL 5
Kentucky River
Clear Creek
Lock 6
Lexington
West Hickman Creek
POOL 6
Wilmore
Jessamine Cr
Nicholasville
KAWC INTAKE
POOL 9
Howards Creek
Lock 7
Town Fork
POOL 7
Hickman Creek
Lock 9
Lock 10
Kentucky River
Camp Nelson
Herrington Lake
Lock
Danville
Clarks Run
Paint Lick Creek
Silver Creek
Tate Creek
Muddy Creek
Boone Cr
Knoblick Creek
POOL 8
Hanging Fork Creek
Berea
Cedar Creek
Cooper Cr
Brodhead Swamp
20 MILES
20 KILOMETERS

FIGURE 1

FIGURE 2. MODEL OF BIOTIC INTERACTIONS FOR A RIVER SYSTEM

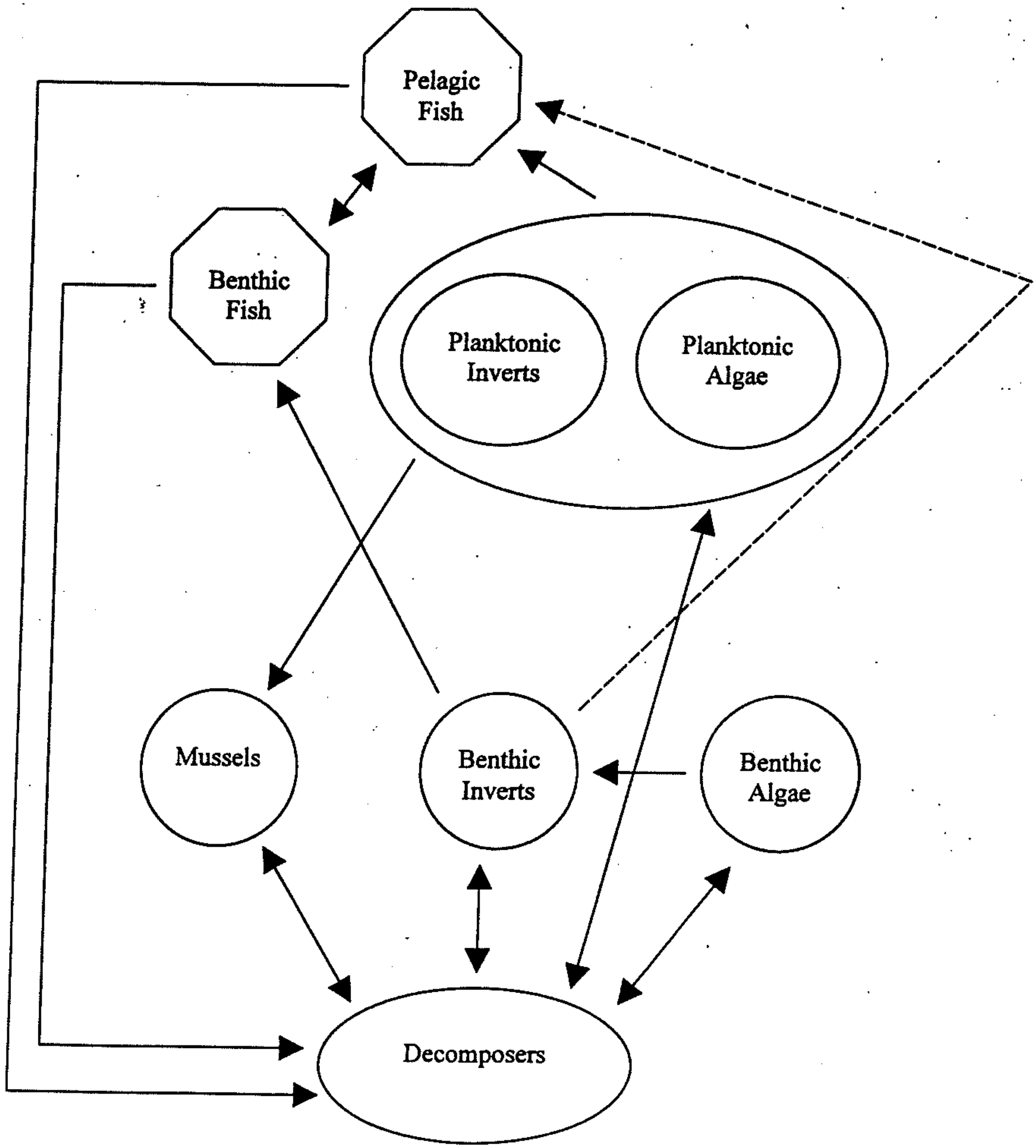

TABLE 1. EFFECT OF STRESSORS ON BIOLOGIC COMMUNITIES

Ecological Endpoints	Stressors Related to Low Flow		Contributing Factors
	Direct Stressors	Indirect Stressors	
Fish (Pelagic/Benthic) Quantity/Species Comp. Reproduction/Development	Temp DO Turbidity	BOD, Algae DIN, Stratification PO_4, Sediments	Land Clearing Agriculture Sewage
Mussels	Temp DO	BOD DIN PO_4	Land Clearing Agriculture Sewage
Benthic Invertebrates (not Mussels)	Temp DO	BOD DIN PO_4	Land Clearing Agriculture Sewage
Zooplankton	Temp DO	BOD DIN PO_4	Land Clearing Agriculture Sewage
Planktonic Algae	Temp DIN PO_4 Cation concentration	Groundwater:Surfacewater	Land Clearing Agriculture Sewage
Benthic Algae	Temp DIN PO_4 Cation concentration Turbidity	Groundwater:Surfacewater Planktonic Algae	Land Clearing Agriculture Sewage
Habitat	Organic Sediment Accrual Bank Erosion	Algal Production Waves, water depth	All related to nutrient loading Recreational Boat Traffic

3.0. REVIEW OF PRIOR RESEARCH ON THE KENTUCKY RIVER.

3.1. Objectives and approaches.

3.1.1. Environmental science and engineering (ESE) 1990 Kentucky River investigation.

Environmental Science and Engineering (ESE) was retained by the Kentucky - American Water Co. (KAWC) to conduct an investigation of the water quality, quantity, and biota of the Kentucky River for the purpose of determining how additional water withdrawals from the Kentucky River during periods of low flow (less than 7Q10) would effect the following:

- Water quantity
- Water quality
- Aquatic life
- Downstream users and dischargers
- Recreational users

ESE refers to this investigation as the Kentucky River Aquatic Study. The study area focused on six pools (4 through 9) located along a 111.4-mile stretch of the Kentucky River. Some of the goals of the report included the following:

- To identify the major industrial and municipal users and dischargers.
- Identify the boat docks and ramps.
- Gather information on river stage and flow from the USGS gauging stations at lock and dam 4, 6, and 10.
- Perform a survey of the biota of the study area through extensive field sampling.
- Gather historical data on water quality and biological communities including freshwater mussels.
- Develop models for the quality and quantity of water, which can be used for evaluating future hypothetical conditions.

One of the models used in the study to represent dynamic water quality was the (WQRRS) Water Quality for River - Reservoir Systems developed by the US Army Corps of Engineers. Calibration of the computer model (WQRRS) was based largely on coefficients recommended by the model developer not on actual empirical coefficients and a limited set of water quality measurements. Estimates of the net gain and leakage from pool to pool are subject to uncertainty due to the inaccuracies in the basic data used to evaluate these measurements.

3.1.2. National water quality assessment program (NAWQA).

Beginning in 1986, Congress appropriated funds for the U.S. Geological Survey to test and refine concepts for the NAWQA program (Smoot et al., 1991). Information obtained on a continuing basis concerning the current water quality conditions for a large part of the Nation's surface and ground water resources would provide an improved scientific basis for evaluating the effectiveness of water-quality management programs.

3.1.2.1. Surface water quality assessment of the Kentucky River Basin, Kentucky: analysis of available water-quality data through 1986 (Smoot et al., 1991).

The objective of this report was to compile, screen, and interpret available water quality data for the Kentucky River Basin through 1986. The report includes information on the sources and types of water quality data available and the utility of the data, as well as a description of current water quality conditions and trends and their relation to natural and human factors.

The data used for this study was compiled from six agencies, which have collected the most water quality data in the Kentucky River Basin. The water quality monitoring program of the Kentucky Division of Water accounts for most of the data available for individual site statistical analysis. Existing data is not adequate to address questions concerning the distribution and transport of many constituents or to associate water quality data to causative factors (Smoot et al., 1991).

Based on existing data, the report summarizes the current water quality conditions and long term trends for a number of parameters including: temperature, pH, alkalinity, acidity, major cations and anions, suspended sediment, nutrients, dissolved oxygen, organic carbon, major metals, radionucleotides, pesticides, fecal bacteria, and biological indicators.

3.1.2.2. Water quality assessment of the Kentucky River Basin, Kentucky: results of investigations of surface water quality, 1987-90 (Haag et al., 1995).

The objective of this report is to summarize the results of the Kentucky River Basin NAWQA project by (1) summarizing previously published data that describe the effects of oil production on water quality and the distribution of metals and other trace elements, nutrients, sediment, and pesticides in surface waters in the basin; (2) analyze additional data collected to describe the distribution and trends in concentrations of major ions, radionucleotides, synthetic organic compounds other than pesticides, fecal bacteria, and dissolved oxygen; (3) summarize all of the data to describe the quality of water in the streams of the Kentucky River Basin during 1987-90.

Water quality data was collected to determine (1) the spatial, temporal, and stream flow variability of constituents throughout the basin; (2) the effects of point source discharges on water quality; (3) the effects of runoff from nonpoint sources on water quality.

Six fixed stations were located within the basin on the major upstream tributaries and a seventh station was located on Elkhorn Creek near Frankfort. The stations were sampled monthly over a period of three years (1987-90). In addition, synoptic studies were done to evaluate water quality over a broad geographical range. Single samples were collected at many sites to provide information on the occurrence and distribution of selected constituents during stable low-flow conditions when the effects of point source discharges predominate.

3.1.2.3. Summary of biological investigations relating to surface-water quality in the Kentucky River Basin, Kentucky (Bradfield and Porter, 1990).

The objective of this report was to evaluate the biological investigations that relate to surface-water quality in the Kentucky River Basin. A secondary objective was to provide qualitative assessments of biological conditions in the river and the factors that affect those conditions.

Existing data from federal, state, and private sources was used for this investigation. Aquatic biological communities can provide valuable information for stream assessments. Several groups of organisms were evaluated including fish, algae, mussels, and macroinvertebrates to help describe the condition of the river.

3.1.2.4. Water-quality assessment of the Kentucky River Basin, Kentucky: nutrients, sediments, and pesticides in streams, 1987-90 (Haag and Porter, 1995).

The objective of this report was to describe (1) the distributions and trends in concentrations of selected nutrients, sediments, and pesticides in streams; (2) the distributions and trends of these constituents to natural physical and chemical processes as well as human factors that affect water quality; (3) the possible interaction of these constituents and potential effects of observed water quality on aquatic biota.

Suspended-sediment samples were collected monthly at seven fixed stations from 1987-90. Water and sediment samples were also collected during low-flow synoptic surveys at 74 stations in August 1987 and 74 stations in August 1988. In addition, water quality data collected by the Kentucky Division of Water from 1986-89 at 11 fixed stations were analyzed in conjunction with the NAWQA data to enhance the understanding of the spatial distribution of constituent concentrations, loads, and trends.

The Kentucky River Basin assessments of nutrients focused on point and non-point source contamination. Constituents of interest included nitrate, nitrite, and ammonia nitrogen, as well as orthophosphate and phosphorus (Griffin et al., 1994). Relations among algae and nutrients were assessed by collecting monthly phytoplankton samples from October 1987 through August 1988 at the seven fixed stations. Water samples were collected concurrently and analyzed for pH and dissolved oxygen.

3.1.2.5 A Comparison of natural and human determinants of phytoplankton communities in the Kentucky River Basin, USA (Stevenson and White, 1995).

This study compared the variation in phytoplankton communities related to seasonal, spatial, and human related environmental factors in the Kentucky River. 55 locations were analyzed for physical, chemical, and biological characteristics during a summer, low flow period and at a subset of those locations throughout the year. Hypothesis was tested to determine the significance of correlations between phytoplankton and seasonal and longitudinal factors, and human related factors: such as nutrient and heavy metal concentrations, turbidity, and land use.

3.2. Review of water quality in the Kentucky River.

The primary sources of pollution in the study site are siltation from agricultural runoff and nutrient enrichment from wastewater treatment plant effluents (Burr and Warren, 1986). This information is substantiated by the information collected for the National Water Quality Assessment Program by Smoot and others, 1986, and Bradfield and Porter, 1990. During periods of high flow, the siltation effect is intensified due to the diminished floodplain of the Kentucky River. However, during periods of low flow the river essentially becomes a series of pools with flow limited to leakage through the dams and limited discharge from groundwater and tributaries. The result is pool conditions for most of the year contributing to the development of pool-inhabiting species of fish and invertebrates. Geographical features in the basin influence the community composition of all organisms. Results of the biological surveys performed in the study site substantiate these claims.

3.2.1. Summary of water quality observations by ESE.

The following is a list of observations ESE deduced from model simulations developed from data collected in 1990.

- Water quality data collected revealed that upstream pools tended to warm more quickly in the spring and cool more quickly in the fall than the downstream pools. Stratification, when it occurs, begins at the downstream end of each pool and moves upstream.
- Greater variations in water quality will probably occur vertically as compared to longitudinally.
- Dissolved oxygen was reasonably simulated when sediment dissolved oxygen (SOD) was considered.
- Fish from the main channel congregated in creeks and at creek mouths during periods of high flow, which are generally inaccessible for the fish during normal and low flow periods.
- Water quality data collected in 1990 was limited to temperature, DO, pH, and conductivity.
    - max. mid-channel temperature = 26.8 C
    - mid-channel DO = 3.5 to 12.5 ppm (measured during daylight hours)

- Stratification may occur at the downstream end of some of the pools resulting in DO levels to drop below 5.0 ppm.
- There were minimal differences in pH throughout the year.
- Conductivity was similar throughout the year.
- Results from simulations of the model :
    - min DO at the top and middle depth: 7 - 8 ppm
    - min DO at the bottom depth: 0 - 5 ppm
- Pools 8 & 9 had DO conc. = 0 at the bottom due to the increase in organic loading in the bottom sediments.

- Simulated water temperature ranges from 3 C to 30 C.

Temperature, dissolved oxygen, conductivity, pH, current velocity, and turbidity were collected at specific sample locations and sample depths (**Table 2**). In Oct. and Nov., the parameters were measured at the electrofishing sites only.

3.3. Review of macroinvertebrates in the Kentucky River.

3.3.1. ESE survey.

3.3.1.1. Field collection of macroinvertebrates.

Sample regime - 20 sample zones located throughout pools 4 - 9. Pools #4, #5, #6, and #8 contained 3 zones each and pools #7 and #9 contained 4 zones each.

Hester - Dendy (H-D) samplers were set in May, July, and Oct., and allowed to colonize for thirty days. The H-D's were suspended in the water which may lead to selective colonization by organisms that live in the water column thus excluding some organisms that may inhabit the sediments as well. The Ponar and hand grabs were collected only in October, which may lead to some bias in collection due to life cycle influences on particular species of invertebrates.

3.3.1.2. Characterization of the ESE macroinvertebrates of the Kentucky River.

Weber (1973) grouped invertebrates into three categories: tolerant, facultative, and intolerant. The dominant taxa collected in 1990 from the ponar and qualitative samples included mostly pollution tolerant and enbenthic (within the benthos) organisms. The H-D samples consisted of less tolerant and epibenthic (on the benthos) taxa. The combined collections showed some variation due to seasons and sampler type. The dominant species in all of the pools are considered to be tolerant of poor water quality (**Table 3**).

Decorana and correlation analysis was used to relate environmental parameters to variation in the Hester-Dendy sample data. These parameters included season, temperature, diversity, dissolved oxygen, and biotic index. The biotic index was used in evaluating the macroinvertebrate communities sampled during the study. For the purpose of calculating a biotic index, species are assigned pollution tolerance values (TV) of 0-11 (0 being the least tolerant) on the basis of previous field studies (Illinois Environmental

TABLE 2 . WATER QUALITY PARAMETER SAMPLE LOCATIONS.

Location	Depth
electrofishing site	1 meter
gill net site	1 meter
seine site	near surface
trawl and ponar	near bottom
hester - dendy	mid - depth

TABLE 3. ESE MACROINVERTEBRATE SURVEY.

	Common Name	Pool 4 H-D	Pool 4 Sum H-D	Pool 4 Ponar	Pool 5 H-D	Pool 5 Sum H-D	Pool 5 H-D & Ponar	Pool 5 Ponar	Pool 6 H-D	Pool 6 Sum H-D	Pool 6 H-D & Ponar	Pool 6 Ponar
Stenacron interpunctatum TV=4	Mayfly	0.265p	20.4d		c	23.5d	0.295p		5.5d	c	c	
Hydra sp. TV=2		0.206p	20.5d		c	10.9d	0.089p		25d	0.5p	0.345p	
Dicrotendipes modestus	Chironomid								5.5d	c	c	
Dicrotendipes lucifer	Chironomid				c				5.7d		c	
Isoperla sp. TV=2	Plecopteran											
Cymellus fraternus TV=5	Tricopteran		5.2d		c						c	
Cheumatopsyche sp.	Tricopteran	0.126p										
Imm. Tubificidae	Worms			0.56p	c		0.075p	0.255				c
Strictochironomus sp. TV=5	Chironomid			0.113p				0.427				c
Polypedilum simulans/digitifer	Chironomid											c
Chironomus riparius	Chironomid			0.106p								c
Agria sp.	Odonata				c							
Tribelos sp.	Chironomid											
Glyptotendipes sp. TV=10	Chironomid							0.169				
Hexageia limbata TV=5	Mayfly											
Neureclipsis sp. TV=3	Tricopteran											
mean diversity		3.63	2.41	2.42					3.24			
biotic index		4.38	3.79	8.93	5			6.68	4.24			
TV = Tolerance Value												

p designates percentages of total organisms collected in pool

d designates densities of organisms in selected pools (# organisms / sq. meter)

c designates common organism found in the sample

TABLE 3 CON'T. ESE MACROINVERTEBRATE SURVEY.

		Pool 7				Pool 8				Pool 9			
	Common Name	H-D	Sum H-D	H-D & Ponar	Ponar	H-D	Sum H-D	H-D & Ponar	Ponar	H-D	Sum H-D	H-D & Ponar	Ponar
Stenacron interpunctatum TV=4	Mayfly	8d		0.17d		7.1	0.481d	0.208d		0.132d	0.165d		
Hydra sp. TV=2													
Dicrotendipes modestus	Chironomid	7.5d		0.16d						0.172d	0.326d		
Dicrotendipes lucifer	Chironomid			0.064d									
Isoperla sp. TV=2	Plecopteran	3.7d		0.078d		2.4		0.07d					
Cymellus fraternus TV=5	Tricopteran	3.6d		0.077d		3	0.255d	0.093d		0.125d	0.217d		
Cheumatopsyche sp.	Tricopteran												
Imm.Tubificidae	Worms			0.097d	0.645d				0.288d				0.343d
Strictochironomus sp. TV=5	Chironomid				0.04d								0.327d
Polypedilum simulans/digitifer	Chironomid				0.068d				0.313d				
Chironomus riparius	Chironomid				0.032								0.099d
Agria sp.	Odonata												
Tribelos sp.	Chironomid												
Glyptotendipes sp. TV=10	Chironomid		c										
Hexageia limbata TV=5	Mayfly												
Neureclipsis sp. TV=3	Tricopteran												
mean diversity		>3			2.2	4.39				4.16	2.75		2.74
biotic index					9.28	4.98			7.89	5.46	5.5		7.8
TV = Tolerance Value													

p designates percentages of total organisms collected in pool

d designates densities of organisms in selected pools (# organisms / sq. meter)

c designates common organism found in the sample

Protection Agency, 1984). Spring samples were dominated by *Stenacron interpunctatum* (TV=4) and *Cheumatopsyche* sp (TV=6). Summer values reflected the dominance of *Hydra* sp. (TV=2) and *Stenacron interpunctatum* (TV=4). Values for the fall were dominated by the stonefly, *Isoperla* sp. (TV=2) (Table 3). In general, results from the ordination analysis of the Hester-Dendy data indicated that the prevailing factor controlling community composition was season.

The biotic index is an average of tolerance values, and measures saprobity (rate of organic decomposition) and to some extent the trophic state of the environment, which frequently influences saprobity (Caspers and Karpe, 1966). The biotic index for the ponar samples of the study area ranged from 7.8 - 9.28 indicating a high level of organic decomposition in the benthos.

The measure of diversity for this study was the Shannon-Wiener index which is a function of two components: richness of species, and distribution of individuals among the species (Weber, 1973). The following guidelines were used for interpreting the Shannon-Weiner index:

- H' < 2 = ecological stress and unsuitable habitat
- 2 < H' > 3 = moderate stress and marginal habitat
- H' > 3 = little stress and suitable habitat

The ponar samples of the entire study area (Pools 4-9) had a diversity index between 2.2 - 2.74 indicating that the benthos provided a marginal habitat for macroinvertebrates **(Table 3)**.

3.3.2. Historic macroinvertebrate data.

The following is a summary of the Kentucky Division of Water survey conducted on pool 4 & 8 from 1985 - 1988.

- **Lock 4 samples:**
  Dominant taxon = *Cyrnellus fraternus*
  Moderate numbers in 1983 = *Stenacron interpunctatum*
  Commonly encountered in 1985 = *Polypedilum, Tanypus, Dicrotendipes*
- **Lock 8 samples:**
  Dominant taxon in 1985 = *Tanytarsus* out of 15 taxa collected
  60 % of overall sample in 1986 = *Glyptotedipes lobiferus*
  Also abundant in 1986 = *Ablabesmia mallochi*
  Dominant taxa in 1987 & 1988 = *Glyptotedipes lobiferus*
  Moderate number of individuals in 1987 = *Ablabesmia parajenta*

Generally speaking, density, diversity, and biotic index were typically highest in the spring, and decreased during the sampling season.

3.4. Review of the mussels of the Kentucky River.

3.4.1. Williams study (1975).

Williams (1975) conducted a mussel study in pools 1-14 on the Kentucky River main stem and three forks. At this time, no mussels were located in pools 6 & 14. A total of 24 species were found and one exotic clam (*Corbicula fluminea*).

Details of the Williams study included:

- Most abundant organism in pools 4 - 9 was *Amblema plicata plicata.*
- Pool 8 contained 139 individuals.
- Pools 4 & 7 contained 2 of the 3 largest mussel beds.
- The third bed was located in pool 2.
- The dominant taxa were *Amblema plicata plicata, Megnonaias nervosa,* and *Quadrula quadrula.*
- Habitat consisted of rubble, gravel, and sand.
- Most of the mussels were in the age group 10-25 years.
- Few young mussels were found.

The dominant mussels found by Williams are capable of living in a variety of substrates including mud, silt, and gravel. Oesch (1984) states that *Amblema plicata plicata* seems capable of thriving in polluted waters that eliminate many indigenous species. Other species collected (*Megnonaias nervosa, Quadrula quadrula,* and *Lampsilis radiata luteola*) are tolerant of a wide variety of conditions. The predominant fish hosts of the mussels include centrarchids and flathead catfish. In 1990, centrarchids accounted for 20 % of the fish species collected.

3.4.2. Tolin and King Study (1985)

In August of 1985, Tolin and King (1986) conducted a mussel survey for Fish and Wildlife from Lock and Dam #4 downstream to the Ohio River. Thirty-two species were collected and the clam *Corbicula fluminea* and 21 species were collected from the lower 65 miles of the main stem. The three most abundant mussels encountered in the study section included:

- *Obliquaria reflexa* (27.7%)
- *Ambleme plicata plicata* (18.1%)
- *Potamilus alatus* (19.6%)

Most of the mussels were located just downstream of the turbulent tailwater area of the dam. This survey collected many juveniles in contrast to mostly adults collected by Williams. Other common species included *Quadrula quadrula, Q. nodulata, Fusconaia flava, Truncilla truncata, and Leptodea fragilis*

The difference in the two studies may be the result of temporal and spatial variation. The Tolin and King study was from pool 3 to the Ohio River where organisms could work their way up from the Ohio. Williams samples were from further upstream. Even now, the population may have changed dramatically from 1985 due to increased environmental stress on the river. Tolin and King concluded that reduced velocities, increased sedimentation, and other water quality changes would eliminate all populations over time.

3.5. Review of fish in the Kentucky River.

3.5.1. ESE fish survey.

Fish were surveyed in the months of June, July, August, October, and November.

Methods of fish collection included:

- electrofishing
- seining
- gill netting
- trawling

Of the seventy-four taxa collected during the 1990 study, the dominant taxa included:

- Gizzard Shad (26.4%)
- Ghost Shiner (10.3%)
- Bluegill (9.1%)
- Freshwater Drum (8.1%)
- Emerald Shiner (5.9%)
- Largemouth Bass (4.6%)

Other common fish included Smallmouth Buffalo, Golden Redhorse, Channel Catfish, and White Bass. Collection of the species was highly method specific. All of these dominant species are classified as intermediate in their tolerance to pollution (EPA, 1993).

- **The proportion of tolerant species is (7 / 74) * 100 = 9.4%**
- **The proportion of intermediate species is (47 / 74) * 100 = 63.5%**
- **The proportion of intolerant species is (14 / 74) * 100 = 18.9%**

Temporal patterns in the resident species assemblage was correlated to the flow regime and juvenile recruitment (addition to the population by first year fish). When the flows were higher in the spring, catch rate declined in the main channel but more fish were captured in the newly inundated floodplain as well as at the mouth of the tributaries. Spatial difference in abundance and distribution of fish species is most attributable to available habitat in the pools. Bankslope, tailwater areas, shoreline and nearshore areas, and size of creek mouth areas all contribute to suitable habitat for the fish.

3.5.2. Characterization of the fish assemblages of the Kentucky River by ESE.

Community composition was analyzed using ordination analysis to identify factors that influenced observed patterns of species distribution. However, only electrofishing data was used for this analysis with the assumption that this represented the most comprehensive collection of the resident fish assemblage. This may not be an accurate representation because electrofishing itself is a highly species specific sampling method, but in this instance, there were only a few species from the overall community that were not represented adequately in the electrofishing data.

Results of the analysis indicated a correlation between community composition and several factors including pool, station, habitat, temperature, and dissolved oxygen. Littoral species dominated the upstream stations where the habitat consists of greater amounts of nearshore structure. The lower stations, which consist mainly of open water areas and less nearshore structure, maintain a community of pelagic or benthic species **(Refer to Table 4 for fish habitat classification).**

Based on the ordination analysis, the assumption was made that assemblage structure varied in relation to habitat conditions in the specific sampling zones, but there was no visual inspection of the habitat to substantiate this claim.

3.5.3. Summary of infrequently encountered species collected by ESE.

- **Pool #4**

Skipjack Herring, Striped Bass, American Eel, and River Darter

Skipjack Herring have been previously reported in the lower reaches of the Kentucky River (Burr and Warren, 1986). Williams (1975) collected 140 river darters in a 1972 lock chamber study, but only one darter in a 1973 study.

- **Pool #5**

Eastern Sand Darter, Mosquitofish, Red Ear Sunfish, Rainbow Darter, and River Darter

The Eastern Sand Darter is threatened in Kentucky and has previously been sporadically collected in the upper reaches of the river (Burr and Warren, 1986).

- **Pool #6**

Juvenile Paddlefish, Muskellunge, American Eel, and Greenside Darter

TABLE 4. FISH HABITAT CLASSIFICATION.

Pelagic or Limnetic	Benthic	Littoral
Clupeidae (herrings)	Ictalurids (catfishes)	Centrarchids (Bass, sunfish, Crappie)
Lepisosteidae (gars)	Catostomids (suckers)	Esocids (pikes)
Polyodontidae (paddlefish)	Carp	Percids (pike-perches)
Moronidae (temperate basses)	Freshwater Drum	

The collection of the Paddlefish indicates that some natural reproduction is occurring in the river.

- **Pool #7**

Muskellunge, American Eel, Bigeye Shiner, Brook Silverside, and Redear Sunfish

- **Pool #8**

Sharpnose Darter

This species has a conservation status of undetermined and occurs sporadically in the upper reaches of the river (Burr and Warren, 1986).

- **Pool #9**

Rosyface Shiner, Dusky Darter, and Muskellunge

The Dusky Darter is considered occasional to common in the upper Kentucky River.

3.5.4. Historical Fisheries Studies.

- Carter (1954): In 1951, Carter investigated navigational locks for inter-pool movement of fish.
- Jones (1973): Survey conducted for the Kentucky Department of Fish and Wildlife.
- Williams (1975): Follow-up study to detect any significant changes in fish population from the Carter study.

Carter limited his study to ten locks, Williams sampled twelve locks, and Jones included 114 inventory studies, five of which were conducted on the mainstem of the river. The shift in community composition from freshwater drum to gizzard shad indicates the dominance by fish that prefer open water habitats, which correlates to the loss of nearshore structure along the river (**Table 5**).

Williams noted that Blue Sucker and Blue Catfish were not collected above lock #3 and that Sauger was not collected above lock #8 but that Sauger had previously been abundant in the upper reaches of the river.

Burr and Warren suggest that siltation from mining has significantly affected the fish fauna in the upper Kentucky River and siltation from agriculture and discharges from municipalities and industry has impacted the lower basin fish fauna. The numbers of pollution intolerant species that once thrived in the main channel of the river have seen a sharp decline in the past ten years (**Table 6**).

TABLE 5. HISTORICAL SUMMARY OF FISH SURVEYS.

CARTER (1954)	JONES (1973)	WILLIAMS (1975)	ESE (1990)
Freshwater Drum (22.4%)	Ghost Shiner (39.1%)	Emerald Shiner (64.7%)	Gizzard Shad (26.4)
Silver Chub (14.9%)	Bluegill (10.4%)	Ghost Shiner (10.4%)	Ghost Shiner (10.3)
Channel Catfish (12.0%)	Freshwater Drum (9.4%)	Freshwater Drum (5.8%)	Bluegill (9.1)
Emerald Shiner (10.5%)	White Crappie (5.9%)	Gizzard Shad (5.4%)	Freshwater Drum (8.1)
White Crappie (10.0%)	Sand Shiner (5.2%)	Logperch (3.2%)	Emerald Shiner (5.9)

TABLE 6. FISH SPECIES OF SPECIAL CONCERN IN THE KENTUCKY RIVER (Branson et al., 1981 and Warren et al., 1986).

Species	1981	1986	Number collected in 1990 study
Silver lamprey	S*	Delisted	-----
Paddlefish	S	Delisted	1
Muskellunge	S	Delisted	14
Horneyhead chub	Undetermined	S	-----
Blue sucker	T**	Undetermined	-----
Black buffalo	Undetermined	S	-----
Burbot	Undetermined	S	-----
Eastern sand darter	T	S	2
Sharpnose darter	Undetermined	Delisted	1
River darter	T	Delisted	5

S* = Special concern

T** = Threatened

Delisted = Removed from the special concern or threatened list compiled by the Kentucky Academy of Sciences and the Kentucky Nature Preserves Commision.

3.6. Review of algae in the Kentucky River.

Stevenson and White (1995) concluded that phytoplankton densities in the river were positively correlated with water temperature, pH, NO_3, org - N, and alkalinity, and negatively correlated to DO, NH_4, and suspended solids. In addition, Shannon diversity was negatively correlated to nutrient enrichment and most of the variation in species composition was related to increased levels of nutrients. Summer phytoplankton maxima was positively correlated to high temperatures and low discharge. All of these factors contribute to possible negative impacts on water quality and resident biota.

Stevenson and White (1995) reported 276 taxa in the river representing 14 major taxonomic groups. Regression analysis indicated a significant relation between Chroococcales and summertime, benthic diatoms and spring, and chrysophytes and winter. Filamentous bluegreens were associated with areas of high nitrogen concentration, commonly found in agricultural and urban areas.

Bradfield and Porter (1990) reported phytoplankton communities in the river were dominated by centric diatoms such as *Melosira varians*, *Cocconeis placentula* var. *euglypta* which are commonly associated with nutrient enriched waters. Periodic blue-green algae blooms have been reported in several reaches of the river. The Kentucky Division of Water (1982 and 1984b) reported algal communities similar to the U.S. Geological Survey.

Haag and Porter (1995) found significant correlation's between total phosphorus and suspended sediments with the highest concentration of P found at high flows and the highest concentration of nitrate nitrogen at low flows. Bothwell (1988) reported that a concentration of 0.3 - 0.6 µg PO_4-P saturated the growth rate for benthic diatoms. The relationship between nutrient levels and biomass is strong for phytoplankton but weak for benthic algae. Phytoplankton chl *a* concentrations were positively correlated with the concentration of total P and total NH_3. The proportion of river nitrogen coming from wastewater treatment plants increased downstream. A considerable portion of the total nitrogen in the river was transported as algal biomass. Low turbulence and long retention times allow for algal reproduction in the mainstem of the river. Blue-green algae predominate from river mile 158 downstream to the mouth, which is another indicator of nutrient enriched waters.

3.7. Evaluation of the ESE model simulations and the apparent affects to the biota.

3.7.1. Macroinvertebrates.

High temperature stress did not appear to be a limiting factor for the invertebrate community. However, dissolved oxygen was a parameter that could possibly have affected the biotic community. Factors related to dissolved oxygen levels that regulate the diversity and species composition of invertebrates include habitat preference, substrate preference, temperature, and flow rate. For example, species requiring high DO levels usually inhabit riffle areas or along the shorelines that have well-aerated waters. In contrast, enbenthic (within the benthos) species are adapted to the slow or non-flow currents were the DO levels rapidly become depleted.

The relative tolerance to DO levels for a particular species is quite varied **(Table 7)**. Fox (1937) and Benedetto (1970) found that the critical DO levels for mayfly and stonefly nymphs ranged from 2.2 mg/l to 17 mg/l and 4.8mg/l to 7.3 mg/l, respectively. The USEPA (1976) established qualitative levels of DO that have certain affects on invertebrates. These levels are 4 mg/l as acute mortality limit, 5 mg/l as resulting in some production impairment, and 8 mg/l as having no production impairment.

There were some instances that the DO level dropped below 2 mg/l, however no adverse effects were expected because the existing invertebrate population is adapted to low levels of DO. The model indicated the littoral zones would stay well-oxidized cause no change in the population presently inhabiting this area. Although the model did show that bottom DO levels were expected to deplete totally for as long as 30 days in pools 8 and 9 which would cause die-offs of some of the invertebrate community. These conditions were not considered to represent long term significant impacts to the community because of the extensive recolonization pool of organisms present.

3.7.2. Mussels.

Typically, mussels are not capable of moving from areas of less desirable habitat to areas of more desirable habitat. Low DO and higher water temperatures resulting from summer stratification could potentially impact the mussel population. Tolin and King predicted that the mussels would occupy the areas immediately adjacent to the channel borders. Oeschl (1991) stated that the lethal threshold limits for temperature and DO as they relate to mussels are probably close to those of the resident fish community. Miller (1991) indicated that since the majority of the mussels are most likely located at mid-depths, where water temperatures are in the mid-twenties and DO levels around 6 ppm, there should be no adverse affects on the mussel community of the study area. There has been no recent survey of the mussel community to determine their current status or their exact locations.

3.7.3. Fish

Large river and pool inhabiting species (Table 4) represent the Kentucky River fish assemblage. Many factors can influence a fish community including organic inputs, temperature, precipitation, and DO. The prediction of prolonged low DO levels in some of the pools indicates a possible impact to the fish community from the standpoint of affecting certain life stages, reproduction and spawning success, behavior, and the growth of fish. The fish community could become stressed because of low DO conditions, which may lead to eventual mortality **(Table 8)**.

TABLE 8. FISH THRESHOLD (CRITICAL) DISSOLVED OXYGEN CONCENETRATIONS.

Family	Common name	DO (mg/l)
Poyodontidae	Paddlefish	4.0
Lepisosteidae	Gars	4.0
Clupeidae	Herrings	2.0
Esocidae	Pikes	5.0
Cyprinidae	Minnows	3.0
Catostomidae	Suckers	3.0
Ictaluridae	Catfishes	3.0
Moronidae	Temperate basses	2.0
Centrarchidae	Largemouth bass	3.0
Centrarchidae	Smallmouth bass	4.0
Centrarchidae	Crappies	2.0
Centrarchidae	Sunfish	1.5
Percidae	Pikes and perches	4.0
Sciaenidae	Freshwater drum	2.0

The USEPA (1976) set a criterion of a minimum of 5 ppm of DO to maintain good fish populations including the embryos and larvae. Fish can exist at concentrations well below these values but a thriving fish population will not exist. Williamson and Nelson (1985) report that Gizzard Shad are absent from water with a DO of less than 2 ppm. Abnormalities have been reported for Bluegill, Largemouth Bass, Rock Bass, Black Crappie, as a result of DO concentrations falling below 3 ppm (Carlson and Herman, 1978).

The affects of low DO levels on the embryonic and larval stages of fish are of real concern for the Kentucky River. With increased levels of organic and inorganic inputs as well as increased nutrient loads from agricultural runoff, there is a real possibility that the DO levels in the water near spawning areas can drop well below critical levels resulting in growth inhibition, behavioral change, or outright mortality. The maximum temperature (30.5° C) predicted from the model simulation is considered below the threshold limit of 35° C listed for the taxa encountered in the study area (Brungs and Jones, 1977).

The ESE model simulation for DO in the Kentucky River indicated that pools 8 and 9 are affected considerably by oxygen depletion near the bottom. According to the model, stressful conditions are present for an extended period of time (50 - 63 days) at the bottom depths of 0.5 - 0.8 meters. The benthic dwellers could be affected over this extended period. Reduction of water levels may also provide predator species a distinct advantage because of loss of refuge area for the prey species including larval fishes.

4.0. REVIEW OF KNOWN TOLERANCES FOR ORGANISMS AND THEIR USE IN DEVELOPING ECOLOGICAL MODELS.

4.1 Algal Ecology.

This discussion will focus on phytoplankton (algae suspended in water column) ecology, rather than benthic algae (algae on river bottoms). The response of planktonic and benthic algae to environmental changes in rivers is probably very different. Before impoundment, benthic algae were probably a major source of nutrition for the rest of the found web. However after impoundment, turbid and deep waters shade bottom algae and sediments bury benthic algae in most of their previous habitats. Phytoplankton are the dominant algae in large rivers, except in some micro-habitats such as on snags and in aquatic plant beds where algae growing on these substrates are important sources of nutrition for the invertebrates in these important habitats. Phytoplankton will be important for predicting dissolved oxygen changes in the river.

Phytoplankton dynamics in any habitat are affected by immigration from a source, their reproduction rates, grazing rates by zooplankton (very small animals suspended in the water), and sinking rates from the water column. In models of phytoplankton dynamics, the transfer of algae in a parcel of water represents algal immigration from an upstream to a downstream section of the river. During the period that algae reside in a section of the river, algae accumulate faster in that parcel if reproduction rates are faster and grazing and sinking rates are relatively low. Thus it is important to know how environmental conditions affect algal reproduction, grazing and sinking rates in rivers. Nutrient concentrations, light, temperature, and the species of algae in the habitat largely affect reproduction (often referred to as algal growth). Grazing rates are related to zooplankton abundances in large rivers, which are poorly understood. Sinking rates of algae are related complexly to physiological condition of the algae and probably vary greatly among the different algal species in the river. The following discussion provides more discussion of factors affecting algal growth in rivers, but little is known about grazing and sinking rates of algae in large rivers.

4.1.1 Effects of Nutrients on Algal Growth.

Several equations have been used to describe algal growth. All these equations predict that algal growth rates increase with nutrient supply until algae reach a maximum growth rate. When nutrient supply increases above concentration that saturates algal demand, then no further increase in growth rates with nutrient supply is observed.

The Michaelis-Menton nutrient uptake and growth equations relate water column nutrient concentrations (S (S, $\mu M\ L^{-1}$) to algal nutrient uptake rates (V, $\mu M\ d^{-1}\ \mu g$ chl a^{-1}) and growth rates (μ, divisions d^{-1} or cells $cell^{-1}\ d^{-1}$):

$V = V_{max} (S / (K_s + S))$

$\mu = \mu_{max} (S / (K_s + S))$ where K_s is the half-saturation constant (K_s, $\mu M\ L^{-1}$), which is the nutrient concentration at which algae grow at half their maximum growth rate.

Because algae can take-up and store luxury quantities of nutrients, algal growth rates can stay high when some nutrient concentrations in the water column decrease. This is particularly true for phosphorus. For this reason the Droop equation was developed to relate algal growth rates to intracellular concentrations of nutrients.

Droop has argued that growth responds to the size of the internal nutrient pool (cell quota) rather than the external nutrient concentration. The Droop model decouples nutrient uptake and growth rate, which agrees well with experimental data. However, cell quota is controlled by Michaelis-Menten nutrient uptake kinetics for cell division (Haney and Jackson, 1996).

The Droop model is expressed as

$\mu = \mu_{max} (1 - Q_0/Q)$ where Q is the cell quota (intracellular nutrient concentration in $\mu M\ cell^{-1}$)

Q_0 is the intracellular nutrient concentration required for a growth rate of zero.

Fasham *et al.*(1990) published a model that is a fairly simple description of a planktonic system in which temporal changes in the thermocline depth affect the ecosystem. The model follows the evolution of the average mixed layer concentration of seven nitrogen components. Changes for the vertically averaged concentrations of phytoplankton and nitrate are given by (See coefficients for Fasham Model in **Table 9**).

Phytoplankton concentration: $dPHY/dt = (1-\gamma_1)\ P - G_1 - \mu_1 P - (m + h^+(t)) / M * P$

Nitrate concentration: $dNn/dt = -\sigma_n P + (m + h^+(t)) / M * (N_o - N_n)$

Phosphorus as PO_4, nitrogen as NO_3 and NH_4, and silica can limit algal growth in lakes, streams, and wetlands. Relatively little is known about the role of nutrient limitation on algal growth in rivers. Low phosphorus is the most common reason for algal growth limitation in other habitats. However, nitrogen and silica can limit growth in other habitats and during specific periods in the year. Nutrient concentrations in rivers are relatively high compared to many other habitats, so it is possible that nutrient concentrations do not affect algal growth rates in large river. However, Stevenson and White (1995) found evidence that nutrient supplies were being reduced in the Kentucky River in some locations where high phytoplankton abundances occurred. Reduction in nutrient concentrations does not mean, however, that nutrient supply has been reduced to a concentration that limits algal growth. Specific nutrient concentrations and effects on algae must be entered into the equation.

Algal growth bioassays will be important in future work to calibrate a model of Kentucky River water quality. These assays can determine responses of different algal species that are present in the Kentucky River to specific changes in nutrient concentrations. Precision in estimates of different species responses to nutrient concentrations will be important for accurate prediction of the water quality model.

Nutrient uptake rate by cells as a function of nutrient concentration is described by a hyperbolic relation in the form of N/(K+N), where K is the half saturation constant. Nitrate uptake is inhibited in the presence of ammonia and has been expressed by Wroblewski (1977) as an exponential reduction factor $e^{-\Psi Nr}$, where $\Psi = 0.02\ \mu M^{-1}$. The uptake of nitrogen is the combination of ammonia and nitrate.

Evans and Parslow (1985) derived a solution for algal specific growth rate as a function of daylength and surface irradiance. This solution was combined with the Droop equation to give an expression for joint nutrient-light limitation. This expression is:

$$\sigma = \mu_m J(1 - Q_o / Q)$$

Where J is the relative growth rate as a function of peak daily surface irradiance and is influenced by day of the year, mixed layer depth, and the phytoplankton concentration.

TABLE 9. COEFICIENTS FOR THE FASHAM MODEL.

Symbol	Meaning	Units	Values
K_n	Half-saturation concentration for nitrate uptake and growth	μM - N	0.5
K_r	Half-saturation concentration for ammonia uptake and growth	μM - N	0.5, 0.05
K_{dn}	Half-saturation concentration for nitrate uptake in Droop formulation	μM - N	2.265
K_{dr}	Half-saturation concentration for ammonia uptake in Droop formulation	μM - N	2.265
K_Q	Minimum cell quota	μM - N cell $^{-1}$	0.24E -6
γ_1	Fraction of phytoplankton growth excreted as DON		.05
μ_{max}	Maximum specific growth rate	day $_{-1}$	2.9
$\mu_{max,D}$	Droop model maximum specific growth rate	day $_{-1}$	3.58
μ_1	Phytoplankton specific mortality rate	day $_{-1}$	0.045, 0.54
ρ_m	Maximum nutrient uptake rate	μM - N cell $^{-1}$ day $^{-1}$	3.6E -6
Ψ	Nitrate inhibition constant	μM $^{-1}$	1.5, 5.59, 0.02

Growth rate may show strong pulses that are associated with changes in the mixed layer deepening. Mortality from zooplankton grazing is the largest contributor to phytoplankton loss.

Little information is available on the nutrient requirements for individual species of benthic algae because the emphasis has been at the community level. Given a substantial change in the concentration of nutrients, it is possible to predict the changes in benthic algae biomass. Phosphorus and nitrogen are considered to be the most common limiting nutrients. Bothwell (1988) showed that 0.3-0.6 ug PO_4-P liter^{-1} saturated the growth rate for benthic diatoms and this is approximately the same order of magnitude for saturation for planktonic diatoms. However, the relationship between nutrient levels and benthic algae community structure is not well understood. A change in nutrient levels usually but not always initiates a change in the community composition.

The nutrient uptake rates (**Table 10**) and growth kinetic parameters (**Table 11**) reported for benthic algae are similar to those for phytoplankton. It is likely that the values depend more on cell size and shape rather than the type of algae.

4.1.2. Growth kinetics relative to temperature.

The effects of temperature on biochemical reactions make it one of the most important environmental factors affecting freshwater periphyton communities. Reduction in the volume of water from a pool can cause a severe fluctuation in the temperature variation of the pool there fore shallow portions of a pool may experience significant diurnal temperature variation. Temperature primarily affects algal photosynthetic metabolism through its control of enzyme reaction rates causing the rate to increase as the temperature increases. Temperature is assumed to set the upper limit for growth rates when all else is optimized. Epply (1972) reported the maximum specific growth rate for phytoplankton as a function of temperature:

$$\mu = 0.851\ (1.066)^{T°C}$$

μ = maximum growth rate in doublings per day

T = temperature in degrees centigrade

Goldman and Carpenter (1974) described the maximum specific growth rate as it relates to temperature with the following function:

$$\mu = (5.35E9)\ e^{(-6.472/T°K)}$$

Although each species has its own temperature optimum for growth, the temperature specific maximum growth rate for a species approaches a theoretical, absolute maximum.

Temperature interacts with nutrient limitation in a complex manner to affect growth by affecting the half-saturation constant in phytoplankton (K_s). In addition, the optimal temperature for nutrient uptake and growth is not the same. As a result, the combined

TABLE 10. NUTRIENT UPTAKE PARAMETERS FOR FRESHWATER BENTHIC ALGAE.

Species	Nutrient	K_s	ρ_{max}	Reference
Spirogyra fluviatilis	PO4	0.3 - 1.5	322 - 803	Borchardt et al. (1994)
Stigeclonium tenue	PO4	3.0	4320	Rosemarin (1982)
Periphytic diatoms	PO4	0.02 - 0.2	408 - 4082	Bothwell (1985)
Cladophora glomerata	PO4	1 - 8.1	167 - 1875	Auer and Canale (1982a)
Cladophora glomerata	PO4	1.0	210	Rosmarin (1982)
Cladophora glomerata	PO4	0.5 - 2.8	62 - 166	Lohman and Priscu (1992)
Cladophora glomerata	NO3	7.3 - 15.2	0 - 984	Lohman and Priscu (1992)
Cladophora glomerata	NH4	17.4 - 41.9	1137 - 6991	Lohman and Priscu (1992)

Ks = μ M atoms nutrient
ρ max = μg atoms nutrient g dry wt^{-1} hr^{-1}

TABLE 11. GROWTH KINETIC PARAMETERS FOR FRESHWATER BENTHIC ALGAE.

Species	Nutrient	Q_o (5)	Maximum u (day $^{-1}$)	Reference
Spirogyra fluviatilus	N	1.41 - 1.81	3.1 - 3.8 (u'max)	Borchardt (1994)
Cladophora glomerata	P	0.06	0.714 (u'max)	Auer and Canale (1982b)
Cladophora glomerata	P	0.4	0.8	Rosemarin (1982)
Stigeoclonium tenue	P	0.3	2.0	Rosemarin (1982)
Spirogyra fluviatilus	P	0.062 - 0.077	2.6 - 2.7 (u'max)	Borchardt (1994)
Periphytic diatoms	P		0.12 - 0.47 (u'max)	Bothwell (1988)

effects of nutrient limitation and temperature stress may be greater than the sum of their individual effects.

4.1.3. Effects of major metals and inorganic compounds on algae.

Concern about the contamination of receiving waters by metals has increased substantially during the last fifteen years. Many metals such as cadmium, copper, lead, and mercury can be toxic to aquatic organisms when present in high concentrations but probably more important, is their negative impact on organisms even at low concentrations. These impacts include effects on growth rates, reproduction, behavior, and general health. Urban stormwater runoff has been shown to contain substantial concentrations of lead, zinc, and other metals (Martin and Smoot, 1986). Metals are associated with particulate matter in the water and bottom materials. Suspended sediments can act as a vehicle to transport metals, pesticides, and other organic compounds in the river.

The U.S. Department of Energy collected the most extensive data on streambed sediments in the Kentucky River Basin for the National Uranium Resource Evaluation Program. The elements aluminum, arsenic, barium, chromium, copper, iron, lead, manganese, zinc showed a significant correlation with the amount of sediments in the study site.

Rai et al. (1981) and Genter (1996) have reviewed effects of inorganic chemical stressors to cellular structure and function for algae. Some of the effects include:

- disruption of enzyme activity and metabolic pathways
- inhibition of photosynthesis
- reduction in the photosynthetic pigments
- changes in the abundances of macromolecules in the cells
- alter life stage and development
- decrease growth rate

4.1.4. Conclusions.

Understanding the effect of nutrients, light, and temperature on algae in the Kentucky River will be important for predicting water quality, especially DO, and effects of management options for protecting the aquatic fauna. In addition, sinking and grazing rates of algae showed be assessed because so little is known these processes in large rivers and they are also important in models of water quality.

4.2. Fish tolerances.

The fish population can be effected in a variety of ways including man-induced and natural causes, such as acute temperature changes (**Table 12**), decomposition of organic

TABLE 12. FISH TEMPERATURE TOLERANCES

Species	Species	Maximum growth temperatures (c°)	Upper thermal tolerance limit (c°)
Black crappie	Pomoxis nigromaculatus	28.3, Neill and Magnuson, 1974	32.5, Brungs and Jones, 1977
Bluegill	Lepomis macrochirus	30.0, Lemke, 1977	37.3, Banner and Vanarmen, 1973
Carp	Cyprinus carpio	31.2, Neill and Magnuson, 1974	36, Meuwis and heuts, 1957
Channel catfish	Ictalurus punctatus	30, Andrews and Stickney, 1972	37.8, Allen and Strawn, 1968
Flathead catfish	Pylodictis olivaris	32.5, Gammon, 1973	NA
Freshwater drum	Aplodinotus grunniens	31.3, Reutter and Herdendorf, 1976	32.8, Cvancara et. al., 1977
Gizzard shad	Dorosoma cepedianum	31.0, Gammon, 1973	36.5, hart, 1952
Golden shiner	Notemigonus crysoleucas	23.8, Cincotta and Stauffer, 1984	34.7, Hart, 1952
Greensunfish	Lepomus cyanellus	30.6, Cherry et. al., 1977	35.4, Boswell, 1967
Largemouth bass	Micropterus salmoides	29, McCormick and Wegner, 1981	36.4, Hart, 1952
Rock bass	Ambloplites rupestris	27.4, Neill and Magnuson, 1974	36, Cherry et. al., 1977
Sauger	Stizostedion cacadense	22.0, Smith and Koenst, 1975	30.4, Smith and Koenst, 1975
Smallmouth bass	Micropterus dolomieui	28.2, Horning and Pearson, 1973	35, Cherry et. al., 1977
Smallmouth buffalo	Ictiobus bubalus	34, Gammon, 1973	NA
Walleye	Stizostedion vitreum	22.0, Smith and Koenst, 1976	31.6, Smith and Koenst, 1976
White bass	Morane chrysops	31.4	33.5, Cvancara, 1977
White crappie	Pomaxis annularis	28.5, Gammon, 1973	32.8, Peterson et. al., 1974
White sucker	Catostamus commersoni	26, McCormick et. al., 1977	30.5, Smith and Koenst, 1982
Yellow perch	Perca flavescens	26.8, McCormick, 1976	33, McCormick, 1976

material, salinity changes, spawning moralities, municipal and industrial wastes, agricultural activities, and water manipulations.

Fish are good indicators of long-term effects and broad habitat conditions because they are relatively long lived and are mobile; therefore, the fish community structure can present an integrated picture of the health of a stream. Ross et al. (1985) and Matthews (1986) found that in general, stream fish assemblages are stable and persistent indicating that large population fluctuations are unlikely to occur due to natural environmental phenomena. Bottom dwelling species that depend upon benthic habitats for feeding and reproduction are particularly sensitive to siltation and benthic oxygen depletion; thus they make good indicators of habitat degradation. The Kentucky River fish community is dominated by species that are considered to be intermediate in their pollution tolerance level and has been dominated by these species for nearly twenty-five years. Presently a significant percentage of the fish population (26.4 %) consists of Gizzard Shad, which are omnivorous, indicating deterioration in the physical and chemical habitat of the river. As the invertebrate food supply diminishes due to habitat deterioration, there has been a shift in community composition from insectivores to omnivores.

4.3. Macroinvertebrate tolerances.

Resh and Rosenberg (1993) devote an entire chapter in their Freshwater Biomonitoring Book to the study of biomonitoring using individual organisms, populations, and species assemblages. Inorganic and organic pollutants effect macroinvertebrates, at the organism-level, in a variety of ways including energy metabolism, enzyme activities, protein content, ion regulation, changes in physiology such as heartbeat and respiration, morphological deformities, behavioral responses, and life history responses.

The presence of these inorganic chemicals in the river will have a negative effect on the assemblages of biota in the river. If the withdrawal of additional water during periods of low flow causes an increase in concentration of these compounds, then the effect on the organisms will be exacerbated. Increased industrial, municipal, and agricultural runoff into the river will likely contribute additional quantities of inorganic chemicals to the river, also increasing the likelihood of negative impacts on the ecosystem.

4.4. Water quality tolerances relative to pesticides.

A NAWQA study from 1987-1990 detected pesticides in the water samples for all three-study years (Haag and Porter, 1995). Diazinon, malathion, and parathion were the most frequently detected organophosphate insecticides. The concentrations of pesticides seldom exceeded the established maximum contaminant levels in the USEPA Drinking Water Health Advisory (USEPA, 1991).

Many organic compounds have a low solubility in water and tend to adsorb to particulate matter. Organochlorine insecticides were detected in the streambed sediments at numerous sites in the basin. Under the right conditions, pesticides that are tied up in the sediments can solubilize thus representing a chronic problem in the water column. Even when the concentration of these compounds is below the detection limit, they can accumulate in the tissue of fish and other organisms to a level that cause adverse impacts on the biota.

A small scale sampling of the Asiatic Clam *Corbicula fluminea* was done in the Elkhorn Creek near Frankfort in April of 1992. The following compounds were detected in the tissue of the clams: DDE, nonachlor, Lindane, and Chlordane. None of these compounds were actually found in the sediments of Elkhorn Creek.

Many of the pesticides detected in the Kentucky River Basin were in counties of the bluegrass, where agricultural land use is dominant. Residential application of pesticides may also contribute to the presence of chemicals such as 2,4-D and diazinon in streams. Concentrations of arsenic, barium, chromium, iron, lead, manganese, nickel, and zinc in streambed sediments of the Kentucky River equaled or exceeded the USEPA's heavily polluted classification (Haag et al., 1995). Total-recoverable concentrations of many of the metals and trace inorganic compounds exceeded water quality criteria at one or more fixed sites in the Kentucky River Basin during 1987-1990. The concentration in the water column of many of these compounds is correlated to streamflow, however, what is of real concern is the resolubilization of metals and the subsequent bio-accumulation by organisms resulting from extended periods of DO depletion during low flow events. Significant upward trends in the total-recoverable concentrations of many metals have been detected at one or more of the fixed stations on the river.

5.0. CONCLUSION

There is little doubt that altering the natural flow regime of rivers and streams affects the integrity of the flowing water system, which depends largely on its natural dynamic character. The natural flow regime plays a critical role in sustaining natural biodiversity in the stream ecosystem. The natural flow regime of the Kentucky River Basin has been critically altered by humans to such an extent that the biological communities of a free flowing river have all but disappeared in the mainstem of the river. Human alterations such as the construction of dams and encroachment into the floodplain as well as land use practices have negatively impacted the natural river ecosystem. Current pressing demands on the Kentucky River and continuing altering of the watershed require scientists to develop management protocols that accommodate economic use and continue to protect ecosystem function (Poff et al., 1997). Managing the study area for individual species is not recommended. Concentrating on establishing a stable watershed, which will benefit the entire biotic community is a desirable outcome.

Water temperature does not appear to present any threat to the organisms in the study area (ESE, 1990). However, according to water quality models dissolved oxygen can be sufficiently low enough for extended periods of time that some organisms could be selectively eliminated from the river. Recolonization of lost organisms from upstream sources is likely to occur during periods of high flow, but the continued stress on the ecosystem from low dissolved oxygen levels during periods of low flow will decrease the diversity and quantity of organisms present. The following are recommendations for operational constraints for dissolved oxygen levels in the mainstem of the river for three groups of aquatic organisms.

Invertebrates:

Species of invertebrates found in the study area that are considered to be indicators of good water quality include *Stenacron interpunctatum, Cheumatopsysches*, *Hydropsyche*, *Neureclipsis*, and *Polycentropus flavomaculatus*. All of these species require a minimum dissolved oxygen concentration of 4.0 mg/l for survival. The state recommends a minimum dissolved oxygen concentration of 5.0 mg/l in rivers and streams for maintaining a healthy aquatic organism population.

Mussels:

Most mussels can tolerate a minimum dissolved oxygen concentration of approximately 4.0 mg/l for extended periods of time. It appears that the mussels found in the study area inhabit the mid-depth region of the river immediately adjacent to the channel bottom where D.O. concentrations were 6.0 mg/l.

Fish:

The USEPA has set a minimum of 5.0 mg/l D.O. to maintain healthy fish populations in watercourses. Acute D.O. values for most adult fish range from 1.0 – 3.0 mg/l depending on exposure duration, species, age, and water temperature. The embryonic and larval stages of fish are even more sensitive than adults requiring a minimum D.O. range between 3.0 – 6.0 mg/l for survival.

It is recommended that a minimum D.O. concentration of 4.0 – 5.0 mg/l is maintained throughout the entire water column at all time to ensure a healthy, diverse, and sustainable biotic community. Intensive research will be required to determine if concentrations below this recommended will have an effect on particular species in the river. The duration of exposure to low dissolved concentrations is another question that requires further investigation. Low dissolved oxygen concentrations are not only a threat to the survival fish, but can also impact behavior, reproduction success, and general fitness of the organism. Over time, chronic exposure to moderately low D.O. concentrations can be just as lethal as acute exposure to extremely low D.O. concentrations.

There are some headwater streams of the Kentucky River that have remained relatively pristine over time. It is vitally important to protect these resources for their biodiversity of organisms, which can provide a source for recolonization downstream. To protect these systems, we must preserve the natural hydrological cycle by safeguarding against upstream river development and damaging land uses that modify runoff and sediment supply to the river. Any additional significant alteration to the existing flow regime of the Kentucky River will continue to compound the negative impact on the biota of the system.

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