HYDROPOWER STACKING

Prepared by:

U.S. Environmental Protection Agency
Region 3
Philadelphia, Pennsylvania

With the assistance of:

WAPORA, Inc.
Cincinnati, Ohio

Gary R. Finni, Ph.D.
Principal Biologist

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1.0 INTRODUCTION

The Ohio River, one of the Midwest's largest rivers, is formed in Pittsburgh, Pennsylvania, by the confluence of the Allegheny and Monongahela Rivers. From Pittsburgh, the Ohio River flows generally southwest for 981 miles to its mouth at the Mississippi River near Cairo, Illinois. The first 40 miles lie wholly within Pennsylvania; for the remainder of its length, the Ohio River forms the boundary between Ohio, Indiana, and Illinois to the north, and West Virginia and Kentucky to the south. The Ohio drains an area of 203,900 square miles of which approximately 95 percent of this area is drained by tributary streams. The drainage area of the Ohio at its head in Pittsburgh is 19,164 square miles of which the Monongahela and Allegheny Rivers drain 7,386 and 11,778 square miles, respectively. Over 20 million people reside within the basin and eight million reside in areas which drain directly to the mainstem. The largest metropolitan centers along the Ohio River include Pittsburgh, Pennsylvania, Cincinnati, Ohio, and Louisville, Kentucky (Ohio River Valley Water Sanitation Commission [ORSANCO] 1984; U.S. Army Corps of Engineers [COE] 1975).

Waters of the Ohio River and its major tributaries are used for power generation, public water supply, industrial supply, fish and wildlife habitat, recreation, and navigation. Electric power is generated throughout the basin primarily through the burning of coal, with the river used as a source of cooling water. Along the Ohio River, there are 51 intakes for potable water supply, of which 34 provide water to public or private utilities which serve over three million people. Over 100 industries use the Ohio River as a source of process water. The Ohio and its major tributaries support a variety of warm water fish species important both to the sport and commercial catch. In addition to sport fishing, recreational uses include boating, water-skiing, and swimming. Commercial navigation is maintained along the Ohio River by a series of 20 locks and dams that are operated by the COE. These dams maintain a nine foot navigation channel. Additional locks and dams along the Allegheny and Monongahela Rivers permit commercial navigation to reach the coal fields in West Virginia and Pennsylvania (ORSANCO 1984; Leuthart and Spencer 1979; West Virginia Department of Natural Resources 1983; COE 1975, 1982).

Within the recent past, renewed interest has been kindled in developing the hydropower potential that currently exists at low-head dams along many water courses in the United States. The Federal Energy Regulatory Commission (FERC) reviews permit applications submitted by federal agencies, utilities, municipalities, and others in the private sector (licensees). Prior to receiving their permit to construct, the licensee must prepare an environmental assessment which accompanies the license application. The environmental assessment addresses the following items: (1) general description of locale; (2) water use and quality; (3) fish, wildlife, and botanical resources; (4) historic and archaeological resources; (5) socioeconomic impacts; (6) geological and soil resources; (7) recreational resources; (8) aesthetic resources; (9) land use; and (10) alternative locations, designs, and energy sources. However, these assessments, although complete for a particular hydrosite, do not include an evaluation of the cumulative impacts of hydropower "stacking" within a watershed. Such impacts could be significant in the future as increasing numbers of dams are fitted with electric generating turbines.

Such is the case regarding hydropower development at low-head dams along the mainstem of the Ohio River and its major tributaries, the Allegheny and Monongahela Rivers. License applications are pending for all dams along each of these rivers. From their inception, low-head dams along the Ohio River and its tributaries were constructed to maintain a pool suitable for navigation. During high temperature, low flow conditions of late summer, gates on existing dams are operated by the COE so as to provide downstream reaeration. However, since each dam is a candidate site for hydropower development, a potential exists for downstream alterations in water quality. Each hydroproject proposed for the Allegheny, Monongahela, and Ohio Rivers will be operated as a "run-of-the-river" facility, and under low flow conditions of late summer and early autumn, each will have a high water demand. Without the benefit of reaeration that normally occurs as water passes over the dam or through the gates, the potential exists for water with low dissolved oxygen to pass from upstream pools downstream. As increasing numbers of dams are converted for hydropower production, there is also a potential for cumulative impacts on oxygen levels to occur, as the oxygen deficit continually increases. Thermal

regimes of navigation pools may be altered as well, for the turbines will draw and pass cooler bottom water and reduce mixing currently occurring as water passes over dams.

This study was undertaken to identify and describe the cumulative impacts of hydropower facility "stacking" on water quality and fishery resources of the upper Ohio River Basin (Figure 1-1). The project area includes a 40 mile segment of the mainstem Ohio River and the downstream 15 miles of the Allegheny and the Monongahela Rivers (Figure 1-2). The objectives of the study are: (1) to define the existing aquatic biological resources and water quality conditions in the study area, and (2) to utilize mathematical modeling procedures to predict the potential impacts of hydropower stacking on water quality and aquatic biological resources.

Chapter 2.0 describes the methodogies employed in the study. These include preparing a literature review of baseline water quality conditions and biological features, and conducting the water quality modeling. Chapter 2.0 also includes a description of how the results of the water quality modeling were used to predict impacts on biological resources. Chapter 3.0 describes the results of the literature review and water quality modeling. Chapter 4.0 will address potential impacts, and Chapters 5.0 and 6.0 provide the conclusions and recommendations.

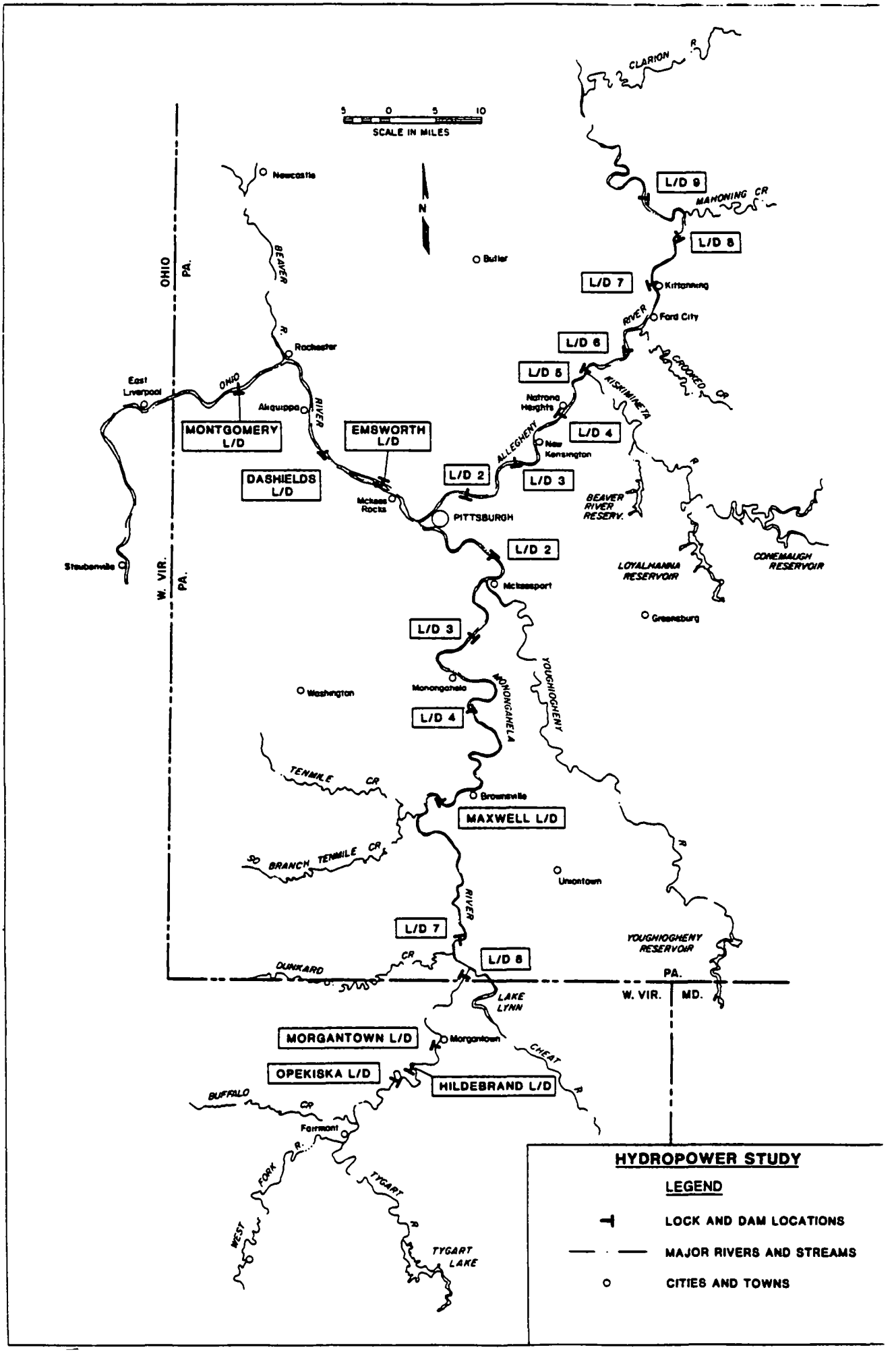


Figure 1-1. Lock and dam locations along the Allegheny, Monongahela, and upper Ohio Rivers.

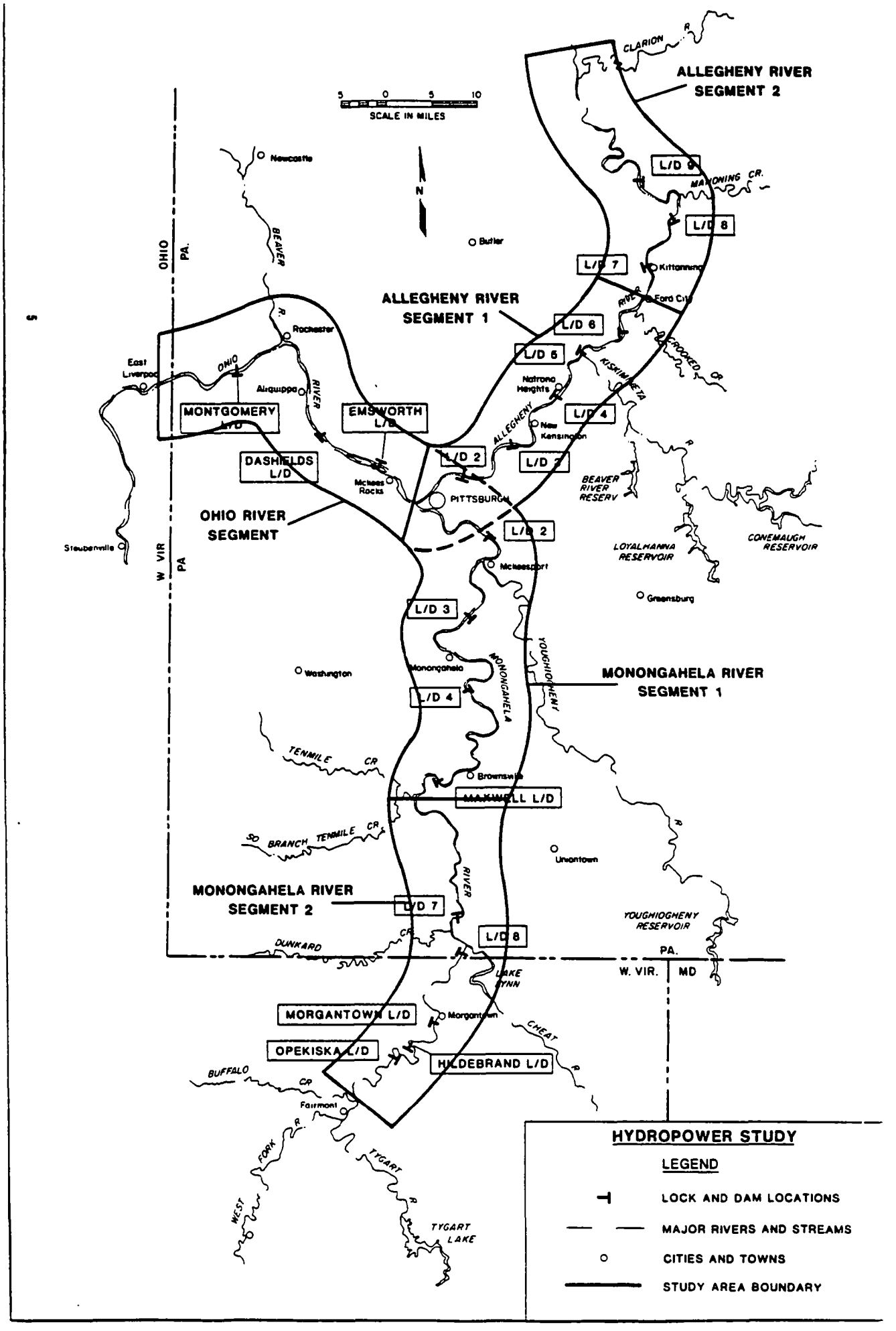


Figure 1-2. Delineation of study area.

2.0 METHODS

2.1 EXISTING WATER QUALITY CONDITIONS

2.1.1 Summary of Available Data

Water quality in the study area has been evaluated by, among others, ORSANCO and the Corps of Engineers. Water quality data were obtained for this study in the form of the: (1) bi-yearly water quality reports published by ORSANCO, describing the results of the member sampling; (2) U.S. Army Corps of Engineers sampling program (AURAS) in conjunction with operation of the locks and dams along the three rivers; and (3) STORET listings of all data from the study area. Table 2-1 lists the stations monitored, the types of data available, and the source from which the information was available for each river. All data were screened using three criteria--how recent, how complete, and how comprehensive the data were--to select those data sets to be used for water quality modeling. The data selected to calibrate the QUAL II Model were the 11 July 1983 data for the Ohio River; the 28 July 1983 data for the Allegheny River; and the 26 August 1983 data for the Monongahela River. The water quality data selected to verify the accuracy of the calibrated model were the 1 August 1983 data for the Ohio River; the 23 July 1981 data for the Allegheny River; and the 24 July 1980 data for the Monongahela River. The dissolved oxygen data from the entire COE data base (years 1976 to 1983) were used for evaluating reaeration across the locks and dams. These data are included in the discussion of dam reaeration.

2.1.2 Overview of Water Quality

Water Quality - Long Term. Prior to development in the watershed, the upper Ohio River was reported to be a clear running stream with a rocky, sandy bottom. The impact of early development was related primarily to runoff from land disturbing activities, with sediment loads from tributaries being a major source. Point source loads became significant with industrial and urban development in the watershed. In conjunction with

Table 2-1. Water quality data available for the study area.

Location	Source:	Period - Description
Allegheny River (RM from confluence with Ohio River)		
RM 14.7	COE:	8/26/76, 6/30/77, 7/20/77, 8/10/78, 7/12/79, 7/23/81, 7/19/82, 7/22/82, 7/28/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	7/79, 7/81, 7/82, 7/83 - algal data
RM 14.3	COE:	8/26/76, 6/30/77, 7/20/77, 8/10/78, 7/12/79, 7/23/81, 7/19/82, 7/22/82, 7/28/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	7/79, 7/81, 7/83 - algal data
RM 13.3	ORSANCO:	1978-1983 electronic and manual sampling
RM 12.8	COE:	8/26/76, 6/30/77, 7/21/77, 7/29/77, 8/2/77, 8/3/77, 8/10/78, 7/12/79, 7/23/81, 7/22/82, 7/28/83, 9/15/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
RM 9.5	COE:	8/26/76, 6/30/77, 8/10/78, 7/12/79, 7/23/81, 7/22/82, 7/28/83 - temperature, DO, pH
RM 8.8	ORSANCO:	1978-1981 water user
RM 7.4	ORSANCO:	1982-1983 organics data
RM 6.9	COE:	8/26/76, 6/30/77, 7/20/77, 7/29/77, 8/10/78, 7/13/79, 7/23/81, 7/19/82, 7/22/82, 7/28/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	6/77, 8/78, 7/79, 7/81, 7/82, 7/83 - algal data
RM 6.5	COE:	8/26/76, 6/30/77, 7/20/77, 8/10/78, 7/13/79, 7/23/81, 7/19/82, 7/11/82, 7/28/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	6/77, 8/78, 7/79, 7/81, 7/82, 7/83 - algal data
RM 3.2	COE:	8/26/76, 7/1/77, 8/10/78, 7/13/79, 7/23/81, 7/22/82, 7/28/83 - temperature, DO, pH

Table 2-1. (continued)

Location	Source:	Period - Description
Allegheny River (RM from confluence with Ohio River) (cont.)		
RM 0.8	COE:	8/1/75, 9/22/75, 8/26/76, 8/30/76, 6/6/77, 7/1/77, 7/20/77, 6/23/78, 7/28/78, 8/10/78, 6/29/79, 7/13/79, 8/13/79, 8/16/79, 7/25/80, 7/24/81, 7/22/82, 8/2/82, 7/11/83, 7/28/83, 8/1/83, 8/26/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	6/78, 8/78, 6/79, 7/79, 8/79, 7/81, 7/82, 8/82, 7/83, 8/83, 7/84 - algal data
Monongahela River (RM from confluence with Ohio River)		
RM 15.1	COE:	7/31/75, 6/22/78, 6/28/79, 7/24/80, 8/25/83 - temperature, DO, pH
RM 11.3	COE:	7/31/75, 6/23/78, 6/28/79, 7/24/80, 8/26/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	6/78, 6/79, 7/80, 8/83, 7/84 - algal data
RM 11.2	STORET:	1975-1978
RM 11.0	COE:	7/31/75, 6/23/78, 6/28/79, 7/24/80, 8/26/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	6/78, 6/79, 7/80, 8/83, 7/84 - algal data
RM 4.5	ORSANCO:	1978-1983 electronic and manual sampling
RM 0.8	COE:	8/1/75, 9/22/75, 8/1/75, 9/22/75, 8/27/76, 8/30/76, 6/6/77, 7/1/77, 7/20/77, 9/2/77, 6/23/78, 7/24/78, 8/10/78, 6/29/79, 7/13/79, 8/13/79, 7/25/80, 7/24/81, 7/22/82, 8/2/82, 7/11/83, 7/28/83, 8/1/83, 8/26/83
	COE:	7/77, 6/78, 8/78, 6/79, 7/79, 8/79, 7/80, 7/81, 8/82, 7/83, 8/83, 7/84 - algal data
Ohio River (RM from confluence with Allegheny and Monongahela Rivers)		
RM 1.0	COE:	8/1/75, 8/27/76, 8/30/76, 6/6/77, 7/1/77, 7/20/77, 6/23/78, 7/24/78, 8/10/78, 6/29/79, 7/13/79, 8/13/79, 7/25/80, 7/24/81, 7/22/82,

Table 2-1. (continued)

Location	Source:	Period - Description
Ohio River (RM from confluence with Allegheny and Monongahela) (cont.)		
RM 1.0	COE:	8/2/82, 7/11/83, 7/28/83, 8/1/83, 8/26/83 - temperature, DO, pH
	COE:	7/82 - algal data
RM 2.0	COE:	6/6/77, 7/24/78, 7/11/83, 8/1/83 - temperature, DO, pH
RM 3.0	COE:	6/6/77, 7/24/78, 8/2/82, 7/11/83, 8/1/83 - temperature, DO, pH
RM 4.0	COE:	6/6/77, 7/24/78, 8/2/82, 7/11/83, 8/1/83 - temperature, DO, pH
RM 4.5	ORSANCO:	1982-1983 organics data
RM 5.0	COE:	6/6/77, 7/24/78, 8/13/79, 8/2/82, 8/1/83 - temperature, DO, pH
RM 6.0	COE:	9/22/75, 6/6/77, 7/24/78, 8/13/79, 8/2/82, 7/11/83, 8/1/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	7/78, 8/79, 8/82, 7/83 - algal data
RM 6.4	COE:	9/22/75, 6/6/77, 6/24/77,7/24/78, 8/13/79, 8/2/82, 7/11/83, 8/1/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	7/78, 8/79, 8/82, 7/83 - algal data
RM 7.0	COE:	6/6/77, 7/24/78, 8/2/82, 7/11/83, 8/1/83 - temperature, DO, pH
RM 9.6	COE:	7/24/78, 8/13/79, 8/2/82, 7/11/83, 8/1/83 - temperature, DO, pH
RM 13.0	COE:	9/22/75, 6/6/77, 7/24/78, 8/13/79, 8/2/82, 7/11/83, 8/1/83 - temperature, DO, pH, NH_3, TKN, NO_3
	COE:	6/77, 8/79, 8/82, 7/83 - algal data

Table 2-1. (continued)

Location	Source:	Period - Description
Ohio River (RM from confluence with Allegheny and Monongahela) (cont.)		
RM 13.5	COE:	9/22/75, 6/6/77, 7/24/78 -b temperature, DO, pH
	COE:	8/13/79, 8/2/82, 7/11/83, 8/1/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
	COE:	8/79, 8/82, 7/83
RM 15.8	ORSANCO:	1978-1983 electronic and manual sampling
RM 17.0	COE:	7/24/78, 8/13/79, 8/2/82, 7/11/83, 8/1/83 -b temperature, DO, pH
RM 23.5	COE:	9/22/75, 6/6/77, 7/24/78, 8/13/79, 8/2/82, 7/11/83/ 8/1/83 - temperature, DO, pH
RM 28.1	COE:	6/6/77, 7/24/78, 8/14/79, 8/3/82, 7/11/83 - temperature, DO, pH
RM 31.3	COE:	9/23/75, 6/7/77, 7/25/78, 8/14/79, 8/3/82, 7/12/83, 8/2/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
RM 32.0	COE:	9/23/75, 6/7/77, 7/25/78 - temperature, DO, pH
	COE:	8/14/79, 8/2/82, 7/12/83, 8/2/83 - temperature, DO, pH, NH_3, TKN, NO_3, T-P
RM 33.1	COE:	6/7/77, 7/25/78, 8/14/79, 8/3/82, 7/12/83, 8/2/83 - temperature, DO, pH
RM 38.0	COE:	7/12/83, 8/2/83 - temperature, DO, pH
RM 40.2	ORSANCO:	1978-1983 electronic and manual sampling
RM 40.3	COE:	6/7/77, 7/25/78, 8/14/79, 8/3/82, 7/12/83, 8/2/83 - temperature, DO, pH

Table 2-1. (continued)

References:

COE 1. U.S. Army Corps of Engineers, Pittsburgh District, Auras Raw Data Report for Water Quality, 9 October 1984

COE 2. U.S. Army Corps of Engineers, Pittsburgh District

STORET: Water quality data retrieval

ORSANCO: 1980, 1982, 1984

these changes, the development of navigation dams along the upper Ohio altered the velocity profile in the river.

These general factors led to a degraded water quality condition in the upper Ohio River in the late 1950's and 1960's. The passage of PL 92-500, with the emphasis on uniform effluent limited point source controls for municipal and industrial discharges, resulted in a high level of point source control. Historical water quality trends have been analyzed by ORSANCO starting in 1977 (ORSANCO 1980). These analyses show that since 1961, pH and D.O. in the upper river have been improving in terms of meeting recommended criteria. Trends show improvement for 1964-1975 for chlorides, hardness, sulfate, and turbidity. Problems were still increasing through 1979 for mercury and fecal coliform bacteria.

Present Water Quality. The range in water quality parameter values for the data sets used in modeling are summarized in Table 2-2. These data reflect generally good water quality and are consistent with the long term results reported by ORSANCO (ORSANCO 1980, 1982, 1984). In particular, the dissolved oxygen levels in the river in the study area are near the saturation limit, generally greater than 80 percent of the saturation level. At several stations, a low dissolved oxygen was measured near bottom, possibly indicating a local area of stratification. However, the data almost always exhibited a uniform temperature and dissolved oxygen distribution at each station, although the surface sample often was slightly higher in temperature and dissolved oxygen than the remaining water column samples.

2.1.3 Stream Flows

It was considered that critical conditions for dissolved oxygen would be the July to September period, where low flow and high temperatures are common. Flow records for the past several years for these months were reviewed to identify the approximate critical conditions. The data reviewed included reports by ORSANCO (ORSANCO 1980, 1982, 1984), the gage data at several locations (Monongahela at Braddock, PA; Allegheny River at New Kensington, PA; Ohio River at Sewickley, PA; and Beaver River at Beaver

Table 2-2. Range of water quality conditions in the study area rivers.

Location	Period	Temperature °C	D.O. mg/l	NH_3 mg/l	TKN mg/l	NO_3-NO_2 mg/l	Total-P µg/l	Chlorophyll a µg/l
Allegheny River								
RM 14.7	7/28/83	26.7-30.3	7.0-7.1	<0.1-0.2	0.6-0.8	1.0-16.7	10-20	3.8-4.0
(ACP 1002)	7/22/82	26.9-30.9	6.5-6.9	0.1-0.2	0.2-0.3	0.3-0.4	<10	5.6
	7/23/81	25.1-25.9	6.8	<0.1-0.1	0.2-0.4	0.4-0.8	<10	1.8
RM 14.3	7/28/83	28.1-28.3	7.7-7.8	<0.1	0.4	0.3	<10	4.2
(ACP 1201)	7/22/82	28.0-28.3	7.0-7.7	0.1-0.2	0.2	0.3-0.4	<10	--
	7/23/81	25.4-25.6	7.6	<0.1	0.3	0.4	<10	0.9
RM 6.9	7/28/83	27.9-28.1	7.6-8.0	<0.1-0.1	0.5-0.6	0.4	10-20	5.5-6.0
SHP 1002)	7/22/82	27.9-28.6	7.0-7.3	0.1	0.2	0.4	<10	5.6
	7/23/81	25.2-25.3	7.3	<0.1	<0.1	0.5	<10	1.6
RM 6.5	7/28/83	27.9-28.0	7.98	<0.1	0.6	0.4	20	6.1
(SHP 1201)	7/22/82	27.9-28.0	7.6-7.8	0.1	0.2	0.4	<10	4.5
	7/23/81	25.3	8.3-8.4	<0.1	<0.1	0.6	<10	1.5
RM 0.8	7/28/83	27.4-27.8	7.7-8.8	<0.1	0.3	0.4	<10	6.7
(ALC 3001)	7/22/82	27.7-28.1	7.1-7.4	0.1-0.2	0.2-0.3	0.4	<10	7.0-7.2
	7/24/81	25.1	7.8-8.0	0.1	0.3	0.5	<10	1.8
Monongahela River								
RM 11.3	8/26/83	28.4-28.6	6.0-6.7	<0.1	0.7	1.1	<10	13.2
(BDP 1002)	7/24/80	24.2-24.7	7.0-7.3	0.1	0.5	1.1	70	--
	6/28/79	24.2-25.9	7.1-7.6	0.3	0.3	0.8-0.9	30-40	--
RM 11.0	8/26/83	28.7-29.1	6.5-6.6	<0.1	0.6	1.2	<10	14.0
(BDP 1201)	7/24/80	24.2-24.3	7.2-7.8	0.1	0.5	1.1	110	--
	6/28/79	26.8-27.0	7.3-7.4	0.4	0.4	0.9	30	--
RM 0.8	8/26/83	28.6-28.8	5.6-6.9	0.3	0.6	1.1	<10	14.2
(MDN 3001)	7/25/80	24.4-24.5	6.1-6.6	0.2	0.7	1.4	70	--
	6/29/79	25.2-25.5	6.2-6.4	2.2-2.8	2.8	1.2	30	--

Table 2-2. (continued)

Location	Period	Temperature °C	D.O. mg/l	NH_3 mg/l	TKN mg/l	NO_3-NO_2 mg/l	Total-P µg/l	Chlorophyll a µg/l
Ohio River								
RM 1.0	8/1/83	26.4-28.0	6.7-7.5	0.1	0.6	<0.1	<10	--
(EMP 1012)	7/11/83	24.6-24.7	8.2-9.0	--	--	--	--	--
	8/2/82	25.0-25.5	6.9-7.4	0.3	0.8	0.7	<10	--
RM 6.0	8/1/83	27.6-27.8	6.8-7.2	0.2	0.8-0.9	<0.1	<10	8.4
(EMP 1002)	7/11/83	24.1-24.4	7.1-8.2	0.2	0.6	0.7-0.8	20	9.3-9.7
	8/2/82	25.3-25.6	6.8-7.1	0.4-0.6	1.1-1.2	0.6	<10	8.2-8.4
RM 6.4	8/1/83	27.7	7.7-8.0	0.3	0.8	<0.1	10	10.2
(EMP 1201)	7/11/83	24.3-24.4	8.1-8.8	0.2	0.5	0.7	20	9.3
	8/2/82	25.4-25.5	6.7-7.0	0.3	1.0	0.6	<10	8.2
RM 13.0	8/1/83	27.5-27.6	7.1-7.7	0.2-0.3	0.6	0.6-0.7	10	--
(DDP 1002)	7/11/83	24.5-26.0	7.3-8.5	<0.1-0.1	0.5	0.7	<10-10	2.1-13.2
	8/2/82	25.2-25.9	6.6-7.2	0.2	0.7-0.9	0.6	<10	8.1
RM 13.5	8/1/83	27.6	8.5-8.7	0.5	0.5	<0.1	10	--
(DDP 1201)	7/11/83	24.9-25.2	8.0-8.2	0.1	0.4	0.7	20	11.6
	8/2/82	25.3-25.5	7.2-7.5	0.2	0.8	0.6	<10	8.4
RM 31.3	8/2/83	27.1-27.2	7.0-7.6	0.5	0.7-0.8	0.3	10-80	14.7
(MDP 1002)	7/12/83	24.6-24.9	7.1-8.4	0.3	0.7-0.8	1.0	<10-10	10.6-12.8
	8/3/82	26.1-26.2	3.4-7.8	0.2	0.7	0.7	<10	14.8
RM 32.0	8/2/83	27.3	8.4-8.7	0.4	0.8	0.3	10	11.1
(MDP 1201)	7/12/83	24.8-24.9	8.2-8.7	0.3	0.7	1.0	20	10.8
	8/2/82	26.1-26.2	5.2-8.8	0.2	0.8	0.7	<10	--
RM 40.3	8/2/83	27.3-27.4	8.0-8.5	--	--	--	--	--
	7/12/83	24.8-25.1	8.2-8.9	--	--	--	--	--
	8/3/82	26.1-26.2	5.0-8.2	--	--	--	--	--

Falls, PA), and FERC applications for Montgomery Island Lock and Dam (L/D), Emsworth L/D, and Dashields L/D (C.E. Maguire 1983a, 1983b; C.T. Main 1984). The development of flows at specific recurrence intervals was not included in this study. Rather, the stream flows for the impact modeling were selected to evaluate the typical condition (i.e., the long term monthly average, LTMA) and the expected worst case situation (i.e., lowest flow expected, LFE). The LTMA was developed for the Ohio River and Allegheny River using the information in the ORSANCO reports, with a flow balance used to estimate the flow for the Monongahela River headwater. The LFE was developed in a similar manner using the conditions observed in September 1983. These data are presented in Table 2-3.

2.2 WATER QUALITY MODELING

Subsequent to reviewing the existing data base, initial values for the QUAL II model parameters were selected. Calibration involved selecting the most complete data set to serve as a target and adjusting model parameters to reflect these data. This included: (1) estimating headwater conditions; (2) estimating point source loads to be consistent with in-stream pollutant levels; (3) developing hydraulic conditions; and (4) identifying target levels for model predictions (mainly dissolved oxygen, but also including BOD, ammonia, and chlorophyll a). Once the predictions matched the observed condition reasonably well, a new set of modeling conditions was established to verify the model calibration. The model was run using the parameters as adjusted during calibration and the conditions of the verification data set. The predicted dissolved oxygen values were compared to the observed values for the calibration and verification to determine the relative accuracy of the individual runs.

During the calibration/verification of the model, a series of runs were performed under several hydropower development scenarios. These runs were used to develop the range of water quality impacts expected due to development of each lock and dam as well as the cumulative impacts of complete development.

Table 2-3. Stream flows used for the hydropower impact analysis.

Location	Long Term Monthly Average Flow (cfs)	Lowest Flow Expected (cfs)
(1) HW Allegheny River	4,730 (a)	1,890 (c)
(2) HW Monongahela River	3,990 (c)	1,440 (d)
(3) Confluence/HW Ohio	8,720 (a)	3,330 (d)
(4) ALCOSAN WWTF	300 (b)	300 (b)
(5) Beaver River	1,410 (a)	670 (d)
(6) DS Ohio	10,430 (c)	4,300 (c)

(a) Based on data by ORSANCO
(b) Based on permit limitation
(c) Computed by flow balance: (1) + (2) = (3); (3) + (4) + (5) = (6)
(d) Based on lowest flow observed September 1983

2.2.1 Model Selection, Parameter Selection, and Model Set-up

The water quality model selected was the Vermont version of the QUAL II model (WAPORA 1984a). This is a steady-state, one dimensional model that uses the classical Streeter-Phelps approach for carbonaceous BOD oxidation, ammonia oxidation, and reaeration. In addition, the model will predict the level of algal activity in the water body, including photosynthetic activity and respiration demand. The model includes the capability to predict reaeration at dams at various levels of flow. This capability was used in the modeling effort to simulate various levels of hydropower diversion of water through the turbine. A major disadvantage with QUAL II is that it requires a great amount of data for proper calibration and verification. In this study, the existing water quality data were quite extensive, allowing a fairly good basis for using the QUAL II model.

The QUAL II model simulates the river as a series of reaches, each reach selected to represent areas of similar hydraulic and hydrologic features. The reaches are subdivided into a number of computational elements, each representing a length of stream to which the model equations are applied. The physical layout of the rivers including model reaches is presented in Figures 1-2 and 2-1. The computational element length selected was 0.2 mile. This resulted in a model with 350 computational elements (75 each for the Allegheny and Monongahela Rivers, and 200 for the Ohio River). Each of the six locks and dams in the study area was therefore defined as a reach of 0.2 mile length (i.e., one computational element), which provided very good definition of the influence of the dams on water quality.

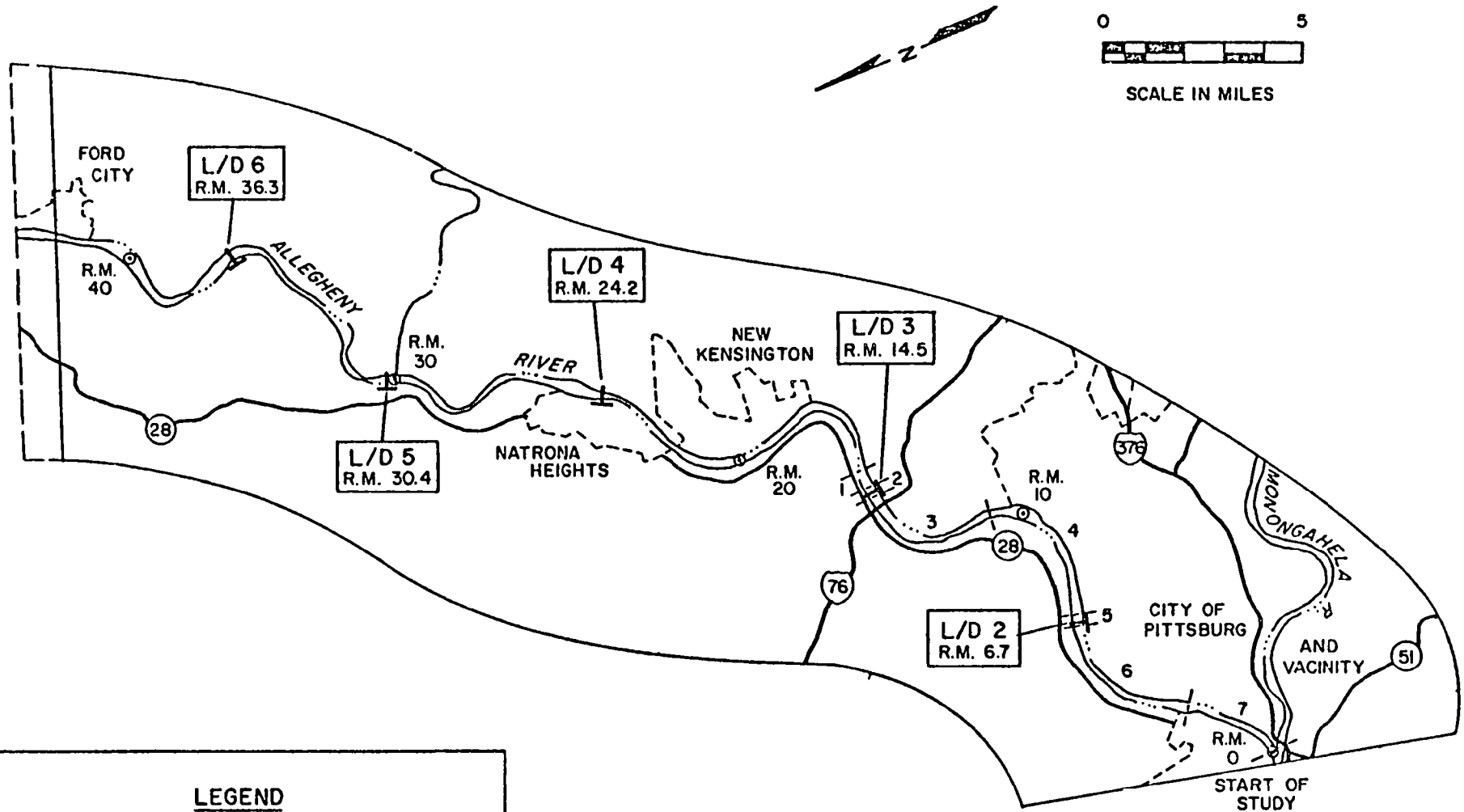
The point source discharges to the river were reviewed to determine those that should be included in the model. The factors considered were a flow greater than 10 mgd, and high BOD or ammonia levels. The point source characteristics data were obtained from USEPA and from conversations with dischargers (Gearing,personal communication). The sources that met these criteria are listed in Table 2-4. Based on the load from these sources, only the ALCOSAN source (Allegheny County Sanitation Authority) was included in the model setup. The discharges from the three Duquesne power plants were considered to not represent a major organic load on the river.

Table 2-4. Discharge monitoring report data for the five major point sources in the study area.

Facility	Average[a] Flow (mgd)	Average[a] BOD_5 (mg/l)	Average[a] NH_3 (mg/l)
ALCOSAN	156.8	13	6.6[b]
Duquesne Mifflin	250	NA	NA
Duquesne Light Co.	229.6	NA	NA
Duquesne Light Co. Cheswick	317	NA	NA
Neville Coke & Iron	13.5	NA	3.05

[a]Source October 1984 discharge monitoring report.

[b]Calculated based on observed BOD_5 average, BOD_u and percent nitrogenous demand input to model.



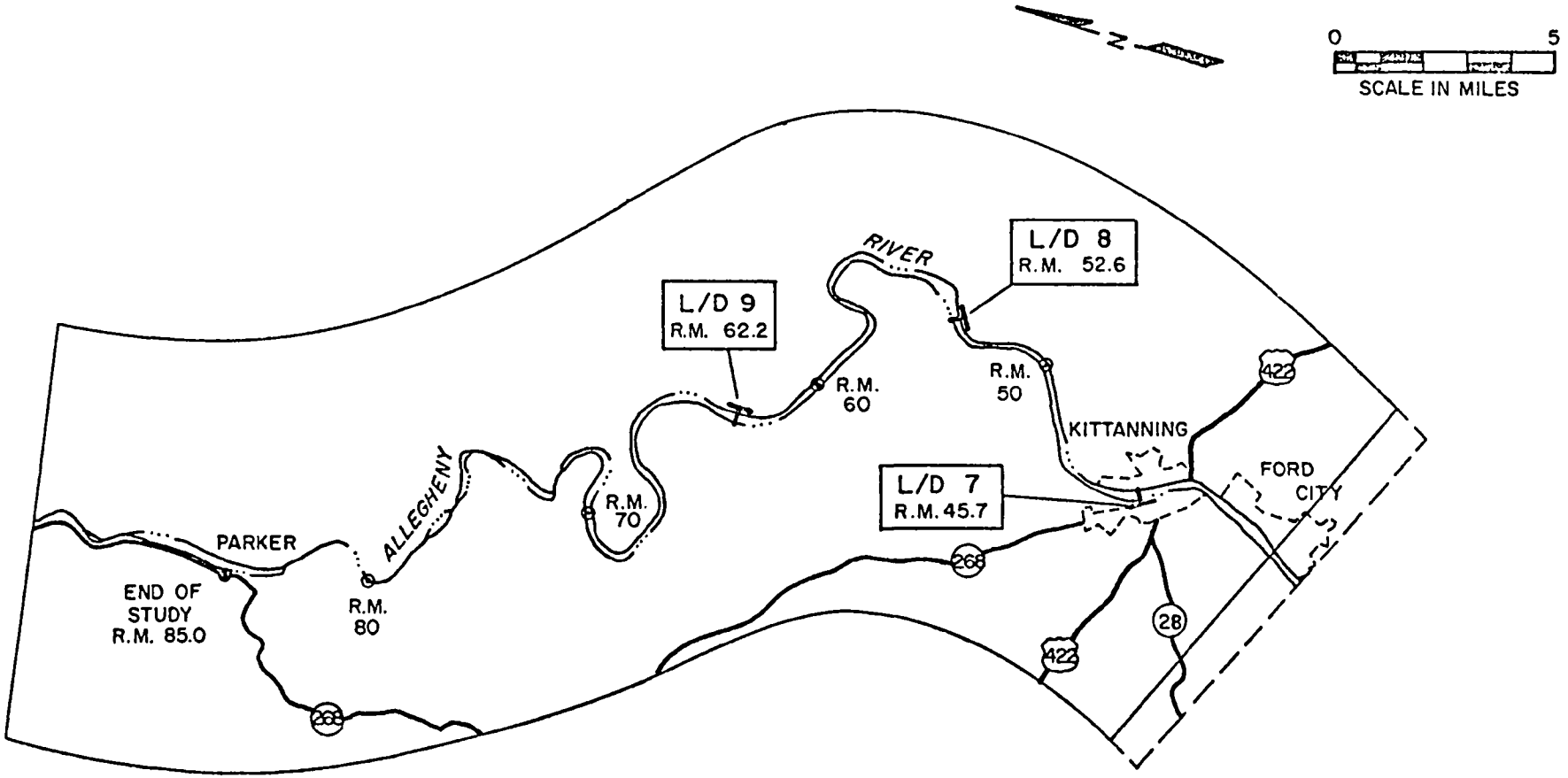
LEGEND

⊣	LOCK AND DAM LOCATIONS
⊙ R.M.	RIVER MILE POINTS
———	STUDY AREA BOUNDARY
—— ··· ——	RIVERS, STREAMS
- - - - - -	URBAN AREA BOUNDARIES
○—○—○	MAJOR HIGHWAYS
—3—	STUDY REACHES

Figure 2-1. Study area reaches.

HYDROPOWER STUDY

ALLEGHENY RIVER - SEGMENT 1



LEGEND

⊣	LOCK AND DAM LOCATIONS
⊙ R.M.	RIVER MILE POINTS
———	STUDY AREA BOUNDARY
—— ··· ——	RIVERS, STREAMS
- - - - - - - -	URBAN AREA BOUNDARIES
-○-○-○-	MAJOR HIGHWAYS

Figure 2-1. (continued)

HYDROPOWER STUDY

ALLEGHENY RIVER - SEGMENT 2

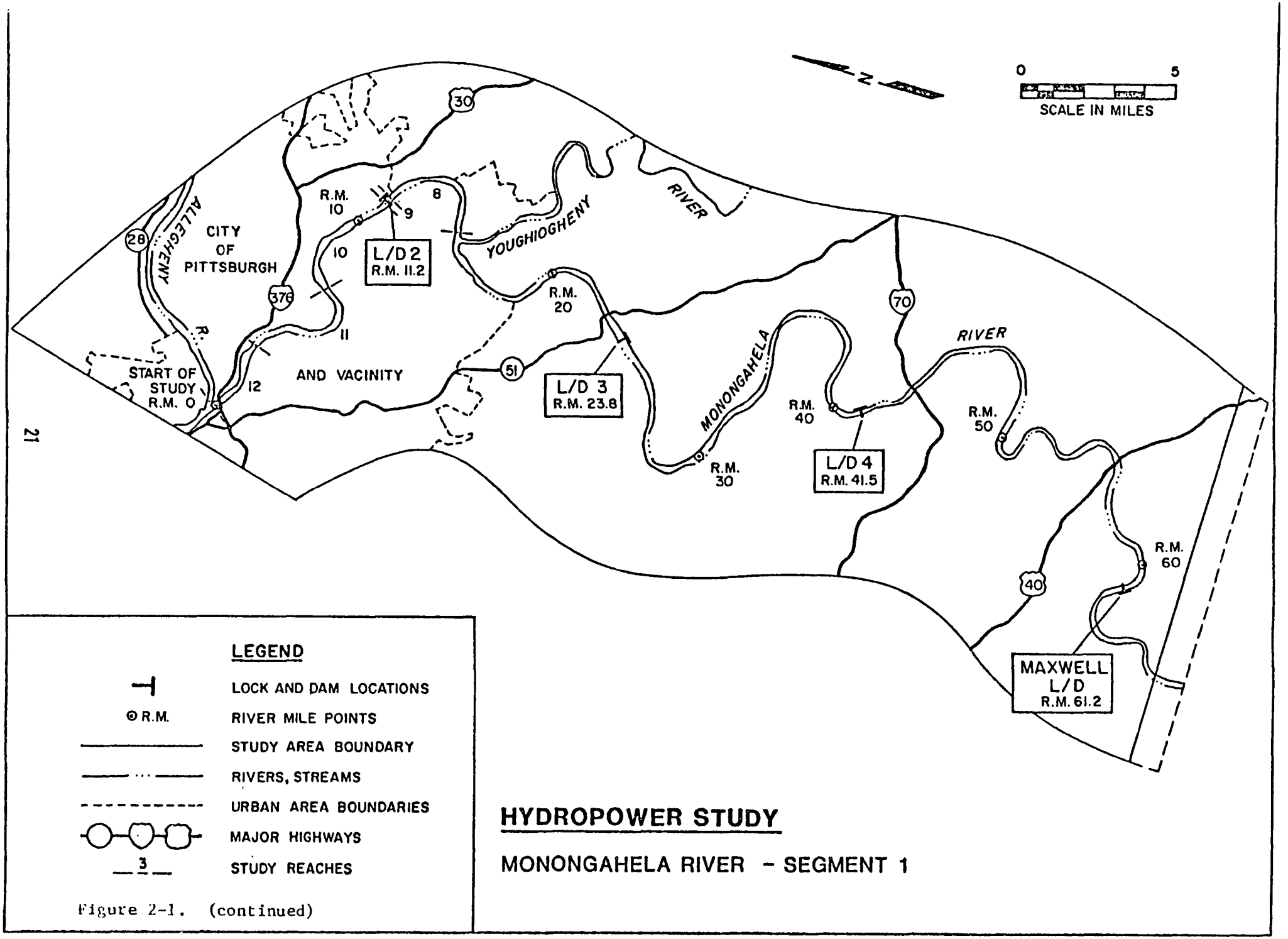
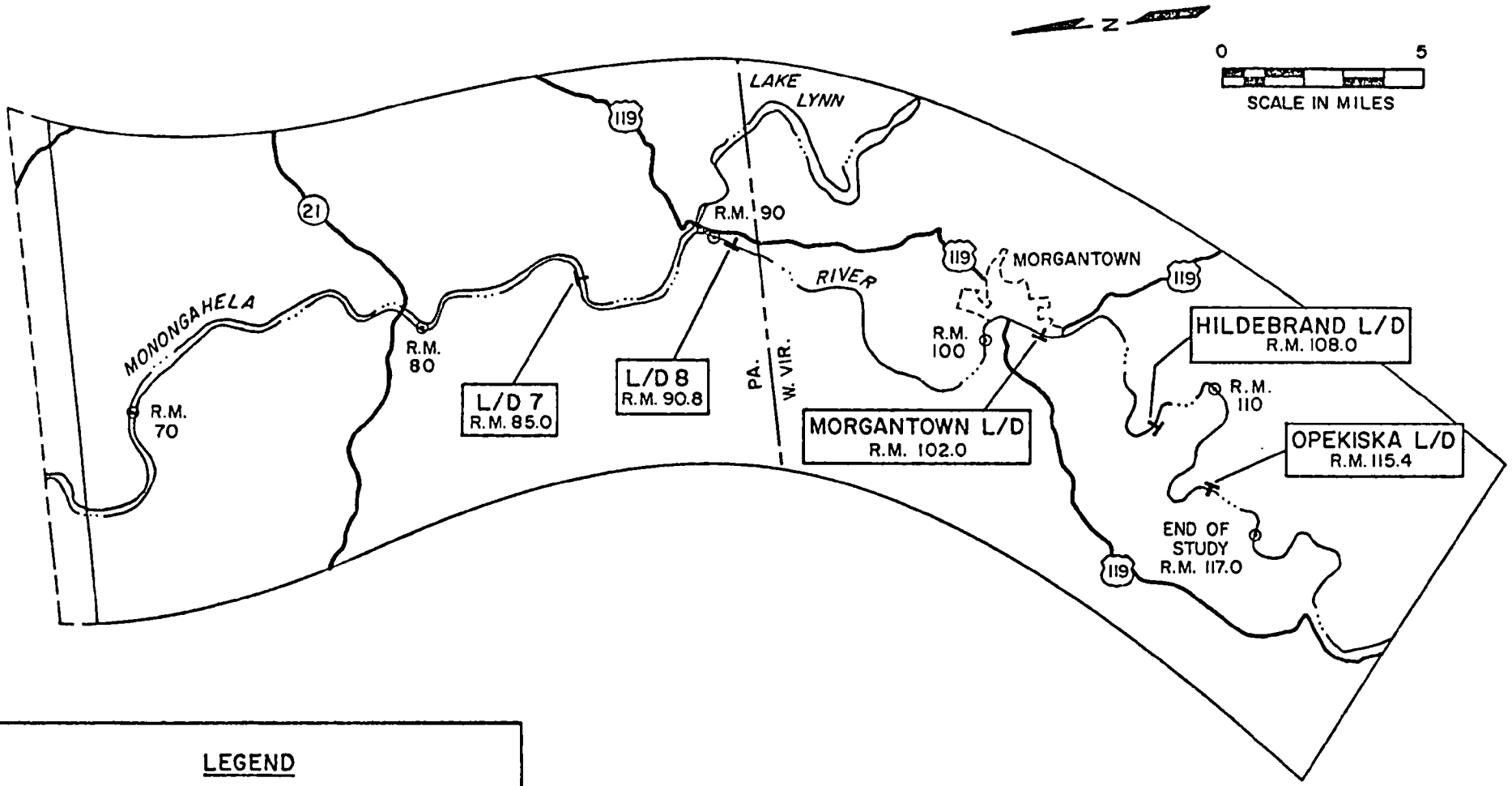


Figure 2-1. (continued)



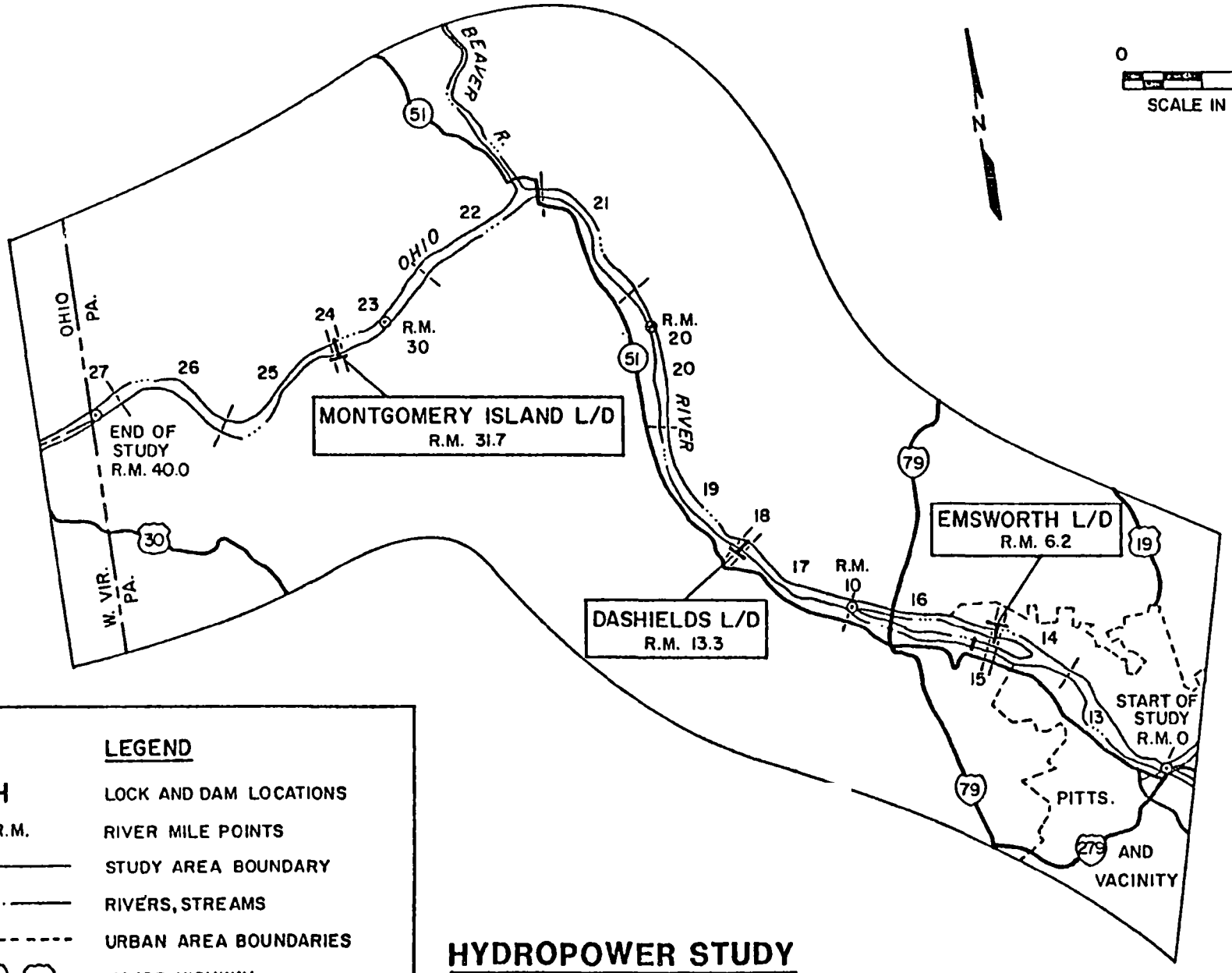
LEGEND

⊣	LOCK AND DAM LOCATIONS
⊙ R.M.	RIVER MILE POINTS
———	STUDY AREA BOUNDARY
——— ··· ———	RIVERS, STREAMS
- - - - - - - - - -	URBAN AREA BOUNDARIES
○—○—○	MAJOR HIGHWAYS

Figure 2-1. (continued)

HYDROPOWER STUDY

MONONGAHELA RIVER - SEGMENT 2



LEGEND

- LOCK AND DAM LOCATIONS
- ⊙ R.M. — RIVER MILE POINTS
- STUDY AREA BOUNDARY
- RIVERS, STREAMS
- URBAN AREA BOUNDARIES
- MAJOR HIGHWAY
- 3 — STUDY REACHES

HYDROPOWER STUDY

OHIO RIVER SEGMENT

Figure 2-1. (continued)

The Neville Coke and Iron discharge was not included because at the flow and limits indicated, the impact on the river would be expected to be minor. The model set-up also included the Beaver River tributary to the Ohio River. This was modeled as a point source to the main stem.

The model parameters are established on a system-wide basis (invariant parameter) and on a reach-specific basis. The invariant parameters (and their normal range) selected are shown in Table 2-5; the values selected were based on a review of the data for the study area and sensitivity analyses (for several parameters) with the selection of a value consistent with the data.

The model parameters established on a reach-specific basis are identified in Table 2-6. These values were initially established based on published guidance for the QUAL II model (WAPORA 1984; USEPA 1980) and a review of the published reports and data for the rivers. The values for selected parameters were developed during the sensitivity analyses performed for model calibration.

Another model set-up activity included the development of hydraulic parameters to predict the velocity, depth, and width of the rivers. The QUAL II model uses equations of the form:

$$(\text{characteristic}) = (\text{coefficient}) \times (\text{flow})^{(\text{exponent})}$$

where:

characteristic = velocity (ft/sec), width (ft), or depth (ft)

coefficient = value (a for velocity, c for depth, and e for width), such that

$$a + c + e = 1.0$$

exponent = value (b for velocity, d for depth, and f for width), such that

$$b \times d \times f = 1.0$$

flow = river flow, cfs

Table 2-5. QUAL II water quality model invariant parameters.

Variable		Description	Units	Recommend Value Range	Value Selected
α_1	ALPHA1	N content of algae biomass	$\frac{mg\ N}{mg\ A}$	0.07 - 0.09	0.09
α_2	ALPHA2	P content of algae biomass	$\frac{mg\ P}{mg\ A}$	0.01 - 0.02	0.02
α_3	ALPHA3	O production by algae (photosynthesis)	$\frac{mg\ O}{mg\ A}$	1.4 - 1.8	2.0
α_4	ALPHA4	O uptake by algal (respiration)	$\frac{mg\ O}{mg\ A}$	1.6 - 2.3	1.4
α_5	ALPHA5	O uptake by NH_3 oxidation	$\frac{mg\ O}{mg\ N}$	3.0 - 4.0	3.4
α_6	ALPHA6	O uptake by NO_2 oxidation	$\frac{mg\ O}{mg\ N}$	1.0 - 1.14	1.17
P_o	ALGDRT	Algal death rate	1/day	0.024 - 0.24	0.02
ρ	RESPRT	Algal respiration rate	1/day	0.05 - 0.5	0.4
P_1	PREFN	Algal preferential uptake of NH_3	(no units)	0.0 - 0.9	0.8
P_2	ALGNRT	Algal-N to organic-N decay rate	1/day	0.11	0.11
K_{MN}	CKN	Half saturation constant for N	mg/l	0.01 - 0.20	0.20
K_{MP}	CKP	Half saturation constant for P	mg/l	0.01 - 0.05	0.05
σ_4	CKPORG	Organic-P decay rate	1/day	0.1 - 0.7	0.6
β_5	SVPORG	Organic-P settling rate	1/day	0.001 - 0.10	0.001
u_{max}	GROMAX	Maximum specific growth rate for algae	1/day	1.0 - 3.0	2.0

Table 2-5. (continued)

Variable		Description	Units	Recommend Value Range	Value Selected
K_{ML}	CKL	Half saturation constant for light	Ly/min	0.02 - 0.10	0.03
λ_A	EXALG	Algal light extinction coefficient	$\frac{1/ft}{\mu g\ Chl\text{-}a/L}$	0.005 - 0.02	0.05

Table 2-6. QUAL II water quality model reach-variable parameters.

Variable		Description	Units	Recommend Value Range	Value Selected
K_{10}	CK1	Laboratory deoxygenation rate	1/day	0.02 - 3.4	0.01
BACT	BACT	Bed activity coefficient	(no units)	0.10 - 0.60	0.03
K_2	CK2	Reaeration rate	1/day	0.0 - 100.0	variable
K_3	CK3	Settling rate for CBOD	1/day	-0.36 - 0.36	0.0
K_4	CK4	Benthic O_2 demand	$\frac{\text{mg O}}{\text{ft-day}}$	highly variable	0
α_o	ALPHA	Mass ratio of chl-a to algae	$\frac{\mu\text{g chl-a}}{\text{mg A}}$	10 - 100	10
α_1	ALGSET	Settling rate for algae	ft/day	0.5 - 6.0	variable
σ_2	SDIS	Benthos source rate for dissolved P	$\frac{\text{mg P}}{\text{day-ft}}$	highly variable	0
σ_3	SNH3	Benthos source rate for NH_3	$\frac{\text{mg N}}{\text{day-ft}}$	highly variable	0
β_1	CKNH3	NH_3 oxidation rate	1/day	0.10 - 1.00	0.10
β_2	CKNO2	NO_2 oxidation rate	1/day	0.20 - 2.00	2.0
β_3	CKNH2	Organic-N hydrolysis rate	1/day	0.01 - 1.00	0.1
β_4	DKP	Dissolved-P removal rate	1/day	0.01 - 1.00	0.05
λ_o	EXCOEF	Non-algal light extinction coefficient	1/ft	variable	variable

For the Ohio River reaches, the coefficients and exponents for velocity were selected based on a regression equation developed by ORSANCO. The values for the Allegheny and Monongahela Rivers were selected to predict a velocity considered to be reasonable based on mass balance considerations. The width parameters were selected to predict channel widths reported for the rivers. The depth parameters also were selected to match reported depths. The values were selected on a reach-specific basis, and they are included in Table 2-7.

The model set-up also requires specifying the climatic condition for each run (light intensity, hours of daylight) and headwater conditions. These values were developed for each run to reflect the conditions being modeled.

2.2.2 Calibration and Verification Procedures

The model was calibrated using three data sets: Ohio River reaches with 1 August 1983 data; Allegheny River with 28 July 1983 data; and Monongahela River with 26 August 1983 data. This involved three separate model set-ups, with adjustment of model parameters as required to match the observed data as closely as possible. This calibration approach was selected because there was no consistent data set applicable to the entire study area. There were no major problems encountered with this approach.

The model verification also was performed using the segmented approach. The Ohio River reaches in the calibrated QUAL II model were verified using a 11 July 1983 data set, the Allegheny River using a 23 July 1981 data set, and the Monongahela River using a 24 July 1980 data set. An evaluation of the model verification results versus calibration results was performed by an error analysis. This involved comparing the predicted dissolved oxygen to the observed level at each station where data were available. The average error, absolute value average error, and error standard deviation were computed for the calibration and verification runs (using each station as a replicate). This analysis does not establish an absolute level of confidence in the model, but serves to characterize relative performance.

Table 2.7. Hydraulic parameters selected for the QUAL II water quality model.

River-Reach-Mile		Velocity a	Velocity b	Depth c	Depth d
Allegheny River					
1	15.0-14.6	0.007	0.78	2.03	0.197
2	14.6-14.4	0.007	0.78	2.03	0.197
3	14.4-10.6	0.007	0.78	2.03	0.197
4	10.6-6.8	0.007	0.78	2.03	0.197
5	6.8-6.6	0.007	0.78	2.03	0.197
6	6.6-2.8	0.007	0.78	2.03	0.197
7	2.8-0.0	0.007	0.78	2.03	0.197
Monongahela River					
8	15.0-11.2	0.0013	0.702	1.18	0.266
9	11.2-11.0	0.0013	0.702	1.18	0.266
10	11.0-7.2	0.0013	0.702	1.18	0.266
11	7.2-3.4	0.0013	0.702	1.18	0.266
12	3.4-0.0	0.0013	0.702	1.18	0.266
Ohio River					
13	0-3.8	0.003	0.796	5.25	0.156
14	3.8-6.0	0.003	0.796	5.25	0.156
15	6.0-6.2	0.003	0.796	5.25	0.156
16	6.2-20.0	0.004	0.790	4.87	0.153
17	10.0-13.2	0.004	0.790	4.87	0.153
18	13.2-13.4	0.004	0.790	4.87	0.153
19	13.4-17.2	0.004	0.790	4.87	0.153
20	17.2-21.0	0.004	0.790	4.87	0.153
21	21.0-24.8	0.004	0.790	4.87	0.153
22	24.8-28.6	0.004	0.790	4.87	0.153
23	28.6-31.6	0.004	0.790	4.87	0.153
24	31.6-31.8	0.004	0.790	4.87	0.153
25	31.8-35.6	0.003	0.796	5.25	0.156
26	35.6-39.0	0.003	0.796	5.25	0.156
27	39.0-40.0	0.003	0.796	5.25	0.156

2.2.3 Impact Analysis

The impact analysis was performed using the calibrated and verified model to predict dissolved oxygen levels in the rivers under several hydropower development scenarios. The model was run for all three rivers in each analysis. The conditions at each lock and dam were modified to reflect a separate development scenario.

The environmental conditions selected for the analysis included hot, low flow conditions expected during July-September. The river flow and temperature were selected by reviewing the data available from ORSANCO, the Pittsburgh District Corps of Engineers, STORET, the Pennsylvania Department of Environmental Resources, and FERC applications for hydropower development at the Dashields L/D, Emsworth L/D, and Montgomery L/D. The conditions selected for analysis correspond to an expected LTMA flow, and a LFE. These were developed by inspection of the available data and were not developed from an independent review of the gage data.

The low-head dam retrofit to hydropower was simulated by using QUAL II model features for dam reaeration. The literature for dam reaeration predictive methods and theory was reviewed. This review indicated that the formula included in the Vermont version of the QUAL II model followed the form of the British dam formula and is widely accepted. Therefore, the existing upstream/downstream dissolved oxygen data for each lock and dam were evaluated to establish the parameters required for the dam reaeration formula. The hydropower conversion was modeled as a bypass of flow around the dam (i.e., through the turbine with no reaeration rather than across the dam with reaeration). Bypasses of zero percent, 50 percent, and 100 percent flow were modeled to establish a range of impacts. An intermediate bypass level can be inferred from these results by interpolation.

The impact analysis included the evaluation of the calibrated model at the three levels of hydropower development (i.e., zero, 50 percent, and 100 percent of flow bypassing the dam) for the LTMA and LFE. The sensitivity of the model parameters selected with respect to the calibration and the impact analysis results was also analyzed. The sensitivity analyses

addressed (see Tables 2-5 and 2-6 for variable definition) were: (1) oxidation rates for biochemical oxidation demand and ammonia (CK_1, $CKNH_3$); (2) reaeration rate for the river (CK_2); and (3) algal parameters (light extinction, EXALG and EXCOEF; oxygen production and respiration rates, ALPHA 3 and ALPHA 4; growth rate, GROMAX; and light saturation constant, CKL). The effect of these sensitivity runs is discussed in Chapter 3.

2.3 BIOLOGICAL RESOURCES: REVIEW OF LITERATURE

2.3.1 Characterization of the Fisheries of the Study Area

The fisheries resource of the Ohio River varies considerably from its origin in Pittsburgh to its mouth in Cairo, Illinois. The fisheries of the study area--the upper Ohio River and lower reaches of the Allegheny and Monongahela Rivers--were characterized based upon information obtained from the following sources:

- Regional fisheries studies;
- Utility prepared 316(a) and 316(b) and related documents;
- Biological resource characterizations contained in F.E.R.C. Exhibit E's for study area low-head dams;
- U.S. Army Corps of Engineer District Offices;
- Ohio River Valley Water Sanitation Commission;
- State agencies; and
- University faculties.

Although this review focuses on the study area, information for the upper 260 miles of the Ohio River was included. The reasons for this are two-fold: (1) to increase the information available, especially for ichthyoplankton, and (2) to include species presently not in the study area, but whose distribution may include the study area as water quality in the upper basin continues to improve. Changes in community composition through time were noted where such comparisons could be made.

2.3.2 Characterization of Spawning Period and Habitat Requirements

Subsequent to describing the composition of the fish community in the study area, each species' spawning period, i.e., season, and specific habitat requirements, were characterized. It was anticipated that the high temperature-low flow period of each year, and possibly attendant low dissolved oxygen concentrations, would be that period most critical to successful fish spawning and egg and larval survival. Species spawning prior to or after the August-September period should encounter temperature and dissolved oxygen conditions nearer their optima for survival and growth. Spawning habitat requirements also vary considerably among species. Characterization of spawning habitat requirements will provide insight to the species that could be expected to spawn in the Ohio River, and where in the river they might spawn, (i.e., shoreline, mid-river, etc.).

2.3.3 Composition and Temporal Occurrence of Ichthyoplankton Taxa

Although several species of fish potentially spawn in the upper Ohio River, actual utilization is best indicated by documentation of the occurrence of various taxa of ichthyoplankton in samples collected from the river. Data concerning the composition and temporal occurrence of each taxon were compiled from 316(b) demonstration documents prepared for utilities with generating facilities along the Allegheny, Monongahela, and Ohio Rivers. These data were then used to supplement information presented in several annual "Ohio River Ecological Research Program" reports prepared by WAPORA, Inc. (1973-1981) and Geo-Marine, Inc. (1982, 1983).

2.3.4 Influence of Low Dissolved Oxygen Concentrations on Fish Eggs, Larvae, and Adults

A potential impact associated with retrofitting low-head dams for hydropower production is a reduction of reaeration and depressed dissolved oxygen concentrations at the downstream face of the dam. To assess the potential for biological impacts (i.e., reduced spawning, embryo or larval mortality, or exclusion), a review of literature was undertaken that focused on survival and behavior of fish at depressed dissolved oxygen

concentrations. Literature pertinent to the fishery of the Ohio River is also included. An extensive literature base for salmonids exists but was not considered because the Ohio is a Midwestern river with a warm-water fishery. Doudoroff and Shumway's 1970 comprehensive review of the dissolved oxygen requirements of freshwater fishes served as the initial source for this overview.

2.3.5 Impacts of Hydropower Plant Operation on Indigenous Fish Species

Hydropower facilities impinge and entrain fish occurring in the source water. The emphasis of this portion of the literature review will be to focus on the types of injuries sustained by fish passing through hydro-facilities, and on mortality rates sustained by warm-water species passing through bulb-turbine equipped hydrofacilities.

2.3.6 Impact Analysis

The water quality modeling results will project levels of dissolved oxygen through the study reach. If, and where, dissolved oxygen levels are below accepted water quality standards for this parameter (5.0 mg/l), then the projected levels will be used to define impacts to the fishery by comparing projected river dissolved oxygen values with tolerance levels for various fish species. Zones of exclusion, linear distances, downstream from dams from which fish would be excluded, will then be evaluated.

3.0 RESULTS

3.1 WATER QUALITY

3.1.1 Hydropower Facility Development

The study area includes six locks and dams, two on the Allegheny River, one on the Monongahela River, and three on the Ohio River. Hydropower conversion is being investigated at all of these locations.

Study Area Locks and Dams. The major design features of the study area locks and dams (L/Ds) are identified in Table 3-1. Four have a fixed crest design, therefore, no operating control on the overflow is possible. These include the Allegheny L/D 2 and L/D 3, the Monongahela L/D 2, and the Ohio River Dashields L/D.

The Ohio River Emsworth L/D includes a narrow uncontrolled spillway (34.4 ft long at elevation 709.0) and a gated spillway (fixed sill elevation 698.0, 800 ft total length). There also is a back channel dam, with a gated controlled spillway (600 ft total length with a fixed sill elevation 698.0). The Montgomery L/D includes an uncontrolled spillway (218 ft total length with crest at 680.33) and a gated controlled spillway (1,000 ft total length with a fixed sill elevation 667.0).

Hydropower Proposals. Hydropower projects are currently proposed for the Dashields L/D, the Emsworth L/D, and the Montgomery L/D. The development of hydropower projects at the other study area dams is in the planning stage.

The Dashields L/D hydropower project is being applied for by Allegheny County, Pennsylvania (C.E. Maguire 1983). The project includes a submerged powerhouse and five bulb-type 5 MW horizontal turbine-generator units and will replace about 250 ft of the present dam and spillway. The roof of the powerhouse will be at the existing spillway elevation so that spillway length and discharge capacity will not be reduced to any appreciable

Table 3-1. Characteristics of study area lock and dams.

Allegheny River L/D 2
- Location - Allegheny River Mile 6.7
- Type - Fixed crest, 1393.0 ft length, 721.0 elevation
- Normal Pool Elevation - Upper 721.0, Lower 710.0

Allegheny River L/D 3
- Location - Allegheny River Mile 14.5
- Type - Fixed crest, 1435.75 ft length, 734.5 elevation
- Normal Pool Elevation - Upper 734.5, Lower 710.0

Monongahela River L/D 2
- Location - Monongahela River Mile 11.2
- Type - Fixed crest, 747.92 ft length, 718.7 elevation
- Normal Pool Elevation - Upper 718.7, Lower 710.0

Ohio River, Emsworth L/D
- Location - Ohio River Mile 6.2 (back channel dam is at Mile 6.8)
- Type - Controlled spillway, 8 gated sections at 100 ft each, fixed sill elevation 698.0; uncontrolled spillway, fixed weir adjacent to river wall, 34.42 ft length, crest elevation 709.0
  Back Channel Dam - controlled spillway, 6 gated sections each at 100 ft length, fixed sill elevation 698.0
- Normal Pool Elevation - Upper 710.0, Lower 692.0

Ohio River, Dashields L/D
- Location - Ohio River Mile 13.3
- Type - Fixed crest, 1585 ft length, 692.0 elevation
- Normal Pool Elevation - Upper 692.0, Lower 682.0

Ohio River, Montgomery L/D
- Location - Ohio River Mile 31.7
- Type - Controlled spillway, 10 gated sections at 100 ft each, fixed sill elevation 667.0; uncontrolled spillway, 2 fixed weir sections at 109 ft length each, crest elevation 680.33
- Normal Pool Elevation - Upper 682.0, Lower 664.5

Source: U.S. Army Corps of Engineers 1984a, 1984b.

extent. The structure will include inlet and tailrace channels for the turbines. The flow range for one turbine operation is 1,500 cfs minimum to 6,700 cfs maximum, with maximum capacity at 33,500 cfs for all five units. The power plant will not operate with a flow in the river less than 2,500 cfs or more than 80,000 cfs.

The Emsworth L/D hydropower project is being applied for by the Allegheny Electric Cooperative, Inc. (C.T. Main 1984). The project includes construction of an intake channel, powerhouse, and tailrace with two 10 MW full-Kaplan bulb-type turbines. The construction will require removal of 95 feet of the 101-foot long uncontrolled spillway. The structure will have a top-of-roof deck elevation of about 701.0 feet, which is two feet above the 100-year flood elevation. The minimum flow required for operation is 6,450 cfs, including 3,600 cfs for turbine flow, and 2,850 cfs for leakage and uncontrolled spillway flow. Between river flows of 6,450 and 21,850 cfs, all flow will pass through the turbines (except the leakage flow of 2,850 cfs).

The Montgomery L/D hydropower project is also owned by Allegheny Electric Cooperative, Inc. The project would include a 20 MW hydroelectric generating facility utilizing full-Kaplan bulb-type turbines (14,400 HP each). Complete specifications are not currently available for the proposed hydroelectric retrofit (C.T. Main 1984).

3.1.2 Results of Calibration and Verification

The selection of model parameters and the model set-up for these analyses followed the methods described in Chapter 2. During calibration, it was found that the hydraulic parameters could be adjusted to model observed conditions in the rivers very well for the flow regimes under evaluation. The oxidation rates for biochemical oxygen demand and for ammonia oxidation were selected based on previous work by ORSANCO (ORSANCO 1974). The parameters for algal dynamics were selected based on a review of available data. The reaeration rate for the rivers and for the locks and dams were selected based on the evaluations discussed below.

Reaeration. River reaeration includes oxygen transfer resulting from turbulence and diffusion into the water column, and oxygen transfer from the production of dissolved oxygen by algae. Reaeration at the locks and dams is discussed in the next section.

A recent assessment of the literature identified more than 20 predictive equations for river reaeration due to the physical (hydraulic) characteristics of the river (WAPORA 1984b). The conditions upon which these equations were developed indicated that the O'Connor-Dobbins predictive equation should be a reasonable technique for estimating the reaeration rate, K_2, for the study area rivers. Therefore, the QUAL II model Option 3 (O'Connor-Dobbins equation) was used. This resulted in the model calculating the reaeration rate, K_2, for each reach. The rates calculated for the calibration and verification runs are shown in Table 3-2. This represents the physical transfer of oxygen into the river.

Modeling of algal activity using QUAL II requires estimating various rates and constants for the entire study area (invariant parameters) and for each reach (reach variant parameters). The invariant model parameters that could affect the oxygen levels in the stream include algal respiration and photosynthesis rates. These parameter values were selected based on the recommended values (Chapter 2). The sensitivity of the selected values was tested under a wide range of conditions, as discussed in a later section.

The reach variant parameters used in controlling the algal oxygen contribution in the study area were the light extinction coefficient and the algal settling rate. The light extinction coefficient was used to control the algal growth, whereas algal settling rates were used to control instream concentrations of chlorophyll a (e.g., settling increased to reduce instream chlorophyll a levels), which resulted in the indrect control of dissolved oxygen levels. During calibration these parameter values were adjusted for each reach, within the accepted limits, in order to match as closely as possible observed dissolved oxygen and chlorophyll a levels. The values for these parameters were developed during calibration and were then used during verification.

Table 3-2. Reaeration rates predicted by the model (O'Connor-Dobbins) for verfication and calibration.

Reach	Reaeration Rate, K_2, Calibration (day^{-1})	Reaeration Rate, K_2, Verification (day^{-1})
1	0.295	0.168
2	0.295	0.168
3	0.295	0.168
4	0.295	0.168
5	0.295	0.168
6	0.295	0.168
7	0.295	0.168
8	0.269	0.337
9	0.269	0.337
10	0.269	0.337
11	0.269	0.337
12	0.269	0.337
13	0.091	0.088
14	0.092	0.089
15	0.092	0.089
16	0.120	0.116
17	0.120	0.116
18	0.120	0.116
19	0.120	0.116
20	0.120	0.117
21	0.120	0.117
22	0.120	0.120
23	0.123	0.120
24	0.123	0.120
25	0.094	0.091
26	0.094	0.091
27	0.094	0.091

The data sets used for model calibration and verification indicated that portions of each river were above saturation dissolved oxygen levels. This was interpreted to mean that algal activity in the study area is a significant source of dissolved oxygen (see Greeson 1967). Based on this, the algal growth parameters were adjusted to approximate the level of algal activity (represented as chlorophyll a) without attempting to exactly match the observed concentrations. The sensitivity of the dissolved oxygen predictions to the selected values for these parameters was evaluated during the modeling to determine the reasonableness of this approach. As described in a later section, the sensitivity analyses confirmed the general reasonableness of the values selected.

Lock and Dam Reaeration. The flow across a dam can be a significant source of reaeration and is a major concern in this study. It is generally considered that the reaeration across a dam is a function of the head loss, the dissolved oxygen deficit, water conditions (temperature and contamination), and the physical characteristics of the dam. The dam reaeration formula used in the QUAL II model is the equation (WAPORA 1984a):

$$D_a - D_d = 1 - \frac{1}{1 + 0.11\ a\ b\ H\ (1 + 0.046\ T)}\ D_a$$

where:

D_a = dissolved oxygen deficit above dam, mg/l
D_b = dissolved oxygen deficit below dam, mg/l
a = coefficient characteristic of water quality (1.8 = clean water; 1.6 = slight contamination; 1.0 = moderate contamination; 0.65 = gross contamination)
b = dam characteristic
H = height through which water falls, feet
T = temperature, °C

The water in the study area rivers was considered to be slightly contaminated (a = 1.6). As summarized in Table 3-3, the value for b for each dam was developed from dissolved oxygen data provided by the Corps of

Table 3-3. Summary of dam characteristic values computed for the study area dams.

Identification	Survey Date	T, °C	D mg/l	D mg/l	b	
Monongahela L/D 2	7/31/75	29.9	1.61	1.34	0.055	
height = 8.7 ft	6/23/78	26.2	1.14	0.81	0.121	
	6/28/79	26.2	0.81	0.73	0.032	
	7/24/80	24.3	1.35	0.85	0.181	
	8/26/83	28.6	1.50	1.28	0.048	
					0.10	sd_{n-i} = 0.06[a]
Allegheny L/D 2	8/26/76	25.2	0.0	-0.14	--	
height = 11.0 ft	6/30/77	25.3	0.18	-0.28	--	
	7/20/77	26.7	1.20	-0.11	--	
	8/10/78	24.0	1.05	0.21	0.989	
	7/13/79	16.1	2.13	0.99	0.344	
	7/23/81	25.2	1.05	-0.02	--	
	7/19/82	28.0	0.57	-0.18	--	
	7/22/82	28.0	0.80	0.20	0.682	
	7/28/83	28.0	0.15	-0.06	--	
					0.67	sd_{n-i} = 0.32
Allegheny L/D 3	8/26/76	25.2	0.59	0.04	2.684	
height = 13.5 ft	6/30/77	27.2	0.50	-0.74	--	
	7/20/77	26.4	0.85	0.79	0.015	
	8/10/78	24.4	1.42	0.61	0.263	
	7/12/79	23.9	0.58	-0.19	—	
	7/23/81	25.4	1.52	0.70	0.227	
	7/19/82	28.0	1.18	0.41	0.345	
	7/22/82	28.0	1.16	0.70	0.121	
	7/28/83	27.9	0.92	0.17	0.811	
					0.64	sd_{n-1} = 0.94
Emsworth L/D	9/22/75	18.0	0.44	0.25	0.133	
height = 18.0 ft	6/06/77	23.7	1.81	1.24	0.070	
	7/24/78	26.8	1.26	0.54	0.191	
	8/13/79	24.7	0.84	0.80	0.007	
	8/02/82	25.4	1.32	1.45	—	
	7/11/83	24.3	0.63	0.19	0.351	
	8/01/83	27.7	1.06	0.14	0.924	
					0.28	sd_{n-1} = 0.34
Dashields L/D	9/22/75	18.0	0.39	-0.19	—	
height = 10.0 ft	6/06/77	23.4	1.72	0.40	0.906	
	7/24/78	26.6	0.92	-0.25	—	
	8/13/79	24.8	1.06	0.74	0.114	
	8/02/82	25.4	1.45	0.99	0.121	
	7/11/83	25.0	0.82	0.26	0.570	
	8/01/83	27.6	0.63	-0.62	--	
					0.43	sd_{n-1} = 0.38

Table 3-3. (continued)

Identification	Survey Date	TOC	D mg/l	D mg/l	b	
Montgomery Island L/D height = 17.5 ft	9/23/75	17.9	0.41	-0.76	—	
	6/07/77	23.0	2.43	-0.03	—	
	7/25/78	27.0	0.68	0.06	1.470	
	8/14/79	24.2	0.94	-0.34	—	
	8/13/82	26.2	2.68	0.65	0.453	
	7/12/83	24.8	0.75	0.00	—	
	8/02/83	27.2	0.86	-0.49	—	
					0.96	sd_{n-1} = 0.72

[a] sd_{n-1} represents the unbiased standard deviation of the values for b

Engineers. The observed reaeration at each dam (indicated by upstream and downstream dissolved oxygen measurements in the rivers) was used to calculate b. The dam height (H) was estimated as the difference between the upper and lower pool elevations. The modeling was performed using the b for each lock and dam (Table 3-3) and the H based on pool elevations.

Calibration Results. The predicted average dissolved oxygen levels for the Ohio River, the Allegheny River, and Monongahela River are presented in Figures 3-1 through 3-3. The observed dissolved oxygen levels for the calibration data set are also presented in these figures with the upper and lower reported values shown. Concurrence between the predicted and observed dissolved oxygen levels is considered good. The areas where the predicted dissolved oxygen deviates most from the observed levels correspond to locations where the river levels are greater than saturation. The rivers/temperatures were about 28°C, indicating a saturation dissolved oxygen level of about 7.9 mg/l.

It is possible for the QUAL II model to predict dissolved oxygen levels above saturation when the contribution from algal photosynthesis is sufficiently large. The adjustments to the algal growth parameters made during calibration reflect this, with dissolved oxygen levels predicted above saturation at several locations. These adjustments were constrained to generally agree with reported levels of chlorophyll a in the data set. As a result, it was not possible to exactly match the data set.

Another characteristic of the data set could not be matched. The dissolved oxygen data indicated an increase downstream of the Montgomery L/D even though the upstream levels were greater than saturation. The predictive equation used by the model for dam reaeration would result in a decrease in dissolved oxygen in this situation. Therefore, it was impossible to exactly match the observed conditions during calibration.

Verification Results. The calibrated model was tested using a second data set for the Ohio River and the two tributaries. The adjustments to the model for these runs included only modification of headwater and point source conditions. All other parameters, including the reaeration predic-

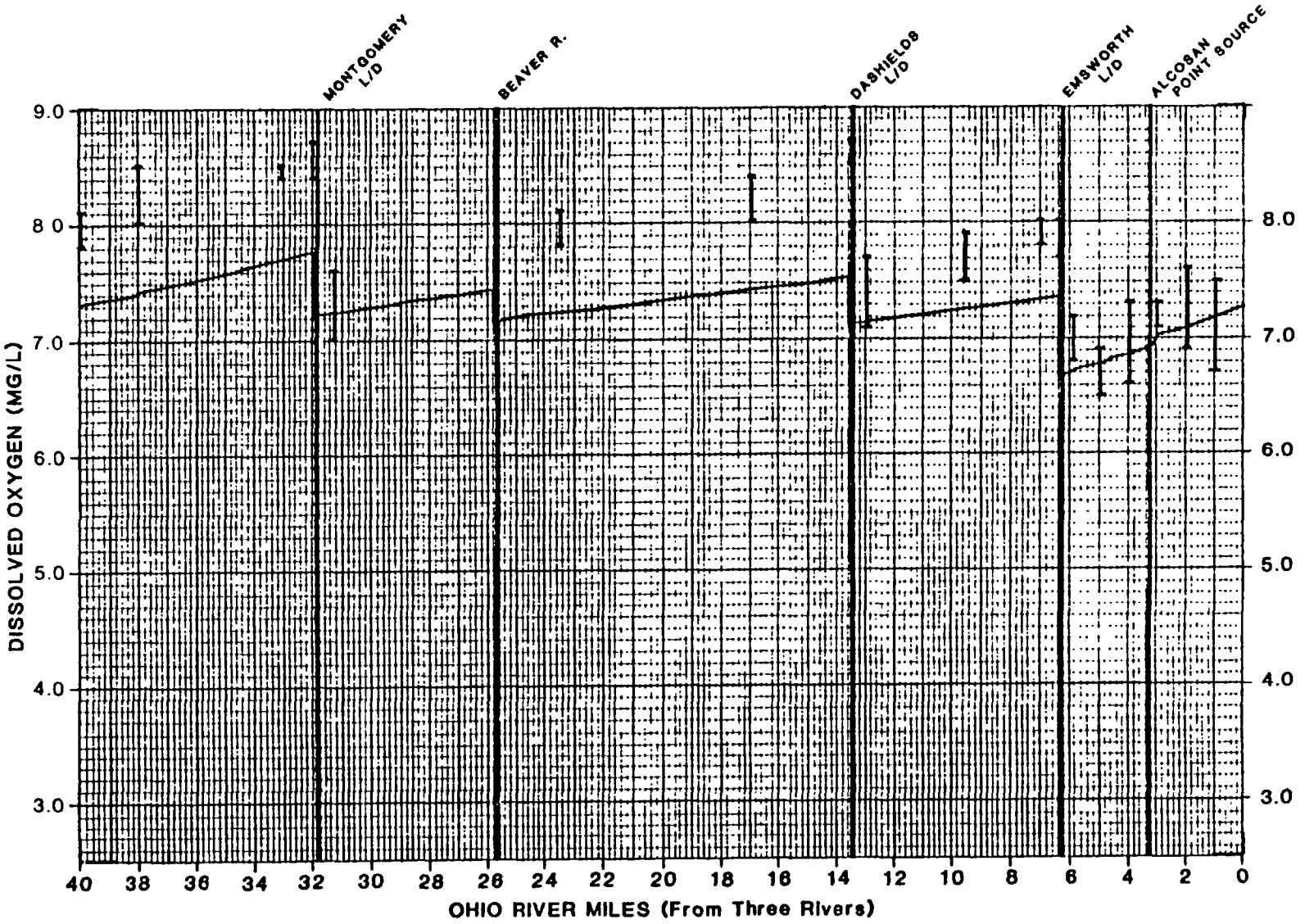


Figure 3-1. Dissolved oxygen predictions and observed data for QUAL II model calibration of the Ohio River (data set 11 July 1983).

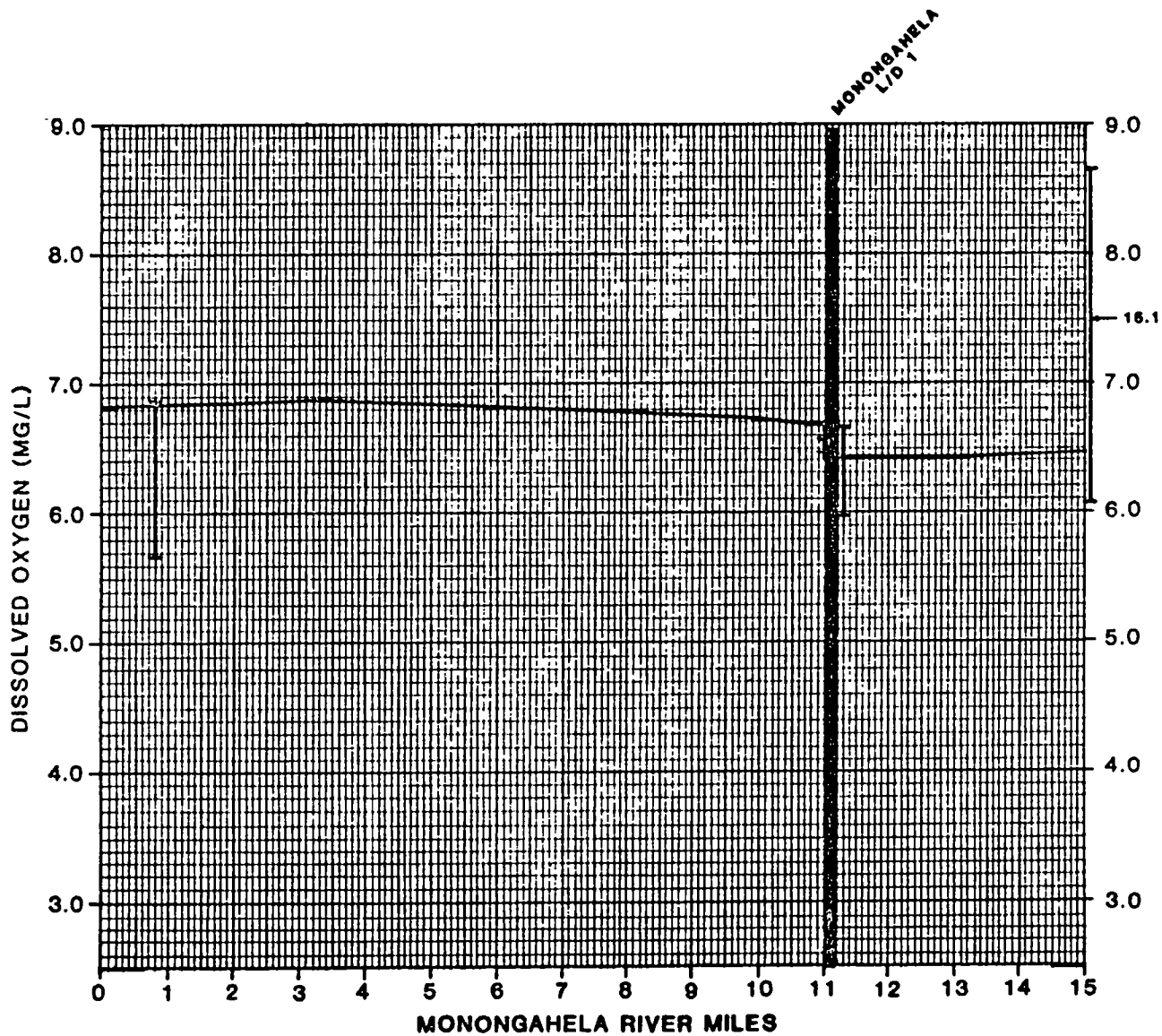


Figure 3-2. Dissolved oxygen predictions and observed data for QUAL II model calibration of the Monongahela River (data set 26 August 1983).

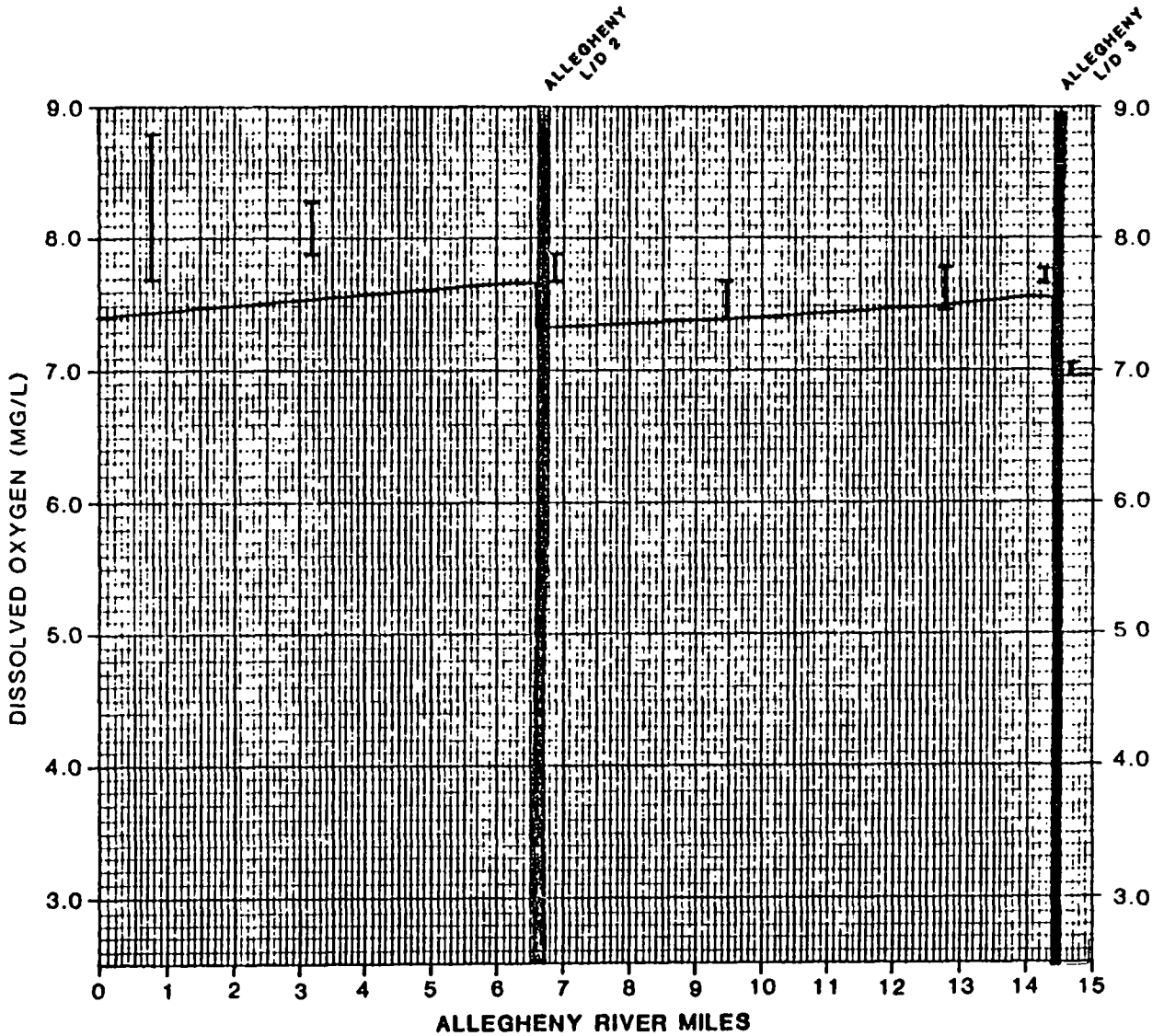


Figure 3-3. Dissolved oxygen predictions and observed data for QUAL II model calibration of the Allegheny River (data set 28 July 1983).

tive method and dam characteristics, were retained at the values developed during model calibration. However, the reaeration predictive method (O'Connor-Dobbins) relies on stream velocity to develop K_2. Stream velocity is computed by the QUAL II model based upon stream flow. Since flows for the verification and calibration data sets differed, different reaeration rates for the two flow regimes were used (see Table 3-2).

Figures 3-4, 3-5, and 3-6 present the verification data and model predictions for the Ohio mainstem and the two tributaries. The predicted dissolved oxygen levels are greater than saturation at some locations. The river temperatures were about 24.5 to 25.0°C, indicating a saturation dissolved oxygen level of about 8.4 mg/l. Also, the chlorophyll a predictions were consistent with the observed conditions of about 10 μg/l. These predictions are considered good, and indicate that the calibrated model is a reasonably accurate predictive tool for dissolved oxygen.

Sensitivity Analyses. During calibration, the model was run with a wide range of parameter values to determine the sensitivity of the dissolved oxygen predictions. The parameters evaluated included the carbonaceous and nitrogenous oxidation rates; the reaeration (K_2) prediction method; and algal parameters, photosynthesis and respiration rates, light extinction coefficient, and algal settling rate. The range evaluated was typically an order of magnitude per parameter, unless physical constraints or river conditions indicated that a smaller range was more appropriate. As described in Chapter 2, there are many other parameters that could be adjusted, but those selected were considered to be most critical for the study area.

Oxidation Rates. The oxidation rates for the carbonaceous and nitrogenous reactions can directly affect dissolved oxygen predictions because these represent major oxygen sinks. In particular, the nitrogenous oxygen demand had been identified by previous modeling to be a significant sink for the study area (ORSANCO 1974).

The carbonaceous oxidation rate was varied from 0.1 to 0.01 day^{-1}, and the value of 0.01 day^{-1} was selected for modeling. It

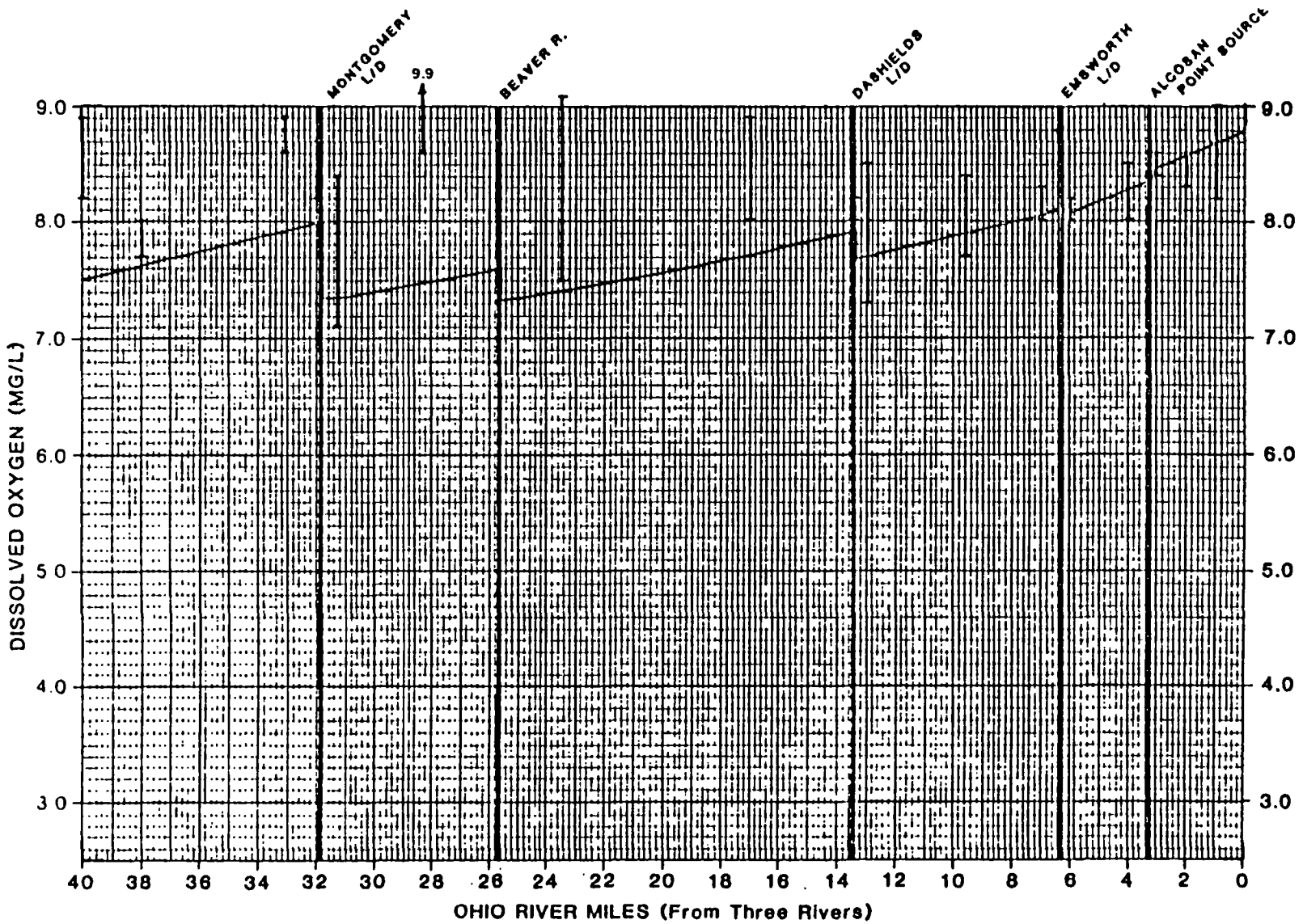


Figure 3-4. Dissolved oxygen predictions and observed data for QUAL II model verification of the Ohio River (data set 1 August 1983).

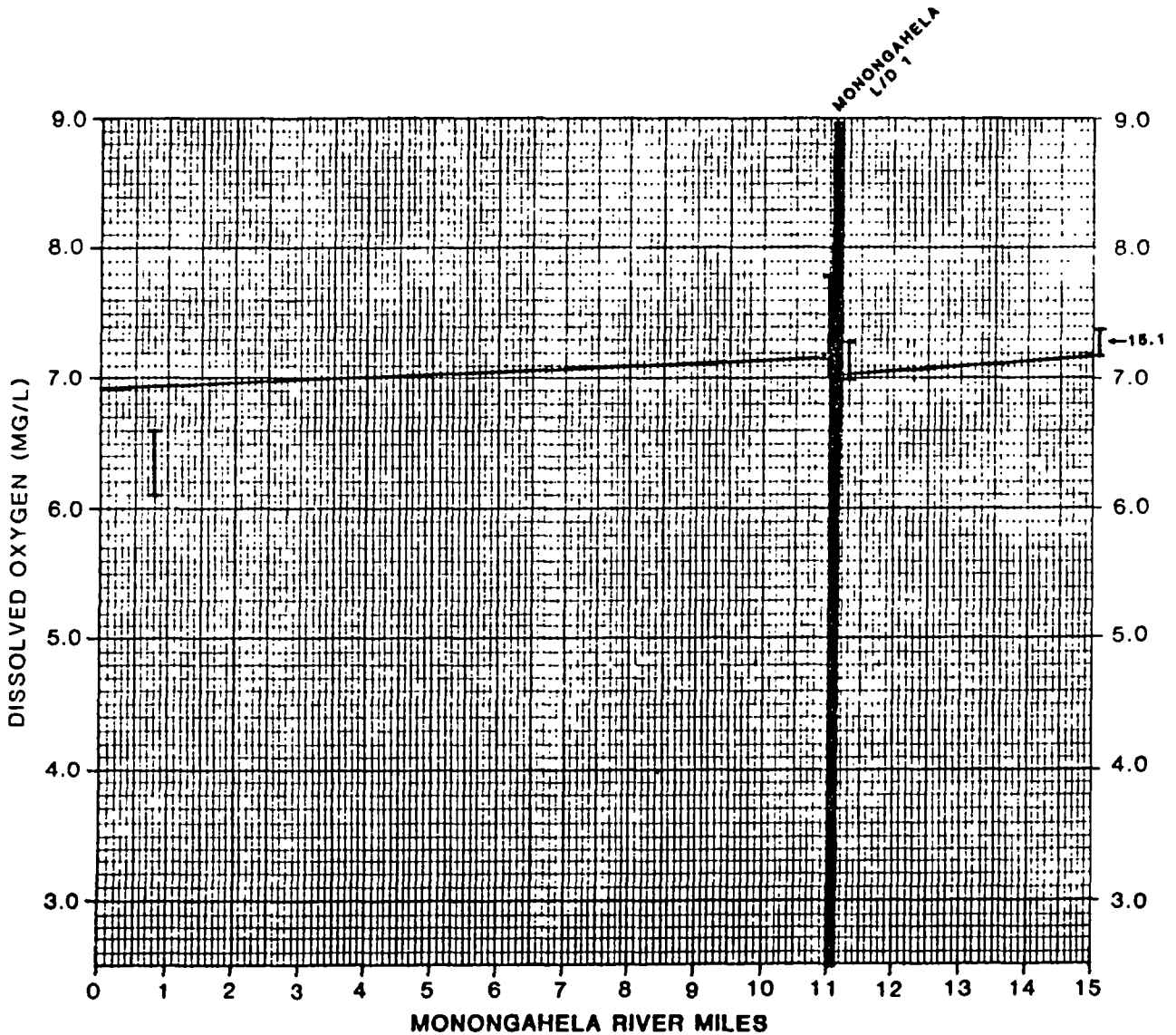


Figure 3-5. Dissolved oxygen predictions and observed data for QUAL II model verification of the Monongahela River (data set 24 July 1980).

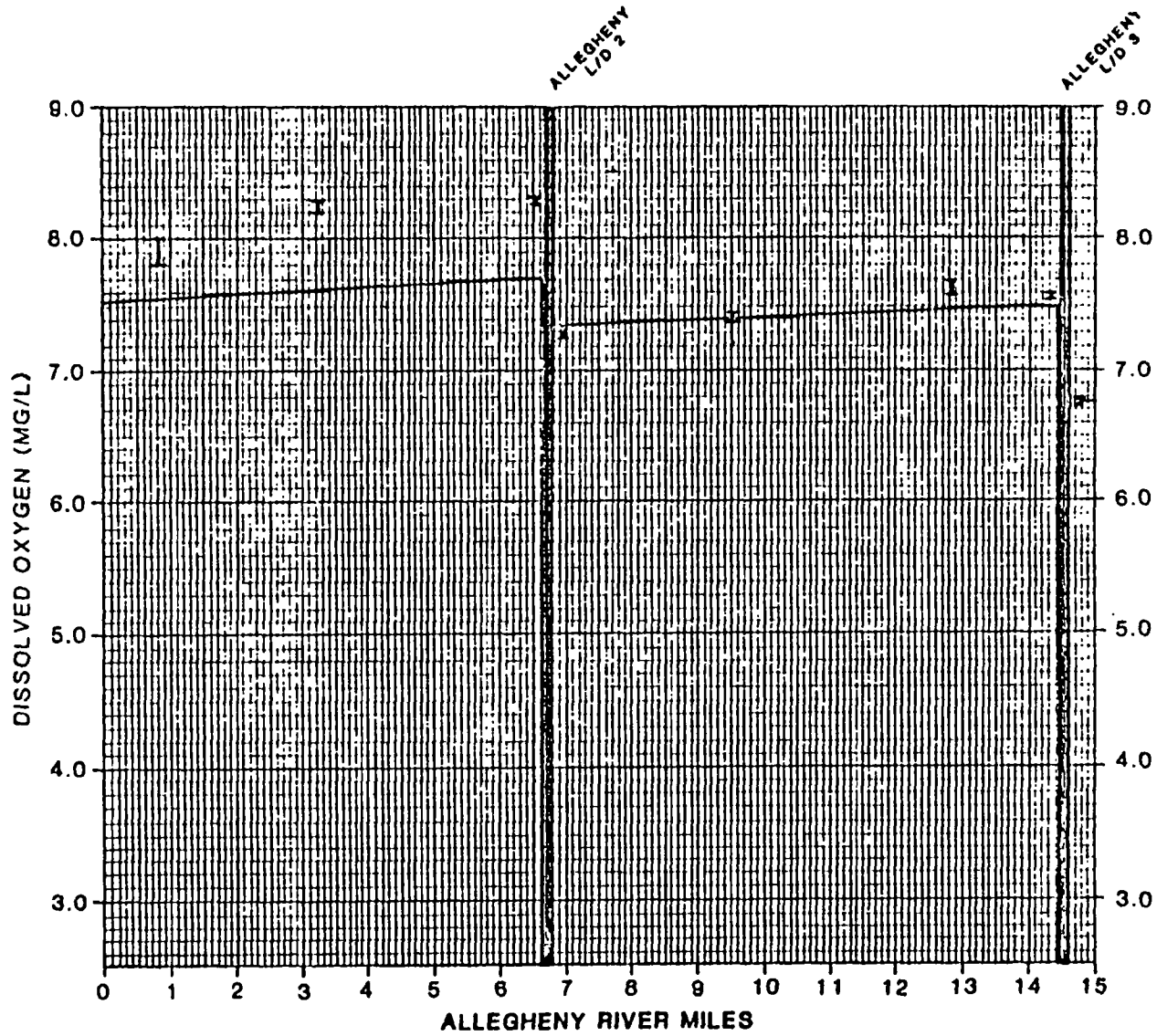


Figure 3-6. Dissolved oxygen predictions and observed data for QUAL II model verification of the Allegheny River (data set 23 July 1981).

was found that dissolved oxygen values were insensitive to carbonaceous oxidation rates (less than 0.1 mg/l change in DO predicted).

The nitrogenous rate was varied from 0.10 to 0.01 day^{-1}, and the value of 0.1 day^{-1} was selected for modeling. It was found that the dissolved oxygen was more sensitive to this rate than to the carbonaceious oxidation rate. A maximum change of 0.3 mg/l was observed at the highest rate versus the lowest rate.

It was concluded from this analysis that the rates selected were adequate for further use in the modeling. The predicted dissolved oxygen levels should not be particularly sensitive to slight changes in values for these parameters.

Reaeration Rates. The sensitivity of the model calibration to the method selected for predicting reaeration was evaluated by running the other options available in the QUAL II model (WAPORA 1984a). It was found that many of the other predictive equations generated reaeration rates generally similar to the O'Connor-Dobbins method and yielded similar dissolved oxygen predictions. A rigorous analysis was not performed to identify the relative accuracy of these predictions, but inspection of the results indicated that the O'Connor-Dobbins method provided the best match.

Another sensitivity analysis conducted involved selecting reaeration rates (K_2) from 0.1 to 1.0 day^{-1}. This was performed while also adjusting the flow through the hydropower turbines at 0 percent (i.e., existing conditions) and 100 percent (i.e., maximum hydropower development). The impact on dissolved oxygen predictions for existing conditions (0 percent hydropower) while increasing K_2 from 0.1 to 1.0 day^{-1} was an increase in the predicted dissolved oxygen at the higher rate that ranged from 0.6 to 1.7 mg/l greater than at the lower rate for the study area reaches. When maximum hydropower development (100 percent flow through the turbines and no reaeration from the dams) was modeled, the predicted dissolved oxygen at the higher rate (1.0 day^{-1}) was 1.0 to 4.5 mg/l higher than at the lower rate (0.1 day^{-1}).

These results indicate that the selection of the reaeration rate (or method) is a major potential source of error in the accuracy of the dissolved oxygen predictions during calibration. However, the accuracy of the selected method during calibration and verification indicates that the potential error in this study is probably not very large.

Algal Parameters. The algal parameters were varied while the reaeration option was kept constant (i.e., the O'Connor-Dobbins equation). The algal parameter values were selected to maintain chlorophyll a predictions near the observed levels. The impact on dissolved oxygen was used as the indicator of model sensitivity.

The invariant model parameters adjusted during the sensitivity analyses included oxygen production by algae (photosynthesis) and oxygen uptake by algae (respiration). The initial model runs were made using values consistent with the available literature: oxygen production = 1.8 mgO/mgA; oxygen uptake = 2.3 mgO/mgA. During sensitivity analyses, the oxygen production was increased to 2.0 mgO/mgA and oxygen uptake was decreased to 1.4 mgO/mgA. These changes produced results that better matched the observed conditions. However, the changes resulted in an increase in predicted dissolved oxygen levels of about 0.3 mg/l, when compared to the initial values.

The light extinction coefficient was lowered from an initial value of 2.0 ft^{-1} to an extreme value of 0.2 ft^{-1}. This resulted in increased algal production, with a higher chlorophyll a concentration and an increased instream dissolved oxygen level. The chlorophyll a concentration was used to control the adjustments to the algal settling rate. The order of magnitude decrease (2.0 to 0.2 ft^{-1}) predicted a dissolved oxygen increase of about 0.5 mg/l. The light extinction coefficient values selected for the calibrated model were fairly accurate in predicting dissolved oxygen and chlorophyll a values. The accuracy of the selected values also was indicated by predicted Secchi disc readings of 2 to 3 ft, which are consistent with the observed conditions for the calibration and verification data sets.

The algal settling rate was increased from 4.0 to 6.0 ft^{-1}, with a resulting decrease in dissolved oxygen of about 0.2 mg/l. This indicates a low sensitivity of dissolved oxygen to this parameter. The algal settling rate as used in the QUAL II model represents a removal mechanism for algae (chlorophyll a). The adjustment from 4.0 to 6.0 ft^{-1} resulted in a decrease in chlorophyll a of about 3 μg/l.

The results of the model sensitivity runs indicated that the dissolved oxygen levels predicted by QUAL II are most sensitive to the light extinction coefficient. This agrees with observations by others (Miller personal communication). It has been hypothesized that algal blooms observed in the Ohio River are triggered by low velocities at the lower stream flow rates. This results in reduced turbidity and greater light penetration (Miller personal communication).

Evaluation of Calibrated Model Performance. The ability of the model to accurately predict dissolved oxygen conditions in the study area rivers was analyzed by comparing the observed conditions in each data set to the predictions during calibration and verification. This evaluation is summarized in Table 3-4. These results indicate that the model performed well during both calibration and verification.

3.1.3 Projected Water Quality With Hydropower Development

The calibrated and verified QUAL II water quality model was used to predict the effect of hydropower development on study area river dissolved oxygen levels. Hydropower development was simulated by varying the amount of flow passing over the dam versus passing through a turbine. The levels of water quality parameters other than dissolved oxygen also were predicted by the model. These predictions are not discussed in this report, since dissolved oxygen was the focus of the present study. Moreover, it was observed that the flow adjustments for dam reaeration did not have an affect on the predicted levels of the other parameters.

Conditions Evaluated. Low flow and hot summer weather were the critical conditions selected for modeling. These summer conditions were

Table 3-4. Performance statistics for calibration and verification of QUAL II model (dissolved oxygen data).

	Average Error mg/l	Absolute Value Error mg/l	RMS Error mg/l	Average Percent Error
Calibration Data				
Ohio River	0.38	0.38	0.56	4.7
Allegheny River	0.15	0.15	0.21	1.9
Monongahela River	0	0	0	0
Verification Data				
Ohio River	0.13	0.13	0.25	2.2
Allegheny River	0.19	0.20	0.30	2.7
Monongahela River	-0.08	0.08	0.16	1.45

$$\text{Average Error} = \frac{1}{n} \Sigma\ O-P$$

$$\text{Absolute Value Error} = \frac{1}{n} \Sigma\ /O-P/$$

$$\text{RMS Error} = \left[\frac{1}{n} \Sigma\ (O-P)^2\right]^{1/2}$$

$$\text{Average Percent Error} = \frac{1}{n} \Sigma\ \frac{O-P}{O}$$

where:

O = observed data
P = model predicted data

selected based on a review of ambient conditions observed in the study area between 1978 and 1983. Worst case conditions reported for August 1983 (Ohio River temperature 26.7°C) was selected. The most important aspect of selecting this temperature is to establish the level of dissolved oxygen saturation. Higher temperatures lower the dissolved oxygen saturation level, while lower temperatures increase the saturation level. Sensitivity analyses for the affect of temperature selection were not performed for this study using the water quality model.

The flow conditions selected for the modeling analysis included the lowest Long Term Monthly Average (LTMA) and the Lowest Flow Expected (LFE). These flows were estimated for the headwaters (Allegheny at Mile 15.0 and Monongahela at Mile 15.0) and a tributary (Beaver River). Flows at other points in the study area were determined for the modeling using point source flows and a mass balance. The available flow data included gage information at the Allegheny River (Mile 13.3), Monongahela River (Mile 11.2), Ohio River (Mile 15.2), and the Beaver River (Mile 5.3). These data were combined using a flow balance to develop the flow rates in the model, as presented in Table 3-5.

The impacts of hydropower development were evaluated by considering a fraction of the available flow for passage through the turbines as opposed to across the dam. The flow through the turbine was modeled at 0 percent, 50 percent, and 100 percent of the river flow. The condition with zero flow through the turbine was modeled to establish the baseline condition. The 50 percent and 100 percent flow conditions were run at all locks and dams to reflect a varying level of conversion to hydropower. The cumulative impact of hydropower development at all locks and dams is indicated by the successive changes in dissolved oxygen levels (as predicted by the model) as a function of increasing distance down river. The impact at a specific lock and dam can be inferred by the shape of the dissolved oxygen curve upstream and downstream of the facility.

Model Predictions. The impact of hydropower conversion on dissolved oxygen is presented for the three rivers in Figures 3-7, 3-8, and 3-9, for the lowest LTMA flow rate. The baseline condition on the rivers (0 percent

Table 3-5. Flow rates used in impact analysis.

Long Term Monthly Average (LTMA) (lowest value)

Location	Flow (cfs)	Basis
HW Allegheny (15.0)	4,730	Records at Mile 13.3, for September flow average (ORSANCO 1984)
HW Monongahela (15.0)	3,990	Calculated from flow balance with Allegheny and Ohio Rivers, and intermediate point source flows
Ohio River (0.0)	8,720	Records at Mile 15.2, for September flow average (9,020 cfs) adjusted for intermediate point source flows
Beaver River (enters Ohio River at 25.6)	1,410	Records at Mile 5.3 on Beaver River, for September flow average
Ohio River (25.6)	10,430	Calculated from flow balance

Lowest Flow Expected (LFE)

Location	Flow (cfs)	Basis
HW Allegheny (15.0)	1,890	Calculated from flow balance with Monongahela and Ohio Rivers
HW Monongahela (15.0)	1,440	Records at Mile 11.2, for lowest flow observed September 1983
Ohio River (0.0)	3,330	Records at Mile 15.2, for lowest flow observed September 1983 (3,630 cfs), adjusted for intermediate point source flows
Beaver Run (enters Ohio River at 25.6)	670	Records at Mile 5.3 on Beaver River, for lowest flow observed September 1983
Ohio River (25.6)	4,300	Calculated from flow balance

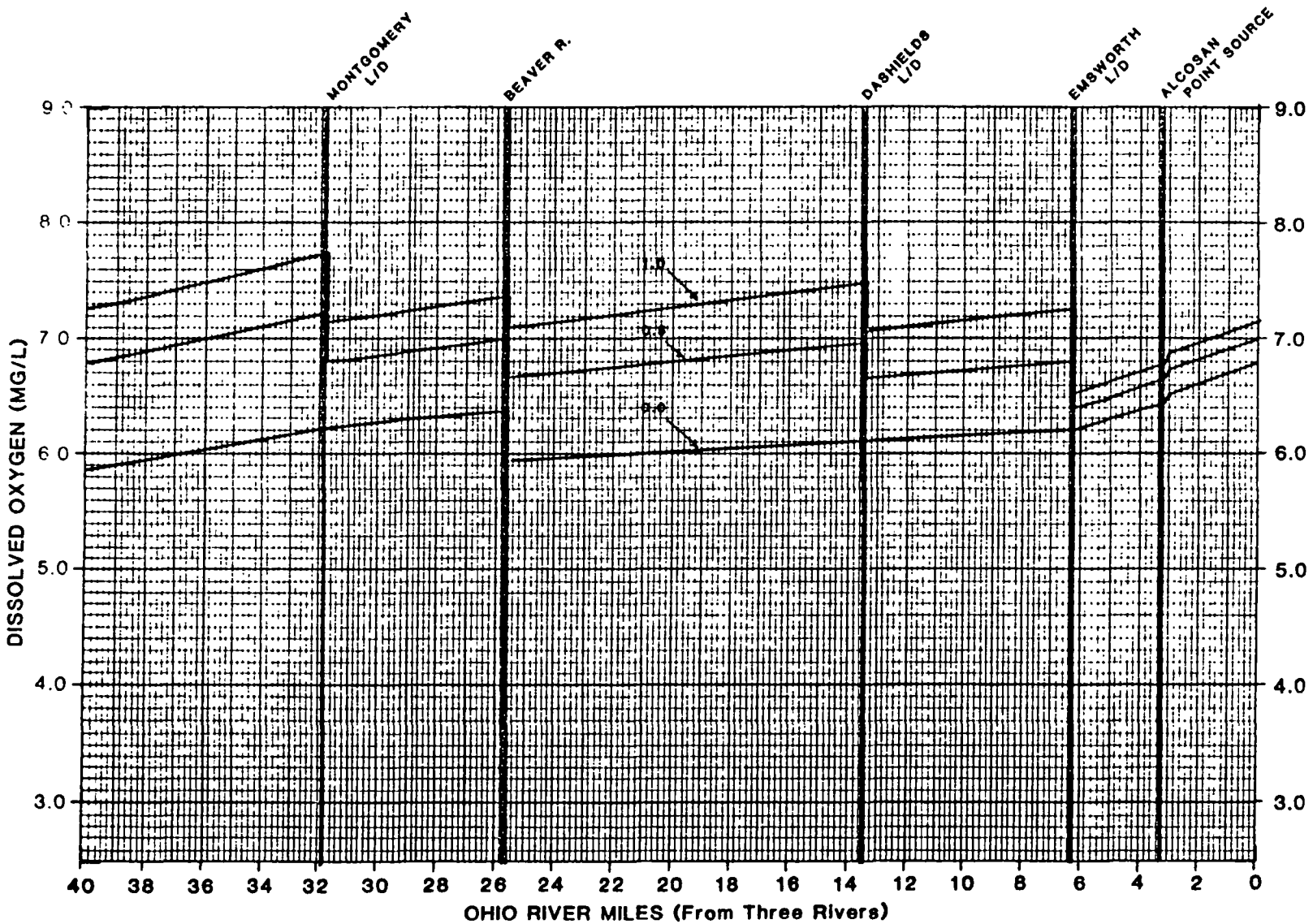


Figure 3-7. Model prediction for Long Term Monthly Average (LTMA) flow for the Ohio River. Three scenarios for Hydropower Retrofit (1.0 = ambient conditions; 0.5 = partial hydropower development; 0.0 = development at all dams).

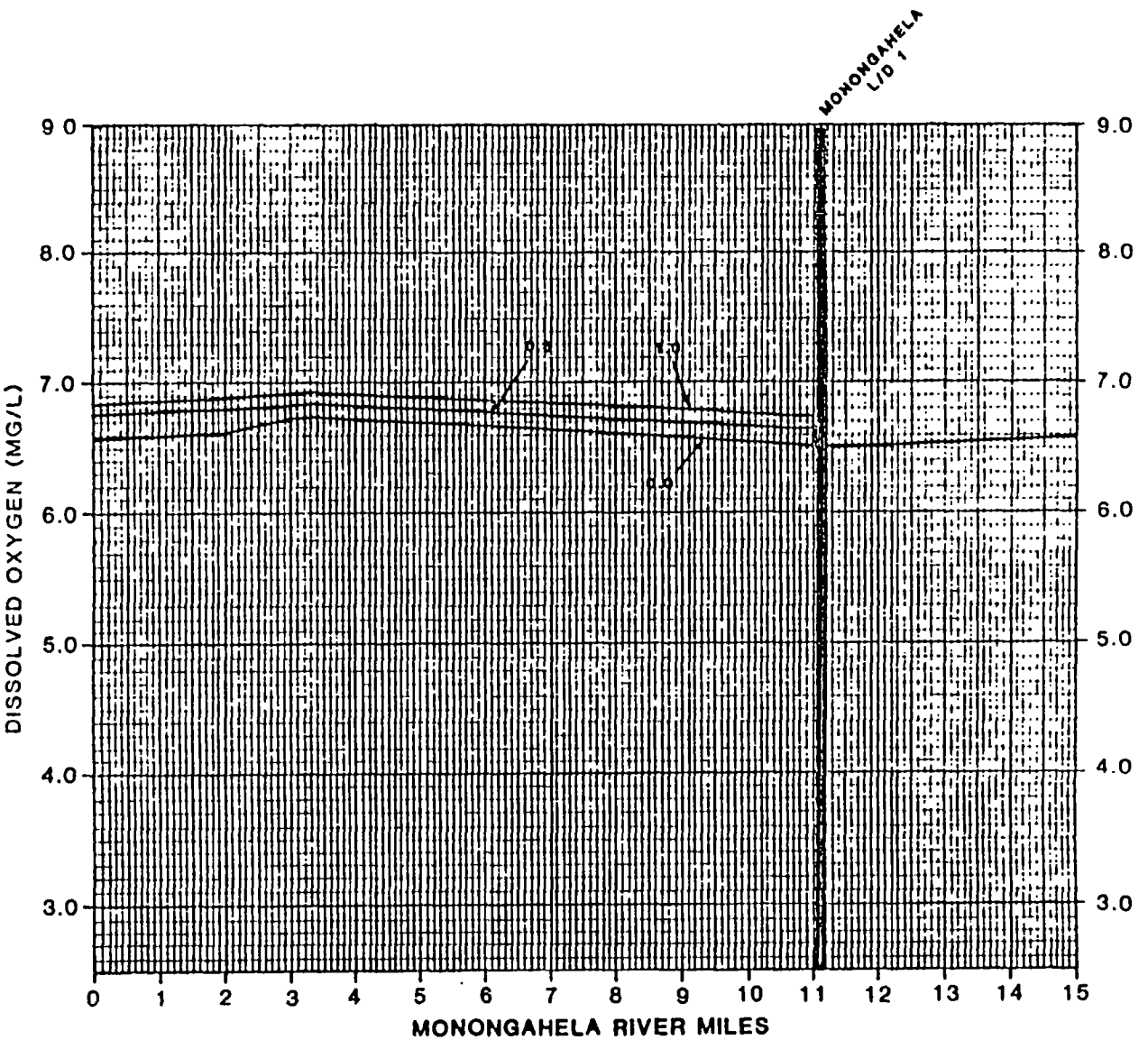


Figure 3-8. Model prediction for Long Term Monthly Average (LTMA) flow for the Monongahela River. Three scenarios for Hydropower Retrofit (1.0 = ambient conditions; 0.5 = partial hydropower development; 0.0 = development at all dams).

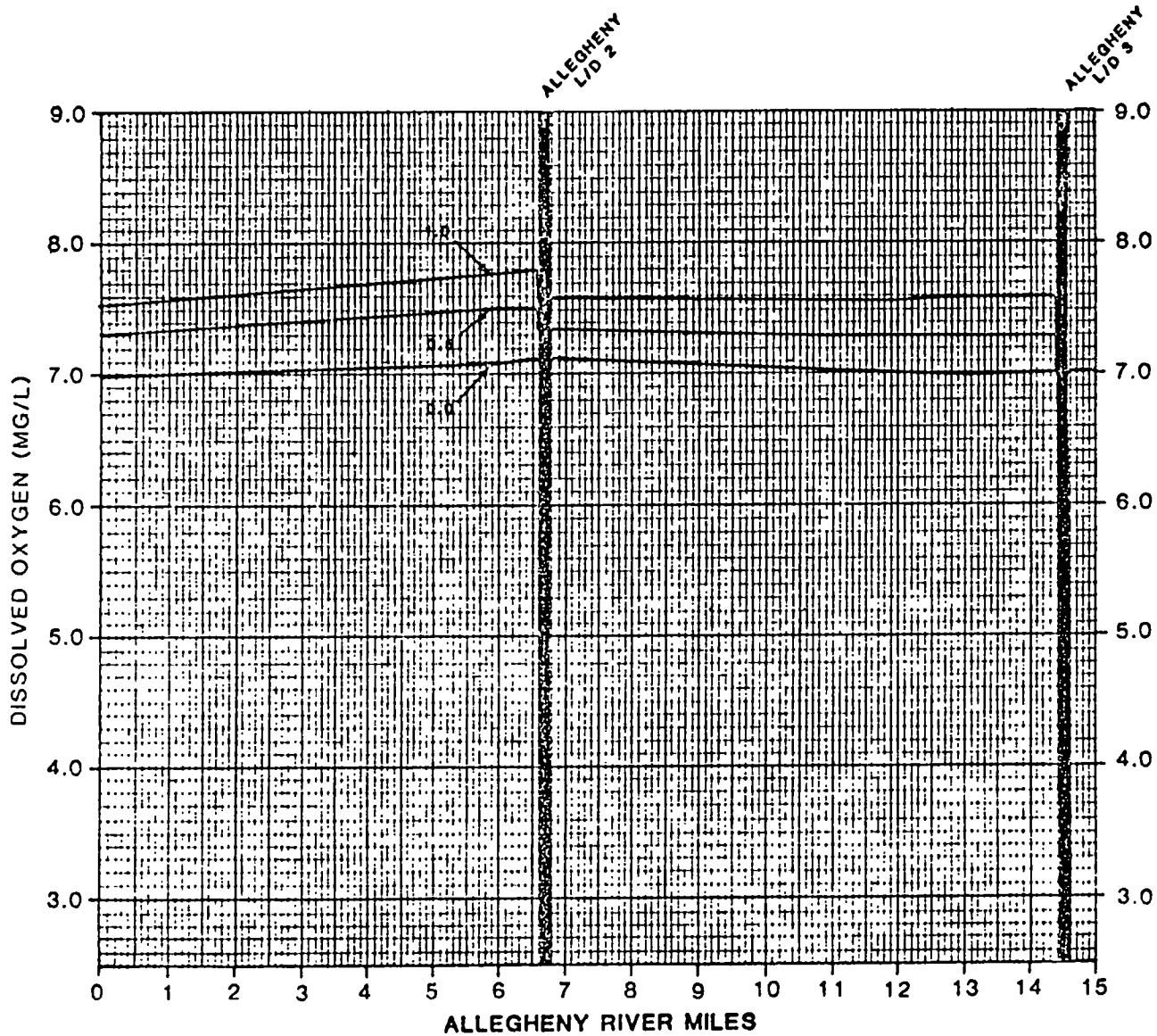


Figure 3-9. Model prediction for Long Term Monthly Average (LTMA) flow for the Allegheny River. Three scenarios for Hydropower Retrofit (1.0 = ambient conditions; 0.5 = partial hydropower development; 0.0 = development at all dams).

hydropower development) reflects the maximum reaeration condition; with hydropower development there is a decrease in reaeration. The reaeration predicted in this analysis for the locks and dams was:

Source	DO Increase at 0% Hydropower mg/l		DO Increase at 50% Hydropower mg/l		DO Increase at 100% Hydropower mg/l	
	LTMA	LFE	LTMA	LFE	LTMA	LFE
Allegheny L/D 2	0.2	0	0.15	0	0	0
Allegheny L/D 3	0.6	0.6	0.3	0.2	0	0
Monongahela L/D 2	0.25	0.2	0.12	0.1	0	0
Ohio Emsworth L/D	0.7	1.0	0.4	0.5	0	0
Ohio Dashields L/D	0.4	0.5	0.3	0.4	0	0
Ohio Montgomery L/D	0.6	0.8	0.4	0.5	0	0

A cumulative impact from hydropower development would be demonstrated as a dissolved oxygen deficit that increases down river at higher levels of hydropower conversion. At Ohio River Mile 40.0, the difference between the existing condition (0 percent hydropower) and the maximum hydropower conversion dissolved oxygen levels is 1.4 mg/l, while the difference at Ohio River Mile 0.0 is 0.4 mg/l. The existing condition dissolved oxygen is predicted to remain at high levels, while the maximum hydropower development shows a slightly degraded condition. This indicates that the loss of reaeration by reducing flow over the locks and dams will be demonstrated as a cumulative impact. However, the loss in reaeration will be partially offset by higher reaeration in the river due to the higher deficit in the river. The results for the LTMA condition, as shown in Figure 3-7, do not indicate that the cumulative impact would cause a water quality violation (i.e., dissolved oxygen below 5.0 mg/l). The results in Figures 3-8 and 3-9 do not demonstrate a significant impact.

The impact of hydropower conversion on dissolved oxygen for the Lowest Flow Expected (LFE) is presented in Figures 3-10, 3-11, and 3-12. These results generally agree with the results from the LTMA evaluation. However, the dissolved oxygen levels show a more rapid decrease downstream of the Montgomery L/D. The results do not indicate a water quality violation within the study area, but extending the curves (at the same rate of decline) would result in a dissolved oxygen of 5.0 mg/l at about River Mile 51 for the 100 percent flow conditions. This could indicate the potential for adverse impacts downstream of the study area.

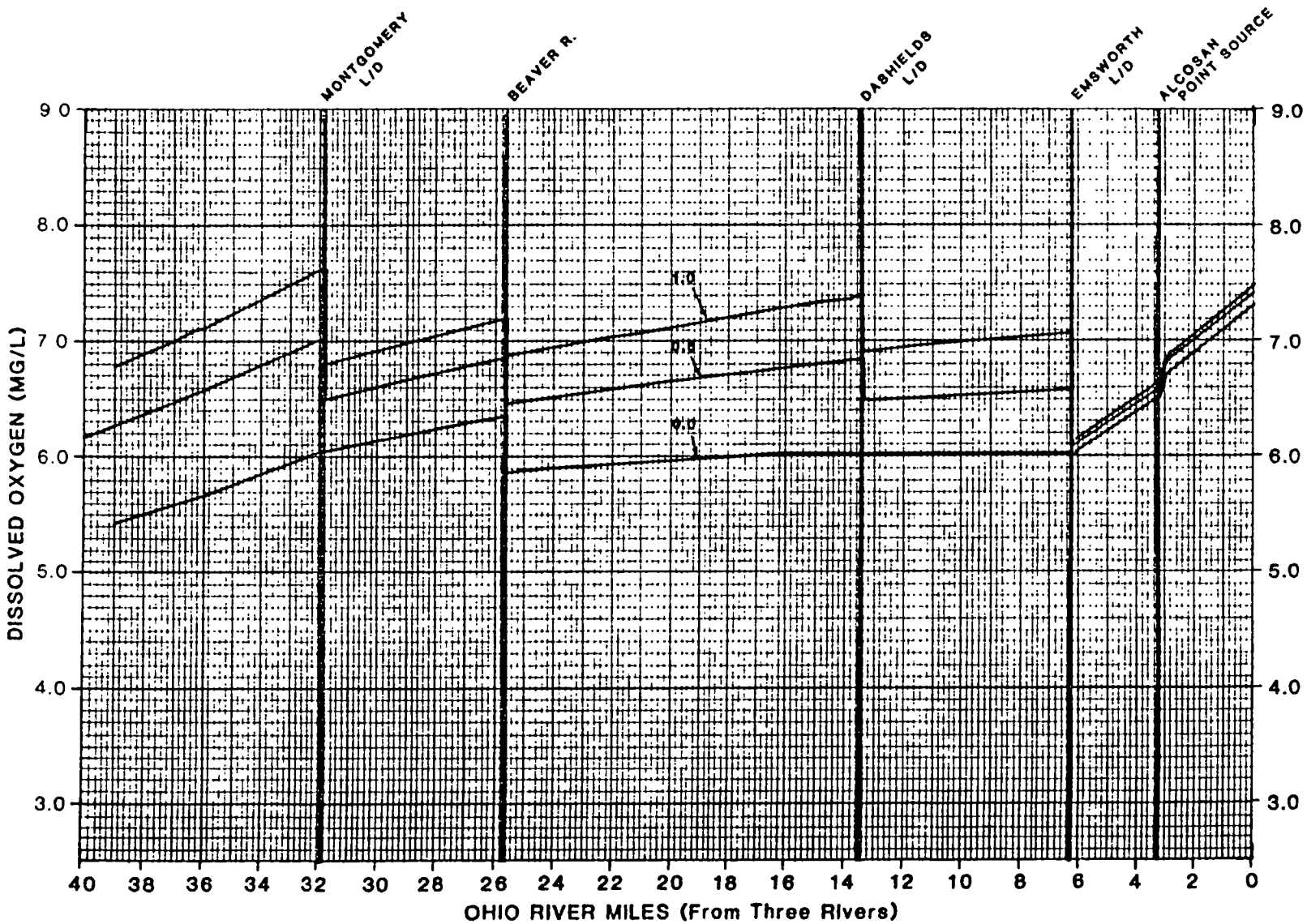


Figure 3-10. Model prediction for Low Flow Expected (LFE) flow for the Ohio River. Three scenarios for Hydropower Retrofit (1.0 = ambient conditions; 0.5 = partial hydropower development; 0.0 = development at all dams).

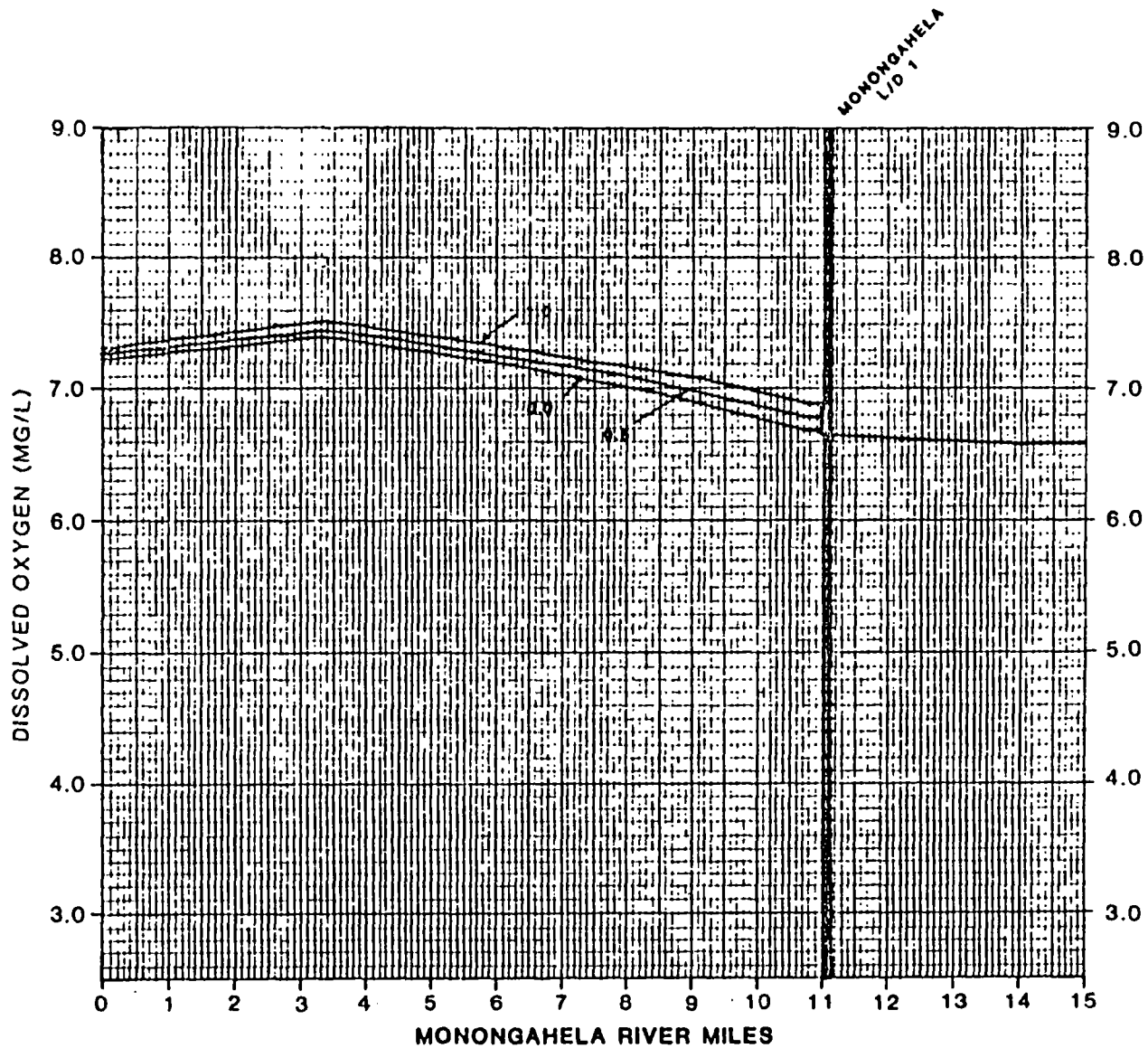


Figure 3-11. Model prediction for Low Flow Expected (LFE) flow for the Monongahela River. Three scenarios for Hydropower Retrofit (1.0 = ambient conditions; 0.5 = partial hydropower development; 0.0 = development at all dams).

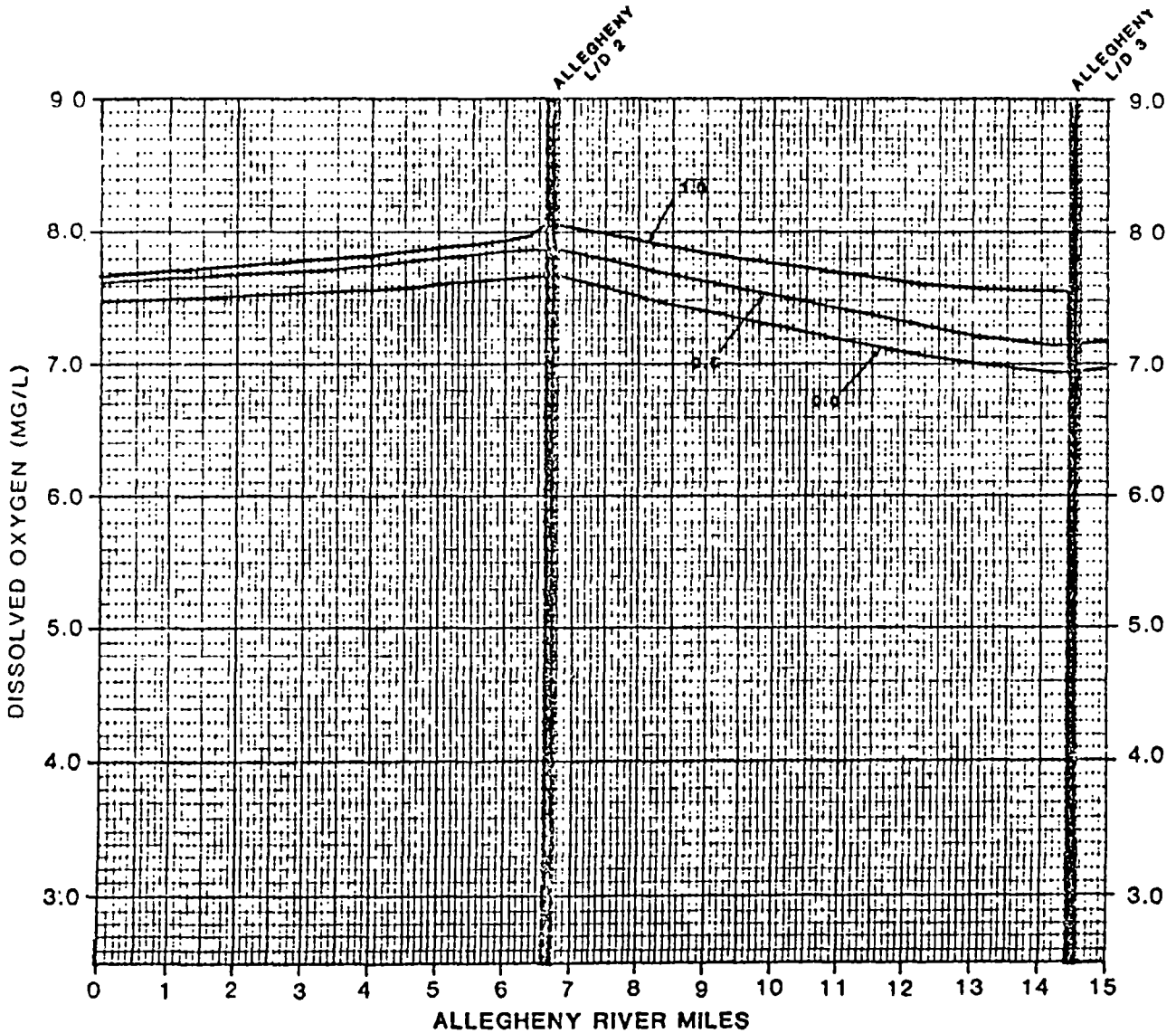


Figure 3-12. Model prediction for Low Flow Expected (LFE) flow for the Allegheny River. Three scenarios for Hydropower Retrofit (1.0 = ambient conditions; 0.5 = partial hydropower development; 0.0 = development at all dams).

3.2 THE STUDY AREA FISHERY

3.2.1 Composition of the Community

A thorough historical perspective regarding ichthyological studies of the Ohio River basin, documentation of changes in composition of the fishery along the river and through time, and attendant changes resulting from man's activities has been prepared by Lachner (1956), ORSANCO (1962), Krumholz (1981), Trautman (1981), and Pearson and Krumholz (1984). These sources document changes in the fishery from the period of colonization of the basin by Europeans to the 1980's. They ascribe major changes in the fishery to increases in turbidity and siltation as a result of clearing of the watershed for farming; depression of dissolved oxygen concentrations as a result of population increases in metropolitan areas and increased discharge of septage to study area rivers; degradation of water quality as a result of metal and organics discharges by industry; reduction of river water pH as a result of acid mine drainage from the coal fields along the Allegheny and Monongahela Rivers; and changes resulting from impounding the free-flowing rivers to enhance navigation. Recent recovery of the fishery of the upper basin has occurred as a result of the installation, use, and upgrading of industrial and sanitary waste treatment facilities.

Some of the earliest accounts of the fishes of the Ohio River were published by travelers on the Ohio prior to 1818 (Pearson and Krumholz 1984). Subsequently, regional, state, or Ohio River basin-wide fisheries surveys have been conducted and have documented the occurrence of some 154 species. Through time, 111 species were reported from the river prior to 1920; between 1920 and 1969, 121 species were reported; and between 1970 and 1983, 130 species were collected. The upper basin, from Pittsburgh downstream to River Mile 327, has yielded 120 species (Pearson and Krumholz 1984).

The study area, the upper Ohio River and lower reaches of the Allegheny and Monongahela Rivers, has yielded 122 species (Table 3-6) distributed among the following 20 families: Petromyzontidae (lampreys), Acipenseridae (sturgeons), Polyodontidae (paddlefishes), Lepisosteidae

Table 3-6. Fishes occurring in the upper mainstem of the Ohio River and lower Allegheny and Monongahela Rivers.[a,b]

Family Name Scientific Name Common Name
Petromyzontidae
Ichthyomyzon bdellium Ohio lamprey
Ichthyomyzon castaneus Chestnut lamprey
Ichthyomyzon greeleyi Allegheny brook lamprey
Ichthyomyzon unicuspis Silver lamprey
Lampetra aepyptera Least brook lamprey
Acipenseridae
Acipenser fulvescens Lake sturgeon
Scaphirhynchus platorynchus Shovelnose sturgeon
Polyodontidae
Polyodon spathula Paddlefish
Lepisosteidae
Lepisosteus osseus Longnose gar
Lepisosteus platostomus Shortnose gar
Amiidae
Amia calva Bowfin
Anguillidae
Anguilla rostrata American eel
Clupeidae
Alosa chrysochloris Skipjack herring
Alosa pseudoharengus Alewife
Dorosoma cepedianum Gizzard shad
Hiodontidae
Hiodon alosoides Goldeye
Hiodon tergisus Mooneye
Salmonidae
Salmo gairdneri Rainbow trout
Salmo trutta Brown trout
Esocidae
Esox americanus americanus Redfin pickerel
Esox americanus vermiculatus Grass pickerel
Esox lucius Northern pike
Esox masquinongy Muskellunge

Table 3-6. (continued)

Family Name Scientific Name Common Name	Family Name Scientific Name Common Name
Cyprinidae	Cyprinidae (continued)
Campostoma anomalum Stoneroller	*Notropis boops* Bigeye shiner
Carassius auratus Goldfish	*Notropis buchanani* Ghost shiner
Clinostomus elongatus Redside dace	*Notropis chrysocephalus* Striped shiner
Cyprinus carpio Carp	*Notropis cornutus* Common shiner
Ericymba buccata Silverjaw minnow	*Notropis heterolepis* Blacknose shiner
Hybopsis aestivalis Speckled chub	*Notropis hudsonius* Spottail shiner
Hybopsis amblops Bigeye chub	*Notropis photogenis* Silver shiner
Hybopsis dissimilis Streamline chub	*Notropis rubellus* Rosyface shiner
Hybopsis storeriana Silver chub	*Notropis spilopterus* Spotfin shiner
Hybopsis x-punctata Gravel chub	*Notropis stramineus* Sand shiner
Nocomis micropogon River chub	*Notropis umbratilis* Redfin shiner
Notemigonus crysoleucas Golden shiner	*Notropis volucellus* Mimic shiner
Notropis ariommus Popeye shiner	*Notropis whipplei* Steelcolor shiner
Notropis atherinoides Emerald shiner	*Phenacobius mirabilis* Suckermouth minnow
Notropis blennius River shiner	*Phoxinus erythrogaster* Southern redbelly dace

Table 3-6. (continued)

Family Name Scientific Name Common Name
Cyprinidae (continued)
Pimephales notatus Bluntnose minnow
Pimephales promelas Fathead minnow
Pimephales vigilax Bullhead minnow
Rhinichthys atratulus Blacknose dace
Semotilus atromaculatus Creek chub
Catostomidae
Carpiodes carpio River carpsucker
Carpiodes cyprinus Quillback
Carpiodes velifer Highfin carpsucker
Catostomus commersoni White sucker
Cycleptus elongatus Blue sucker
Hypentelium nigricans Northern hog sucker
Ictiobus bubalus Smallmouth buffalo
Ictiobus cyprinellus Bigmouth buffalo
Ictiobus niger Black buffalo

Family Name Scientific Name Common Name
Catostomidae (continued)
Minytrema melanops Spotted sucker
Moxostoma anisurum Silver redhorse
Moxostoma carinatum River redhorse
Moxostoma duquesnei Black redhorse
Moxostoma erythrurum Golden redhorse
Moxostoma macrolepidotum Shorthead redhorse
Ictaluridae
Ictalurus catus White catfish
Ictalurus furcatus Blue catfish
Ictalurus melas Black bullhead
Ictalurus natalis Yellow bullhead
Ictalurus nebulosus Brown bullhead
Ictalurus punctatus Channel catfish
Noturus eleutherus Mountain madtom
Noturus flavus Stonecat

Table 3-6. (continued)

Family Name / Scientific Name / Common Name
Ictaluridae (continued)
Noturus gyrinus — Tadpole madtom
Noturus miurus — Brindled madtom
Noturus stigmosus — Northern madtom
Pylodictis olivaris — Flathead catfish
Percopsidae
Percopsis omiscomaycus — Trout-perch
Cyprinodontidae
Fundulus diaphanus — Banded killifish
Fundulus notatus — Blackstripe topminnow
Atherinidae
Labidesthes sicculus — Brook silverside
Percichthyidae
Morone chrysops — White bass
Morone saxatilis — Striped bass
Centrarchidae
Ambloplites rupestris — Rock bass
Centrarchidae (continued)
Lepomis cyanellus — Green sunfish
Lepomis gibbosus — Pumpkinseed
Lepomis gulosus — Warmouth
Lepomis humilis — Orangespotted sunfish
Lepomis macrochirus — Bluegill
Lepomis megalotis — Longear sunfish
Lepomis microlophus — Redear sunfish
Micropterus dolomieui — Smallmouth bass
Micropterus punctulatus — Spotted bass
Micropterus salmoides — Largemouth bass
Pomoxis annularis — White crappie
Pomoxis nigromaculatus — Black crappie
Percidae
Ammocrypta pellucida — Eastern sand darter

Table 3-6. (continued)

Family Name Scientific Name Common Name	Family Name Scientific Name Common Name
Percidae (continued)	Percidae (continued)
Etheostoma blennioides Greenside darter	*Percina copelandi* Channel darter
Etheostoma caeruleum Rainbow darter	*Percina macrocephala* Longhead darter
Etheostoma flabellare Fantail darter	*Percina maculata* Blackside darter
Etheostoma nigrum Johnny darter	*Percina oxyrhyncha* Sharpnose darter
Etheostoma spectabile Orangethroat darter	*Stizostedion canadense* Sauger
Etheostoma variatum Variegate darter	*Stizostedion vitreum vitreum* Walleye
Etheostoma zonale Banded darter	Sciaenidae
	Aplodinotus grunniens Freshwater drum
Perca flavescens Yellow perch	Cottidae
Percina caprodes Logperch	*Cottus bairdi* Mottled sculpin

[a]Nomenclature used herein follows that of Bailey, et al. 1970.

[b]Sources Reviewed: ORSANCO 1977, 1981; Pearson and Krumholz 1984; Energy Impact Assoc. 1978, 1980; Raney 1938; Geo-Marine, Inc. 1978, 1981, 1982; WAPORA, Inc. 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981; Trautman 1981; NUS 1975, 1979a and b, 1982; Atlantic Power Development Corp. 1983; Allegheny County, PA 1982; Allegheny Electric Cooperative, Inc. 1982; C.E. Maguire 1983a and b; Chas. T. Main, Inc. 1984; Burgess & Niple, Ltd. 1983; Allegheny Power System 1977; Krumholz 1981; Pennsylvania Power Company 1976; Westinghouse Electric Corp. 1975a, b, c, d, e, and f, 1976, 1977; Denoncourt, et al. 1975; Preston and White 1978; Smith and Shema 1982; U.S. Army Corps of Engineers 1978, 1980; Ecological Analysts, Inc. 1978, 1979; Preston 1974; Equitable Environmental Health, Inc. 1979a and b; Duquesne Light Co. 1977, 1979; Krumholz and Minckley 1964.

(gars), Amiidae (bowfins), Anguillidae (eels), Clupeidae (herrings), Hiodontidae (mooneyes), Salmonidae (trouts), Esocidae (pikes), Cyprinidae (minnows and carps), Catostomidae (suckers), Ictaluridae (freshwater catfishes), Percopsidae (trout-perches), Cyprinodontidae (killifishes), Atherinidae (silversides), Percichthyidae (temperate basses), Centrarchidae (sunfishes), Percidae (perches), Sciaenidae (drums), and Cottidae (sculpins). Species introduced to the river or within the Ohio River basin include the alewife (Alosa pseudoharengus), rainbow trout (Salmo gairdneri), brown trout (S. trutta), northern pike (Esox lucius), goldfish (Carassius auratus), common carp (Cyprinus carpio), white catfish (Ictalurus catus), banded killifish (Fundulus diaphanus), and striped bass (Morone saxatilis) (Trautman 1981, Pearson and Krumholz 1984). Lachner (1956) noted that there has been considerable change in the fish fauna of the upper Ohio River basin since the early nineteenth century. The following species, some of which were common or abundant before 1900, currently have greatly reduced populations or have been extirpated from the upper basin: paddlefish (Polyodon spathula), lake sturgeon (Acipenser fulvescens), shortnose gar (Lepisosteus platostomus), bowfin (Amia calva), goldeye (Hiodon alosoides), gizzard shad (Dorosoma cepedianum), smallmouth buffalo (Ictiobus bubalus), highfin carpsucker (Carpiodes velifer), river carpsucker (C. carpio), blue sucker (Cycleptus elongatus), river shiner (Notropis blennius), blue catfish (Ictalurus furcatus), sauger (Stizostedion canadense), and freshwater drum (Aplodinotus grunniens). The Ohio lamprey (Ichthyomyzon bdellium), shorthead redhorse (Moxostoma breviceps), spotted sucker (Minytrema melanops), flathead catfish (Pylodictis olivaris), and warmouth (Lepomis gulosus) are only rarely captured from the upper Ohio River basin.

3.2.2 Relative Abundance of Fishes in the Allegheny, Monongahela, and Ohio Rivers

Characterization of the relative abundance of fishes, diversity, and changes in fish species composition through time for the Allegheny, Monongahela, and Ohio Rivers for the period encompassing settlement through the mid-1950's are difficult to interpret due to a paucity of fisheries surveys (Pearson and Krumholz 1984). However, in 1957, the "Aquatic-Life Resources Project" was initiated, and sampling was conducted through 1959.

The objective of this study was to appraise the suitability of the Ohio River for maintenance of aquatic life, with emphasis centering on determination of the species composition, the distribution, and the relative abundance of fishes of the lower reaches of the Allegheny and Monongahela Rivers, and the entire length of the Ohio River. During this project, fish were sampled by electrofishing; seining; trawling; netting with hoop nets, trammel nets, and gill nets; and by rotenoning Ohio River and tributary lock and dam-lock chambers, stream mouths, backwaters, and other shoreline areas. The results of these surveys were published in 1962 (ORSANCO 1962). Lock chamber fish surveys were again undertaken in 1967, and samples have been collected from various locations along study area rivers from 1967 to date (ORSANCO 1981, ORSANCO personal communication). The results of the 1967 through 1980 lock chamber studies for the main stem of the Ohio River were compiled and summarized by Pearson and Krumholz (1984). Results of lock chamber rotenone studies for the Allegheny and Monongahela Rivers were compiled by ORSANCO (1981). The lock chamber rotenone studies are one source of fisheries information that has been gathered continuously for over 25 years and will be used here to document trends in fish populations of study area rivers through time. However, as with any sampling method, lock chamber rotenone study results undoubtedly present a biased view of the fishery of a stream reach for shoreline inhabiting species are undoubtedly underrepresented.

With enactment of the National Environmental Policy Act (NEPA) of 1969, Environmental Impact Statements were required to be prepared for new construction projects along the Ohio River. The Federal Water Pollution Control Act of 1972, and its amendments PL 92-500, established a national goal of eliminating the discharge of pollutants into all navigable waters by 1985. Subsections 316(a) and 316(b) of PL 92-500 required electric utilities to evaluate the effects of cooling water withdrawals and discharges of thermal effluents to the biota of source water rivers. Enactment of NEPA and PL 92-500 has resulted in numerous site specific biological studies along the Allegheny, Monongahela, and upper Ohio Rivers between 1970 and 1983. Information concerning the composition of the fish community at various locations along the shorelines of study area rivers has, for the most part, been ignored in previous summaries (Krumholz 1981;

Preston and White 1978; Pearson and Krumholz 1984). The results of the latter are included in the following discussion.

Characterization of the fishery of the Allegheny, Monongahela, and upper Ohio Rivers will focus on the last 27 years. Prior to 1957, improperly treated sewage and industrial wastes, coupled with low pH acid mine drainage, influenced fish populations dramatically in the study area (Lachner 1956; Krumholz 1981; ORSANCO 1962). Recent results from lock chamber rotenone studies will be summarized for each study river (Tables 3-7, 3-8, and 3-9), and in discrete time periods--1957-1960, 1967-1970, 1974-1978, 1978-1980, 1981-1983. Where additional site specific studies are available, these will be summarized for the appropriate time period. This will be followed by an overview.

1957-1960

Ohio River (RM 0-200)

Lock Chamber Rotenone Studies. Twenty-two samples were taken during this period and resulted in the collection of 60 species distributed among 209,068 individuals (Table 3-7). Emerald shiner (*Notropis atherinoides*) numerically dominated (84.8%) and was followed by mimic shiner (*N. volucellus*) (8.4%), black bullhead (*Ictalurus melas*) (3.3%), channel catfish (*I. punctatus*) (1.1%), and sand shiner (*N. stramineus*) (0.8%). Overall, the 20 species of cyprinids collected accounted for 95.0 percent of individuals (Table 3-7) and 66.0 percent of the biomass (993.12 kg). Five species--carp, emerald shiner, black bullhead, channel catfish, and gizzard shad--comprised 90.5 percent of the total biomass.

Allegheny and Monongahela Rivers

All Methods. Nearly 90 percent of all fishes taken were mimic shiners and emerald shiners, and these two species, together with the trout-perch (*Percopsis omiscomaycus*) and the rosyface shiner (*Notropis rubellus*), contributed more than 96 percent of the total numbers of fishes taken. However, in total weight, the carp contributed 34.3 percent, the white sucker (*Catostomus commersoni*) 20.2 percent, the emerald shiner 10.4 per-

Table 3-7. Fish collected during Ohio River lock chamber rotenone studies, Ohio River Miles 0-200, from 1967 through 1983.

	1957 - 1960[a]		1967 - 1970[a]		1974 - 1977[a]		1978 - 1980[a]		1981 - 1983[b]	
	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.
Lampreys										
Ohio lamprey	--	--	--	--	--	--	1	0.02	--	--
Paddlefishes										
Paddlefish	1	4.15	--	--	--	--	--	--	--	--
Gars										
Longnose gar	--	--	--	--	3	1.60	19	8.24	7	2.36
Eels										
American eel	--	--	5	0.31	1	0.09	8	0.30	--	--
Herrings										
Skipjack herring	104	23.23	19	1.89	17	2.93	33	3.07	6	0.31
Alewife	--	--	--	--	1	0.01	--	--	--	--
Gizzard shad	307	33.95	8,036	230.13	9,506	219.34	1,833	91.96	76,773	1016.11
Mooneyes										
Goldeye	5	0.95	--	--	--	--	--	--	--	--
Pikes										
Muskellunge	--	--	--	--	3	2.22	1	0.22	1	0.88
Tiger musky	--	--	--	--	--	--	--	--	2	1.38
Minnows and Carps										
Central stoneroller	3	0.02	--	--	--	--	--	--	--	--
Goldfish	14	2.06	6	1.52	5	1.32	1	0.27	--	--
Carp	699	432.07	5,483	1076.24	2,127	997.54	1,682	788.50	4,047	5074.97
Silverjaw minnow	1	0.01	--	--	--	--	--	--	--	--
Bigeye chub	29	0.04	--	--	--	--	--	--	--	--
Silver chub	573	4.53	5	0.09	13	0.09	78	0.15	29	0.53
Golden shiner	17	0.08	25	0.63	--	--	3	0.08	1	0.04

Table 3-7. (continued)

	1957 - 1960[a]		1967 - 1970[a]		1974 - 1977[a]		1978 - 1980[a]		1981 - 1983[b]	
	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.
Minnows and Carps (cont.)										
Emerald shiner	177,358	195.59	44,194	115.53	94,044	147.44	44,633	47.89	187,389	443.89
River shiner	67	0.03	16	0.04	2	0.01	2	0.01	--	--
Bigeye shiner	--	--	--	--	15	0.02	--	--	--	--
Ghost shiner	31	0.04	7	0.02	139	0.06	423	0.31	--	--
Striped shiner	9	0.01	--	--	--	--	--	--	--	--
Common shiner	83	0.14	1	0.01	--	--	--	--	--	--
Spottail shiner	--	--	--	--	--	--	1	0.01	--	--
Silver shiner	7	0.01	--	--	--	--	--	--	--	--
Rosyface shiner	24	0.02	1	0.01	--	--	--	--	--	--
Spotfin shiner	66	0.12	593	1.23	167	0.27	24	0.03	--	--
Sand shiner	1,740	1.97	373	0.60	258	0.26	152	0.09	1,346	0.73
Mimic shiner	17,581	18.04	1,962	2.66	5,978	7.04	13,625	5.69	6,524	4.24
Bluntnose minnow	343	0.52	4,731	8.04	209	0.22	407	0.35	92	0.10
Bullhead minnow	6	0.01	--	--	--	--	--	--	--	--
Creek chub	2	0.01	1	0.01	--	--	--	--	--	--
Unidentified shiners	--	--	18,464	62.23	--	--	--	--	116,911	119.61
Suckers										
River carpsucker	6	1.79	--	--	5	2.92	2	1.60	26	18.77
Quillback carpsucker	3	0.43	3	0.66	3	1.31	4	2.65	21	15.95
White sucker	105	0.88	7	0.63	9	1.35	19	4.89	4	0.85
Smallmouth buffalo	4	1.66	4	3.17	3	4.99	5	4.36	2	3.12
Bigmouth buffalo	--	--	--	--	--	--	1	6.36	--	--
Spotted sucker	8	1.29	1	0.12	3	1.25	22	6.85	50	22.53
Silver redhorse	4	0.43	--	--	--	--	--	--	1	0.15
River redhorse	--	--	--	--	--	--	--	--	1	0.58
Black redhorse	15	1.98	2	0.35	8	1.66	6	2.48	--	--
Golden redhorse	18	1.32	1	0.36	7	1.47	15	3.59	11	3.51
Shorthead redhorse	--	--	--	--	--	--	3	0.58	9	9.64
Unidentified buffalo	--	--	--	--	--	--	--	--	74	97.64
Freshwater catfishes										
White catfish	--	--	570	9.41	542	10.41	77	14.57	17	2.74
Black bullhead	6,896	146.39	15	4.59	--	--	--	--	1	0.52

Table 3-7. (continued)

	1957 - 1960[a]		1967 - 1970[a]		1974 - 1977[a]		1978 - 1980[a]		1981 - 1983[b]	
	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.
Freshwater catfishes (cont.)										
Yellow bullhead	3	0.14	491	13.20	81	4.60	100	8.27	32	0.93
Brown bullhead	431	12.56	4,309	156.32	752	62.12	284	22.55	28	4.97
Channel catfish	2,283	91.00	5,504	164.86	2,566	157.23	2,491	196.99	2,416	188.71
Mountain madtom	1	0.02	--	--	--	--	--	--	--	--
Stonecat	--	--	1	0.01	--	--	5	0.06	--	--
Tadpole madtom	2	0.01	--	--	--	--	--	--	--	--
Brindled madtom	1	0.01	--	--	--	--	--	--	--	--
Flathead catfish	8	1.42	1	0.80	22	8.83	18	17.10	81	25.48
Unidentified bullheads	--	--	--	--	--	--	--	--	2	0.30
Troutperches										
Troutperch	6	0.02	--	--	1	0.01	40	0.09	2	0.01
Silversides										
Brook silverside	--	--	1	0.01	--	--	1	0.01	--	--
Killifishes										
Banded killifish	2	0.01	2	0.02	--	--	--	--	--	--
Temperate basses										
White bass	4	0.85	--	--	18	0.93	41	3.22	140	12.61
Striped bass	--	--	--	--	2	0.03	--	--	22	0.98
Sunfishes										
Rock bass	7	0.07	5	0.04	2	0.11	3	0.19	8	0.82
Green sunfish	31	0.45	162	2.85	17	0.49	5	0.03	6	0.05
Pumpkinseed	11	0.29	210	2.69	20	0.12	2	0.04	4	0.15
Warmouth	6	0.27	1	0.01	1	0.07	1	0.01	--	--
Orangespotted sunfish	5	0.03	14	0.18	44	0.18	2	0.01	11	0.04
Bluegill	46	1.51	214	4.17	61	1.59	61	1.31	73	1.18
Longear sunfish	8	1.04	7	0.17	9	0.19	2	0.01	--	--
Redear sunfish	1	0.01	18	0.25	--	--	--	--	--	--
Smallmouth bass	3	0.04	2	0.13	2	0.10	4	0.07	14	1.54
Spotted bass	19	0.96	346	27.65	107	15.06	29	3.11	132	15.72
Largemouth bass	10	1.49	61	11.16	37	5.60	14	1.90	14	3.62

Table 3-7. (continued)

	1957 - 1960[a]		1967 - 1970[a]		1974 - 1977[a]		1978 - 1980[a]		1981 - 1983[b]	
	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.
Sunfishes (cont.)										
White crappie	26	1.52	231	2.96	99	3.83	151	9.04	281	14.11
Black crappie	6	0.56	221	7.66	25	1.99	13	1.89	80	5.94
Perches										
Johnny darter	--	--	--	--	1	0.01	1	0.01	--	--
Yellow perch	4	0.24	1	0.05	32	1.48	7	0.38	3	0.13
Logperch	1	0.01	5	0.07	3	0.03	3	0.02	2	0.01
Channel darter	--	--	--	--	1	0.01	--	--	--	—
Sauger	--	--	2	1.58	39	10.69	46	8.98	76	19.70
Walleye	1	1.18	10	5.58	1	0.77	13	4.14	76	30.97
Drums										
Freshwater drum	13	3.64	22	1.59	57	16.03	379	47.89	5,328	263.98
Totals	209,068	993.12	96,366	1924.49	117,068	1697.92	66,796	1322.44	325,403	7433.10
No. of chambers sampled	22		18		8		11		13	
No. of species	60		51		51		54		46	

[a]Data for time periods 1957-1960, 1967-1970, 1974-1977, and 1978-1980 were compiled from Pearson and Krumholz 1984.

[b]Data for 1981-1983 were compiled from unpublished ORSANCO data.

Table 3-8. Fish collected during Allegheny River lock chamber rotenone studies, Allegheny River Locks No. 3 and 8, from 1967 through 1983.

Taxon	1967 - 1970		1974 - 1977		1978 - 1980		1981-1983	
	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.
Eels								
American eel	6	0.44	--	--	2	0.30	--	--
Herrings								
Gizzard shad	--	--	--	--	33	4.36	136	6.66
Pikes								
Muskellunge	1	2.27	--	--	1	0.70	--	--
Minnows and Carps								
Carp	59	31.40	--	--	60	43.20	6	4.35
Bigeye chub	48	0.05	--	--	--	--	--	--
Golden shiner	1	0.04	--	--	--	--	1	0.01
Emerald shiner	15,893	14.70	--	--	319	0.50	--	--
Common shiner	--	--	--	--	1	<0.01	--	--
Spottail shiner	--	--	--	--	3	0.03	--	--
Rosyface shiner	25	0.03	--	--	--	--	--	--
Sand shiner	1	0.01	--	--	1	<0.01	--	--
Mimic shiner	6,387	5.84	--	--	194	0.22	--	--
Bluntnose minnow	151	0.16	--	--	5	0.01	--	--
Suckers								
Quillback carpsucker	4	2.83	--	--	6	3.02	--	--
White sucker	1	0.36	--	--	1	<0.01	--	--
Silver redhorse	--	--	--	--	2	0.70	--	--
Black redhorse	6	0.93	--	--	2	0.75	--	--
Golden redhorse	7	2.02	--	--	--	--	10	0.97
Shorthead redhorse	1	0.20	--	--	4	0.90	--	--
Freshwater catfishes								
Yellow bullhead	16	0.13	--	--	1	<0.01	--	--
Brown bullhead	80	10.95	--	--	--	--	--	--
Channel catfish	85	10.24	--	--	197	25.08	80	9.43
Stonecat	--	--	--	--	8	0.01	2	0.01

Table 3-8. (continued)

Taxon	1967 - 1970 No.	1967 - 1970 Kg.	1974 - 1977 No.	1974 - 1977 Kg.	1978 - 1980 No.	1978 - 1980 Kg.	1981-1983 No.	1981-1983 Kg.
Freshwater catfish (cont.)								
Tadpole madtom	--	--	--	--	1	<0.01	--	--
Flathead catfish	29	1.52	--	--	50	3.69	4	0.15
Troutperches								
Troutperch	121	0.29	--	--	703	1.73	12	0.01
Sunfishes								
Rock bass	22	0.60	--	--	2	0.01	2	0.06
Green sunfish	1	0.01	--	--	--	--	--	--
Pumpkinseed	5	0.02	--	--	1	0.06	--	--
Bluegill	9	0.11	--	--	5	0.04	--	--
Smallmouth bass	6	0.21	--	--	2	0.65	2	0.24
Spotted bass	--	--	--	--	--	--	4	0.67
Largemouth bass	2	0.01	--	--	--	--	--	--
White crappie	--	--	--	--	8	0.64	--	--
Black crappie	7	0.59	--	--	--	--	--	--
Perches								
Rainbow darter	--	--	--	--	1	<0.01	--	--
Johnny darter	4	0.01	--	--	13	0.01	--	--
Yellow perch	1	0.01	--	--	6	0.06	--	--
Logperch	10	0.05	--	--	13	0.10	3	0.01
Sauger	--	--	--	--	1	0.25	--	--
Walleye	12	1.78	--	--	18	2.54	15	4.27
Drums								
Freshwater drum	--	--	--	--	1	0.60	28	1.97
Totals	23,001	87.81	--	--	1,665	90.16	305	28.81
No. of chambers sampled	4		0		3		2	
No. of species	31		0		33		14	

Table 3-9. Fish collected during Monongahela River lock chamber rotenone studies, Monongahela River Lock No. 2 and Maxwell Lock, from 1967 through 1983.

Taxon	1967 - 1970		1973 - 1977		1978 - 1980		1981-1983	
	No.	Kg.	No.	Kg.	No.	Kg.	No.	Kg.
Herrings								
Gizzard shad	18	2.32	983	34.74	45	9.43	681	9.67
Minnows and Carps								
Goldfish	--	--	7	0.47	2	0.34	--	--
Carp	143	20.35	2,403	157.96	691	286.28	194	106.81
Golden shiner	--	--	1	0.03	2	0.02	--	--
Emerald shiner	129	0.30	4,742	8.75	6,768	4.95	--	--
River shiner	--	--	1	<0.01	--	--	--	--
Spotfin shiner	--	--	22	0.05	3	0.01	--	--
Sand shiner	--	--	153	0.16	7	0.01	--	--
Mimic shiner	4	<0.01	18	0.03	64	0.03	--	--
Bluntnose minnow	3	0.01	42	0.06	66	0.13	--	--
Fathead minnow	1	0.01	--	--	--	--	--	--
Creek chub	--	--	--	--	1	<0.01	--	--
Suckers								
Quillback carpsucker	--	--	1	0.38	3	2.10	--	--
White sucker	1	0.05	3	0.55	--	--	--	--
Silver redhorse	--	--	1	0.34	--	--	--	--
River redhorse	--	--	--	--	--	--	2	0.36
Black redhorse	--	--	6	1.10	--	--	--	--
Golden redhorse	1	0.47	1	0.09	1	0.25	4	0.74
Redhorse	--	--	--	--	1	0.29	--	--
Freshwater catfishes								
White catfish	--	--	9	0.59	15	1.40	2	0.10
Yellow bullhead	1	0.01	78	0.43	15	0.07	--	--
Brown bullhead	180	11.71	713	18.90	22	0.80	--	--
Channel catfish	2	0.02	1,317	42.02	699	32.84	548	38.51
Flathead catfish	--	--	4	0.02	3	1.81	5	0.92

Table 3-9. (continued)

Taxon	1967 - 1970 No.	1967 - 1970 Kg.	1973 - 1977 No.	1973 - 1977 Kg.	1978 - 1980 No.	1978 - 1980 Kg.	1981-1983 No.	1981-1983 Kg.
Troutperches								
Troutperch	--	--	--	--	6	0.02	--	--
Sunfishes								
Rock bass	--	--	31	0.09	--	--	--	--
Green sunfish	13	0.19	6	0.08	2	0.06	--	--
Pumpkinseed	7	0.19	68	0.63	6	0.06	2	0.06
Warmouth	--	--	1	0.01	--	--	--	--
Orangespotted sunfish	2	0.04	5	0.01	--	--	--	--
Bluegill	14	0.12	733	1.95	6	0.20	--	--
Redear sunfish	--	--	--	--	1	0.01	--	--
Smallmouth bass	--	--	6	0.48	1	0.01	1	0.03
Largemouth bass	3	0.69	295	15.37	2	0.30	--	--
White crappie	--	--	6	0.50	7	0.86	1	0.26
Black crappie	--	--	6	0.63	1	0.16	--	--
Perches								
Johnny darter	--	--	3	<0.01	--	--	--	--
Logperch	--	--	--	--	1	<0.01	--	--
Sauger	--	--	1	0.45	--	--	--	--
Walleye	--	--	--	--	15	9.62	9	7.44
Drums								
Freshwater drum	--	--	--	--	2	1.16	146	3.39
Totals	522	36.48	11,666	286.87	8,458	353.22	1,595	168.29
No. of chambers sampled	4		6		3		2	
No. of species	16		32		30		12	

cent, the golden redhorse (Moxostoma erythrurum) 5.3 percent, and the mimic shiner 4.9 percent of the total catch.

1967-1970

Ohio River (RM 0-200)

Lock Chamber Rotenone Studies. Between 1967 and 1970, lock chamber studies were conducted and yielded a total of 96,366 individuals, 51 species, and 1925.20 kg of biomass (Table 3-7). The 10 most abundant species during this time period were: emerald shiner (45.9%), unidentified shiners (16.2%), gizzard shad (8.3%), carp (5.7%), channel catfish (5.7%), bluntnose minnow (Pimephales notatus) (4.9%), brown bullhead (I. nebulosus) (4.5%), mimic shiner (2.0%), spotfin shiner (Notropis spilopterus) (0.6%), and yellow bullhead (I. natalis) (0.5%). The 14 species of cyprinids, plus unidentifiables, accounted for a large percentage of the individuals collected (78.7%) during this time period as in the 1957-1960 time period. Carp, gizzard shad, channel catfish, brown bullhead, and emerald shiner yielded highest biomass at 1,076.24, 230.13, 164.86, 156.32, and 115.53 kg, respectively. These five species comprised 90.5% of the total biomass collected during this sampling period.

Allegheny River

Lock Chamber Rotenone Studies. During this time period Allegheny River Locks No. 3 and 8 were each sampled twice. This resulted in the collection of 23,001 individuals, 31 species, and 87.81 kg of biomass. Cyprinids accounted for 98.1% of all individuals collected (Table 3-8) and 59.5% of the biomass. The 10 numerical dominants were: emerald shiner (69.1%), mimic shiner (27.8%), bluntnose minnow (0.7%), trout-perch (0.5%), channel catfish (0.4%), brown bullhead (0.3%), carp (0.3%), bigeye shiner (N. boops) (0.2%), flathead catfish (0.1%), and the rosyface shiner (0.1%).

Monongahela River

Lock Chamber Rotenone Studies. Monongahela River Lock No. 2 and

Maxwell Lock were each sampled twice during this study period and yielded a total of 522 fish distributed among 16 species. The three most abundant species were the brown bullhead (34.4%), the carp (27.4%), and the emerald shiner (24.7%); no other species comprised more than 3.5% of the total. Carp and brown bullhead comprised 87.0% of the 36.84 kg of biomass collected.

1974-1977

Ohio River (RM 0-200)

Lock Chamber Rotenone Studies. Eight lock chamber studies were conducted along the upper Ohio River from 1974 through 1977 yielding 117,068 fish, 51 species, and 1697.92 kg biomass (Table 3-7). Cyprinids continued to numerically dominate, accounting for 87.9% of the total. The 10 most abundant species were: emerald shiner (80.3%), gizzard shad (8.1%), mimic shiner (5.1%), channel catfish (2.2%), carp (1.8%), brown bullhead (0.6%), white catfish (0.5%), sand shiner (0.2%), bluntnose minnow (0.2%), and spotfin shiner (0.1%). Of the biomass, 93.4% of the total was made up by five species--carp (58.8%), gizzard shad (12.9%), channel catfish (9.3%), emerald shiner (8.7%), and brown bullhead (3.7%).

Other Studies. During this study period, Ohio River fisheries surveys or impingement sampling was conducted at power plants located at the following Ohio River miles: 34.9, 53.9, 57.5, 102.5, and 160.5. A summary of the catch at each of these sites follows.

Gill netting and impingement sampling were conducted at the Willow Island Power Plant (RM 160.5) from August 1973 through August 1974. Gill netting yielded 773 fish; this catch was dominated by the following five species: spotted bass (64.6%) (*Micropterus punctulatus*), gizzard shad (9.3%), carp (6.7%), channel catfish (5.4%), and brown bullhead (3.9%). All other species comprised <2.6% of the catch in this shoreline sampling. During this period, 30 species and 2,615 individuals were impinged by the Willow Island Power Plant. Channel catfish, gizzard shad, bluegill, (*Lepomis macrochirus*), emerald shiner, and white crappie (*Pomoxis*

annularis) comprised 94.6% of all fish impinged and 65.3% of the biomass (Monongahela Power Company 1976).

A total of 1,301 fish were collected from the Ohio River near the Toronto Power Plant (RM 57.5) in November 1974 during sampling using gill nets, hoop nets, and electrofishing. The community was dominated by emerald shiner, carp, gizzard shad, bluntnose minnow, sand shiner, and largemouth bass (M. salmoides) which comprised 94.9% of the catch. Twenty-five species were collected during the survey (Westinghouse 1974).

Two fish surveys, one in August 1974 and the second in July 1975, were conducted near the Burger Power Plant (RM 102.5) to describe the fish community at this location. Fish were sampled using gill and hoop nets and electrofishing. The 1974 survey yielded only 45 fish distributed among 12 species; this catch was dominated by spotted bass, channel catfish, carp, gizzard shad, and longnose gar (Lepisosteus osseus). The 1975 survey yielded 20 species and 383 fish. Species numerically dominating included spotfin shiner, bluntnose minnow, sand shiner, emerald shiner, and carp, which together comprised 88.0% of the catch. No other species collected during the latter survey comprised more than 4.0% of the total (Westinghouse 1975).

Preoperational baseline aquatic ecological studies for Duquesne Light Company's Beaver Valley Power Station, located at Ohio River Mile 34.9, were conducted from 1972 through 1976 and are summarized here (NUS Corporation 1976). A total of 2,488 fish were collected from transects 1, 2, 2B, and 3 beween 1972 and 1975, representing seven families and 34 species. The catch was numerically dominated by the cyprinids emerald shiner (43.2%), sand shiner (20.9%), bluntnose minnow (14.1%), carp (4.9%), and the channel catfish (4.9%); these five species made up 87.9% of the total catch over the three year period. Nineteen of the remaining 29 species were represented by 10 or fewer individuals (NUS Corporation 1975).

During 1975, fish were sampled using gill nets, electrofishing, and by trawling during August, September, October, and November near the Beaver Valley Power Station. During this period, 1,661 fish were collected

representing seven families and 23 species. Three species, emerald shiner, sand shiner, and bluntnose minnow, accounted for 89.7% of the fishes collected. Channel catfish (2.7%) and yellow perch (Perca flavescens) (1.6%) were the next most abundant species (NUS Corporation 1975).

Fish populations near the Beaver Valley Power Station were sampled monthly from May through September and again in November 1976, using gill nets and electrofishing apparatus. This sampling resulted in the collection of 837 fish consisting of 27 species representing seven families. Emerald shiner, sand shiner, and bluntnose minnow dominated the collections, accounting for 79% of the total catch. Other abundant species were carp, gizzard shad, channel catfish, and yellow perch (Duquesne Light Company 1976).

Ohio Edison initiated annual fish sampling surveys in the vicinity of the W.H. Sammis Plant (Ohio River Mile 53.9) in 1973 to assess fish community structure; these studies have been conducted annually through 1982 and provide a continuous record of change in the composition of the community at this location along the Ohio River. The fishes near this plant were sampled using a variety of methods including electrofishing, gill and hoop netting, trawling, and beach seining, although not all methods were used each year. Table 3-10 presents an overview of the 10 most abundant species collected from this location each year from 1973 through 1982, the total number of individuals collected, and the percentage of the total catch comprised by the community dominants. Over the ten-year period, 23 different taxa occurred among the most numerous species; however, only two species--emerald shiner and carp--were among the top 10 each year. Species among the top 10 during each of 5 or more years included gizzard shad, bluntnose minnow, sand shiner, spotted bass, and channel catfish (Table 3-10). Species that were among the top 10 during only one or two years included white crappie, goldfish, white sucker, Johnny darter (Etheostoma nigrum), green sunfish (Lepomis cyanellus), ghost shiner (Notropis buchanani), and freshwater drum. The ten most abundant species accounted for 79.7-99.4% of the individuals collected during a year. Species displaying dramatic changes in abundance through time included the gizzard shad, emerald shiner, carp, bluntnose minnow, sand shiner, and pumpkinseed

Table 3-10. The results of annual fish sampling near the W.H. Sammis Plant (Ohio River Mile 53.9). Tabular values present ten most abundant species in the catch from 1973 through 1982, the total number of fish collected, the percentage of the total catch the top ten species comprised, and the total number of species collected.[a,b]

Species	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Gizzard shad	1	2	2	4	-	-	9	8	2	5
Emerald shiner	2	1	1	6	9	4	4	3	1	1
Largemouth bass	3	3	4	7	-	-	-	-	-	-
Carp	4	4	6	1	3	7	8	5	5	6
Pumpkinseed	5	7	9	-	10	-	-	-	-	-
Bluegill	6	6	-	-	-	9	-	-	-	-
White crappie	7	-	-	-	-	-	-	10	-	-
Goldfish	8	10	-	-	-	-	-	-	-	-
Smallmouth bass	9	8	-	5	-	-	-	-	-	-
Logperch	10	-	8	8	-	-	-	-	-	-
Bluntnose minnow	-	5	3	2	1	1	6	2	3	3
White sucker	-	9	-	-	8	-	-	-	-	-
Sand shiner	-	-	5	3	2	3	10	7	7	2
Spotfin shiner	-	-	7	10	-	-	-	-	6	9
Spotted bass	-	-	10	9	-	8	-	9	8	10
Trout-perch	-	-	-	-	4	5	2	-	-	-
Mimic shiner	-	-	-	-	5	-	5	4	-	4
Johnny darter	-	-	-	-	6	-	-	-	-	-
Channel catfish	-	-	-	-	7	6	3	6	10	7
Shiner YOY	-	-	-	-	-	2	7	1	9	-
Green sunfish	-	-	-	-	-	10	-	-	-	-
Ghost shiner	-	-	-	-	-	-	1	-	4	-
Freshwater drum	-	-	-	-	-	-	-	-	-	8
Total catch	1889	19466	2346	444	16110	5417	3238	7783	2127	9555
Top 10 species - % of total	98.6	99.4	92.9	79.7	96.8	90.7	82.6	94.1	88.7	95.4
No. of species collected	23	32	35	41	45	44	51	40	39	50

[a]Sampling methods included electrofishing, gill and hoop netting, trawling, and beach seining. Not all methods were used each year.

[b]Sources: WAPORA, Inc. 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981; Geo-Marine, Inc. 1982, 1983.

(L. gibbosus). Over recent years, sport and commercial species, i.e., channel catfish, spotted bass, and freshwater drum appeared to be increasing in abundance whereas largemouth bass, bluegill, and pumpkinseed decreased.

Allegheny River

Lock Chamber Rotenone Studies. None were conducted during this study period.

Other Studies. During the preparation of a 316(a) demonstration for Duquesne Light Company's Cheswick Power Station, the fish of the Allegheny River between River Miles 14.0 and 18.5 were sampled by electrofishing and gill and hoop netting during August 1975. This sampling yielded 237 individuals distributed among 20 species and having a biomass of 45.5 kg. The catch was numerically dominated by emerald shiner (41.7%), bigeye shiner (14.8%), carp (8.9%), pumpkinseed (8.0%), and northern hog sucker (Hypentelium nigricans) (6.8%); these five species comprised 87.2% of the biomass. No other species accounted for more than 4.0% of the catch in terms of either numbers or biomass.

As part of an environmental assessment regarding the impacts associated with commercial sand and gravel dredging operations in the Allegheny River, the Pittsburgh District Army Corps of Engineers sponsored fisheries studies during 1975 and 1977. Fish were collected in pools 3, 5, and 7 in 1975 by electrofishing and in pools 3 and 7 in 1977 by electrofishing, experimental gill netting, and seining. The combined catch over the entire study was 4,931 fish and 44 species; electrofishing, seining, and gill netting yielded 3,849; 868; and 214 fish, respectively. Species dominating the electrofishing catch included emerald shiner (53.3%), mimic shiner (23.9%), bluntnose minnow (6.2%), trout-perch (3.4%), and smallmouth bass (Micropterus dolomieui) (2.1%); overall, cyprinids comprised the majority of the catch, 87.9%. Species dominating the gill netting catch included carp, rockbass (Ambloplites rupestris), brown bullhead, quillback (Carpiodes cyprinus), channel catfish, and walleye (Stizostedion vitreum)

which together accounted for 83.7% of the total. The shoreline seining catch was numerically dominated by minnows and shiners (95.6%).

Allegheny River fish surveys were conducted in April 1977 concurrently with impingement sampling occurring at West Penn Power Company's Armstrong Power Station, Allegheny River Mile 55.4. River fish surveys were conducted on April 26-27, 1977 using electrofishing apparatus and gill and baited hoop nets; this sampling yielded 736 fish representing 21 species and having a biomass of 60.9 kg. Rosyface shiner (59.2% of total number of fish collected), golden redhorse (11.1%), sand shiner (11.1%), bluntnose minnow (5.7%), and smallmouth bass (3.4%) were the more abundant species in the catch. Carp and golden redhorses comprised the greatest portion of the total fish biomass (39.6% of the total biomass and 36.7%, respectively). Impingement sampling was conducted from November 1976 through October 1977 and resulted in the collection of 31 species, 509 individuals, and a biomass of 4.81 kg. The more abundant fish species in impingement were trout-perch (22.4%), unidentifiable redhorses (16.5%), white crappie (11.6%), emerald shiner (7.1%), and golden redhorse (5.5%); all other species comprised less than 5% of the fish impinged (Energy Impact Associates, Inc. 1978).

Monongahela River

Lock Chamber Rotenone Studies. From 1973 to 1977, six lock chamber studies were conducted along the Monongahela River; these studies yielded 11,666 fish distributed among 32 species. Six species--emerald shiner, carp, channel catfish, gizzard shad, bluegill, and brown bullhead--together accounted for 93.3% of the total; none of the remaining species accounted for more than 2.5% of the numerical catch. Of the 286.87 kg of biomass, carp, channel catfish, gizzard shad, and brown bullhead comprised 88.4% (Table 3-9).

1978-1980

Ohio River (RM 0-200)

Lock Chamber Rotenone Studies. Cyprinids continued to numerically

dominate the catch of the upper Ohio River, accounting for 91.4% of the 66,807 individuals collected. The 10 most abundant species during this study period were: emerald shiner (66.8%), mimic shiner (20.4%), channel catfish (3.7%), gizzard shad (2.7%), carp (2.5%), ghost shiner (0.6%), freshwater drum (0.6%), brown bullhead (0.4%), white crappie (0.2%), and yellow bullhead (0.1%). Carp, channel catfish, gizzard shad, emerald shiner, and freshwater drum comprised 88.7% of the 1,322.44 kg biomass collected. During this study period, 54 species were collected (Table 3-7).

Other Studies. Eighteen impingement samples were collected for the preparation of a 316(b) demonstration for the Frank R. Phillips Power Station (Ohio River Mile 15.2) between January 1 and December 31, 1978. This sampling yielded 1,030 fish representing 35 species and nine families; the total biomass was 12.9 kg. The emerald shiner was the most abundant species impinged, accounting for 47.5% of the total number. Next in numerical dominance were channel catfish, bluegill, white crappie, mimic shiner, gizzard shad, and sand shiner, which each accounted for 9.1, 8.0, 6.0, 5.8, 5.3, and 4.3%, respectively, of the total. Together, these seven species accounted for 86.0% of the total number of fish impinged, and 39.0% of the biomass. Carp catch yielded highest biomass (34.0%). Of the remaining 28 species impinged, 23 were represented by 5 or less fish, and 17 species were comprised of 2 or less individuals (Equitable Environmental Health, Inc. 1979a).

Fourteen impingement samples were collected from the Shippingport Atomic Power Station (Ohio River Mile 35.0) between January 1 and December 31, 1978, and resulted in the collection of 24 species representing eight families of fishes. The samples were dominated by cyprinids which accounted for 63.8% of the total catch (939 fish collected) and 25% of the 7.0 kg total biomass. The emerald shiner was the most numerous species impinged, making up 59.0% of the numerical catch but only 15.3% of the biomass. Gizzard shad represented 20.9% of the numerical catch and 42.2% of the biomass. Bluegill, channel catfish, and white bass (*Morone chrysops*) were next in numerical dominance, representing 8.4, 2.7, and 1.8%, respectively, of the catch; these three species comprised 23.9% of

the total biomass impinged. All other species collected represented only 7% of the total number and 5% of the biomass. Seventeen taxa were represented by 10 or fewer individuals and 13 of these had 2 or less individuals (Equitable Environmental Health, Inc. 1979b).

Impingement sampling was also conducted from May 1978 through May 1979 at the Cardinal Plant (Ohio River Mile 76.5). During this study, 39 impingement samples were collected and yielded a total of 12,772 fish representing 43 species and 11 families. The total weight of all fish impinged was approximately 226.6 kg. Four species, the gizzard shad (63.5% of total number), emerald shiner (14.1%), white crappie (7.8%), and channel catfish (6.4%), accounted for 91.8% of the total number of fish collected. Twenty-two species were represented by 10 or fewer individuals, and nine species had 2 or less individuals. Four species represented 85.1% of the biomass: gizzard shad (62.1% of total weight), carp (10.0%), channel catfish (8.8%), and white crappie (4.2%) (NUS Corporation 1979b).

Fisheries monitoring continued at the Beaver Valley Power Station in 1978 with electrofishing, gill netting, and seining being conducted from May through September and again in November. This sampling yielded 2,329 fish representing 34 species, 10 families, and one hybrid. The catch was dominated by the following species of cyprinids: sand shiner (37.0%), emerald shiner (31.3%), bluntnose minnow (16.6%), and carp (6.1%). No other species comprised more than 1.5% of the catch during 1978 and 24 species and the hybrid were each represented by 10 or fewer individuals in the catch.

During 1979, adult fish surveys were performed once per month, from May through September, and in November near the Beaver Valley Power Station. During each survey, fish samples were collected at three study area transects using gill nets, electrofishing gear, trawls, and seines. Cyprinids continued to dominate the catch numerically with sand shiner, bluntnose minnow, emerald shiner, and mimic shiner comprising 97.2% of the total. None of the other 29 species collected accounted for more than 0.5% of the fish collected, and 23 species were represented by 10 or fewer individuals in the combined catch.

Annual fisheries studies were initiated at the Cardinal Plant (Ohio River Mile 76.7) in 1978 and were conducted through 1982. Fish sampling was conducted by trawling, electrofishing, gill and hoop netting, and beach seining (WAPORA, Inc. 1979, 1980, 1981; Geo-Marine, Inc. 1982, 1983). The results of these surveys indicated that the shoreline fishery at this location was numerically dominated by cyprinids, particularly emerald shiner, sand shiner, bluntnose minnow, spotfin shiner, mimic shiner, striped shiner (Notropis chrysocephalus), and carp, as the following overview, which lists the top ten species per year in terms of numerical abundance, shows:

Taxon/Year	1978	1979	1980	1981	1982
Shiner YOY	1	2	6	-	-
Bluntnose minnow	2	1	1	2	2
Sand shiner	3	4	3	3	3
Emerald shiner	4	3	2	1	1
Carp	5	6	8	9	8
Channel catfish	6	7	8	9	8
Spotfin shiner	7	8	7	7	4
Striped shiner	8	9	-	-	-
Golden redhorse	9	-	-	-	-
Trout-perch	10	10	-	-	-
Mimic shiner	-	5	4	6	-
Cyprinidae (unid.)	-	-	5	-	-
Gizzard shad	-	-	9	4	5
Spotted bass	-	-	-	8	-
Smallmouth bass	-	-	-	10	-
Freshwater drum	-	-	-	-	6
White sucker	-	-	-	-	10
Total catch	6724	7523	12767	4148	12678
Top 10 species % of total	97.0	95.2	96.2	95.1	97.7
Total species	40	43	44	38	41

Channel catfish was among the 10 most abundant species each year. The following species were among the top 10 at some time, but not each year of sampling: striped shiner, golden redhorse, trout-perch, mimic shiner, gizzard shad, spotted bass, smallmouth bass, freshwater drum, and white sucker. The increase in sport species in the catch during latter years is particularly promising. During each year, the 10 most abundant species comprised at least 95% of the total catch, while many of the other species

in the catch during a particular year were represented by only a few individuals.

Allegheny River

Lock Chamber Rotenone Studies. Thirty-three species of fish, 1,665 individuals, and 90.16 kg of biomass were collected during three lock chamber surveys conducted along the Allegheny River between 1978-1980. Trout-perch, emerald shiner, channel catfish, and mimic shiner comprised 84.9% of the numerical catch, and carp and channel catfish accounted for 75.7% of the biomass.

Monongahela River

Lock Chamber Rotenone Studies. Emerald shiner, channel catfish, and carp comprised 96.5% of the 8,458 individuals and 91.7% of the 353.22 kg of biomass collected during three lock chamber studies conducted along the Monongahela River during this time period. Overall, 30 species were collected (Table 3-9).

Other Studies. From October 1977 through September 1978 impingement data were collected at Duquesne Light Company's Elrama Power Station, Monongahela River Mile 25.0, for preparation of a 316(b) demonstration. This power plant has a shoreflush intake, and the species impinged on the plant's traveling screens would be representative of the fishery present in shoreline regions along this river. A total of 8,199 fish representing 28 species and 38.81 kg biomass were collected. Species that numerically dominated the catch included the bluegill (69.9%), pumpkinseed (12.6%), gizzard shad (10.0%), emerald shiner (3.4%), and channel catfish (2.3%), for a total of 98.2% of the catch. These species also comprised 88.1% of the biomass (Ecological Analysts, Inc. 1978).

1981-1983

Ohio River (RM 0-200)

Lock Chamber Rotenone Studies. The catch for this study period,

402,176 individuals and 7,433.09 kg biomass, was the highest recorded for any of the study periods. Cyprinids continued to numerically dominate the catch, accounting for 78.7% of the individuals collected. Among the 10 most abundant taxa collected were the following: emerald shiner (46.6%), unidentified shiners (29.1%), gizzard shad (19.1%), mimic shiner (1.6%), freshwater drum (1.3%), carp (1.0%), channel catfish (0.6%), sand shiner (0.3%), white crappie (0.1%), and white bass (<0.1%). Carp, gizzard shad, emerald shiner, freshwater drum, and channel catfish comprised 94.0% of the total biomass. Overall, 46 species were collected during this period (Table 3-7).

Allegheny River

Lock Chamber Rotenone Studies. Allegheny River L/D No. 3 was sampled twice during this study period and yielded a total of 305 fish distributed among 14 species and weighing 28.81 kg. Gizzard shad, channel catfish, and walleye numerically dominated the catch (80.0% of the total), whereas these three species plus carp comprised 85.8% of the biomass (Table 3-8).

Monongahela River

Lock Chamber Rotenone Studies. Two lock chamber studies were conducted at Monongahela River Lock Number 2 during this period; these yielded 1,595 fish distributed among 12 species and weighing 168.38 kg. Gizzard shad, channel catfish, carp, and freshwater drum comprised 98.4% of the numerical catch and 94.1% of the biomass. Nine walleye were collected and accounted for 4.4% of the biomass.

Other Studies. 316(b) studies were conducted during 1981 and 1982 at the Mitchell Power Station located at River Mile 29.4. That study yielded a total of 415 individuals distributed among 16 species. Six species--gizzard shad, freshwater drum, emerald shiner, channel catfish, bluegill, and white crappie--comprised 93.4% of the catch, with each of the six species accounting for 28.4, 22.4, 16.1, 11.1, 9.9, and 5.5%, respectively, of the catch (NUS Corporation 1982).

Overview

Historical summaries of the ecology and biota of the study area have been provided by ORSANCO 1962, Trautman 1981, Krumholz and Minckley 1964, Pearson and Krumholz 1984, Krumholz 1981, Preston 1974, Preston and White 1978, Lachner 1956, and Westinghouse 1976. A brief overview of information presented by the above authors follows.

Prior to European colonization of the study area the watershed of the Allegheny River, Monongahela River, and upper Ohio River was forested with a variety of forest types which contribute to the ecological stability of the watershed. Soil erosion was minimal, seasonal variations in runoff and water quality were dampened, and as a result the quality of water in the major drainages was excellent (Westinghouse 1976, Trautman 1981, Pearson and Krumholz 1984). Remains recovered from Paleo-Indian habitation sites in the lower Allegheny and Ohio River Valley reveal extensive use of, and perhaps seasonal subsistence on, fishes and turtles taken from the river. The physical characteristics of the pristine study area rivers can only be deduced from the reports of early travelers in the region, who consistently remarked on the beauty of these waters and noted the abundant fish life in them (ORSANCO 1962, Trautman 1981, Krumholz 1981, Pearson and Krumholz 1984).

P.B. Sears (cited in Westinghouse 1976) described the history of the white man's economy in the study region in three sections: pioneer-agricultural phase (1770-1850), the industrial transition (1850-1900), and the neo-technical-urban phase (1900 to present). These categories will be used here to explain the changing ecology of the study area.

During the pioneer-agricultural phase the first changes were caused primarily by the initial clearing of the land in the watershed of each of the rivers. Deforestation, by clearing for farmlands, cutting for charcoal to feed the scattered rural iron furnaces, and timbering for lumber and mine props, proceeded rapidly in the lower reaches of the Allegheny River. The impact of deforestation on the waters of these three rivers was dramatic. Seasonal floods were augmented by increased runoff from denuded

hillsides. Soil erosion inevitably followed, with the result that silt loads in the waters were greatly increased. Scouring and siltation of the main river channels proceeded rapidly with the increase in frequency and severity of floods (Westinghouse 1976). For the most part, however, the waters were normally clear, containing little soil in suspension except during some freshets and floods. The bottoms of the waters were free of clayey silts, and were largely composed of sand, gravel, boulders, bedrock, and organic debris. The fish fauna was also one which required clear waters, and clean bottoms of sand, gravel, boulders, and bedrock (Trautman 1981).

Baseline data for the fauna of the lower Allegheny, lower Monongahela, and upper Ohio River during early European colonization are scanty. Lachner (1956) listed approximately 125 species in 25 families as constituting the original fish fauna of the upper Ohio River Basin. Travelers along the Ohio River in the late 1700's remarked on the abundance of fishes. The catch included sturgeon, freshwater drum, walleye, sauger, muskellunge, white catfish, American shad, blue sucker, blue catfish, flathead catfish, and buffalo (ORSANCO 1962). Pike as large as 100 pounds were taken and sturgeon and spoon-bill catfish (*Polyodon spathula*) were not uncommon.

The immediate effect of deforestation on the fauna of the study area was two-fold. Entire species, susceptible to increased silt-load in the waters, were extirpated from the area. Fish species in this category included the harelip sucker (*Lagochila lacera*), big-eye minnow, and creek chubsucker (*Erimyzon oblongus*). The second event was replacement of the extirpated species by adjustment in the silt-tolerant elements of the fauna, to fill vacant niches and occupy depopulated habitats (Westinghouse 1976).

Comprehensive descriptions of the Ohio River made in 1818 and 1819 list depths varying from 3 feet at low water to 30 feet at high water. At low stages the river was almost clear, with over 130 islands and numerous sandbars identified. Fish species described numbered 60, of which 55 are considered valid.

In the 1800's the Ohio River began to change from a natural stream to one influenced by the activity of man. Steamboats were introduced in 1811 and by 1832 there were approximately 230 operating. Near this time the U.S. Army Corps of Engineers began to remove obstructions from the channel and to construct dikes to improve river navigation. These activities decreased the number of sandbars and gravel beds along the upper Ohio River.

The industrial transitional phase (1850-1900) produced the most profound impact on the aquatic fauna of the study area rivers. In addition to the silt pollution that continued from the deforested and largely agricultural watershed, the river was scourged by chemical pollution from mines and industries, and by sewerage from the rapidly increasing human population of the watershed. The Allegheny River became progressively loaded with brines and oil from the wells and refineries in the Oil City-Franklin area, whereas the Monongahela was influenced by acid mine drainage in the upper portion of the basin, and industrial wastes in the lower basin (Westinghouse 1976, Preston 1974). Added to the acid mine drainage were pollutants from pulp mills, tanneries, steel manufacturing, and other streamside industries. Between 1880 and 1900 the human population along the Ohio River increased from 500,000 to 1,250,000. In 1900, only two cities in the entire Ohio River Basin had sewage treatment plants; many urban areas simply discharged their septage directly to the Ohio River.

Along with deterioration in water quality, the lower Allegheny River was undergoing severe physical changes during this period. As the population of communities along the river (particularly Pittsburgh and Allegheny) increased, the river was progressively straightened and canalized. This eliminated many peripheral aquatic habitats, such as oxbows, meanders, and marshes. Increasing use of the river as a navigation channel also had its effect. The original Lock and Dam Numbers 2 (at River Mile 6.7) and 3 (at River Mile 14.5) were constructed during the period 1894 through 1908. These dams created navigation pools, and eliminated all shallower-water habitats, such as riffles, in the lower 20 miles of the Allegheny. Finally, channel-maintenance dredging of the river was started during this period. Dredging destroyed bottom fauna in the dredged sites, and contrib-

uted to an increased silt-load in the water (Westinghouse 1976). The first cross-channel dam on the Ohio River was constructed at Davis Island, 5 miles downstream of Pittsburgh in 1885. By 1911 there were 12 dams between Pittsburgh and Parkersburg, West Virginia. These dams improved navigation, but were barriers to fish migration (Pearson and Krumholz 1984, Trautman 1981).

The fauna of the study area was devastated during this period. The fish fauna underwent profound changes during the period 1850-1900. Lachner (1956) listed the following 18 species of fishes that were reported in the upper portion of the Ohio River Basin in Pennsylvania prior to 1900, some of them common or abundant, but which have not been reported in recent years: paddlefish, lake sturgeon, shovelnose sturgeon, shortnose gar, bowfin, goldeye, gizzard shad, smallmouth buffalo, highfin carpsucker, river carpsucker, blue sucker, sturgeon sucker, river shiner, silvery minnow, blue catfish, American eel, sauger, and freshwater drum. In addition to extirpation or reduction in distribution of these species, many of them such as the pikes, walleyes, catfishes, buffalofishes, suckers, drum, and sturgeons (desirable food or game fishes), there has been replacement by less desirable species, such as carp and bullheads.

During the early decades of the neo-technical-urban phase (1900 to present) the study area rivers continued to be subjected to the combined influences of physical alteration and pollution. Between 1909 and 1910 a decision to maintain a 9-foot channel throughout the length of the Ohio River was made, and an additional 12 dams were constructed between Louisville, Kentucky and Pittsburgh. The biota that is found in study area rivers today must be viewed as the end product of cumulative impacts associated with habitat modification--channelization, impounding, navigation channel maintenance, and siltation--coupled with impacts associated with the discharge of petrusible and toxic wastes to these waters. Starting around 1950, various activities contributed to improvement of water quality in the upper Ohio River Basin. These included construction of upstream dams on tributary streams which reduced seasonal flow maxima and improved water quality. Municipal sewerage treatment plants have increased in number and efficiency and industrial waste dischargers are now

required to treat wastes prior to discharge. Acid mine drainage treatment is somewhat alleviating acid and iron pollution problems, especially in the Monongahela Basin.

The capacity for rivers in the study area to support a diverse and abundant fish fauna is amply demonstrated by two studies in particular. Krumholz and Minckley (1964) noted changes in the fish population of the upper Ohio River following temporary pollution abatement subsequent to closure of the steel industries on 15 July 1959. Collections of fishes with rotenone from the auxiliary lock chamber at Montgomery Lock and Dam (Ohio River Mile 31.7) yielded more than twice as many species and more than five times as many individuals within 11 days after the beginning of the steel strike than comparable samples taken from the same area before the strike. They concluded that the principal difference in species composition was the occurrence of "clean-water fishes" that invaded the previously polluted area, probably from nearby unpolluted waters.

Fish population studies were conducted in the Monongahela River during the period 1967-1973. The results of these studies were evaluated in relation to trends in water quality. Comparative fish population statistics obtained from the upper Monongahela River showed zero fish in 1967 and 8,071 fish in 1973 at the Maxwell Lock and Dam. The same type of data obtained in the lower Monongahela River at Lock and Dam No. 2 revealed an increase from 20 fish in 1967 to 869 fish in 1973. Improvements in the fishery were attributed to improvement in water quality in the Monongahela River (Preston 1974).

3.3 SPAWNING PERIODS FOR FISHES OF THE ALLEGHENY, MONONGAHELA, AND UPPER OHIO RIVER

Hydropower development in the study area may result in biological impacts through: (1) alteration of habitat required by indigenous fish species for spawning; (2) alteration of current velocity profiles immediately downstream of dams and attendant scour and re-deposition of sediments in transport to other portions of pools; (3) or alteration of dissolved oxygen concentrations immediately downstream of dams as a result of the reduction of reaeration occurring at dams retrofitted with turbines. The

latter impacts would be most prominent on a temporal basis during the period of lowest flow and highest temperature, generally between July and September of each year. Therefore, before an assessment of the potential for biological impacts associated with hydropower development can be undertaken, the spawning period for the fishes of the study area must be characterized as well as their habitat requirements. The habitat available will be discussed, and this will be followed by a discussion of those species which have been documented to spawn in the river.

A summary of the spawning period for species that occur in the upper Ohio River and lower Allegheny and Monongahela Rivers was compiled from Trautman (1981), Scott and Crossman (1973), Pflieger (1975), Smith (1979), Lippson and Moran (1974), Lee et al. (1980), and several publications dealing specifically with the life histories of select species (see Literature Cited). These data are presented in Figure 3-13, which depicts, on an annual basis, the potential period of spawning for species that occur in the study area. Several species (e.g., gizzard shad) have extended spawning periods. However, this reflects spawning throughout the entire geographical range of this species. Spawning by this and other species in the Ohio River Basin is confined primarily to the April to September period, as will be discussed in a later section.

Populations of several species, including rainbow trout, brown trout, muskellunge, and striped bass, are maintained through annual stocking by various state agencies along the study area rivers or through downstream migration into the Ohio River from its tributaries. For most species the primary period of spawning is during spring or late spring and summer. Study area fish that probably complete their spawning during the spring include the lampreys, paddlefishes (if still present in the study area), gars, bowfins, mooneyes, pikes, many suckers, killifishes, temperate basses, perches, and sculpins. Spring and summer spawning species include several of the minnows and carps, some suckers, freshwater catfishes, sunfishes, and drums (Figure 3-13). The American eel is catadromous, a marine spawning species. Information regarding spawning of a few other species was not available.

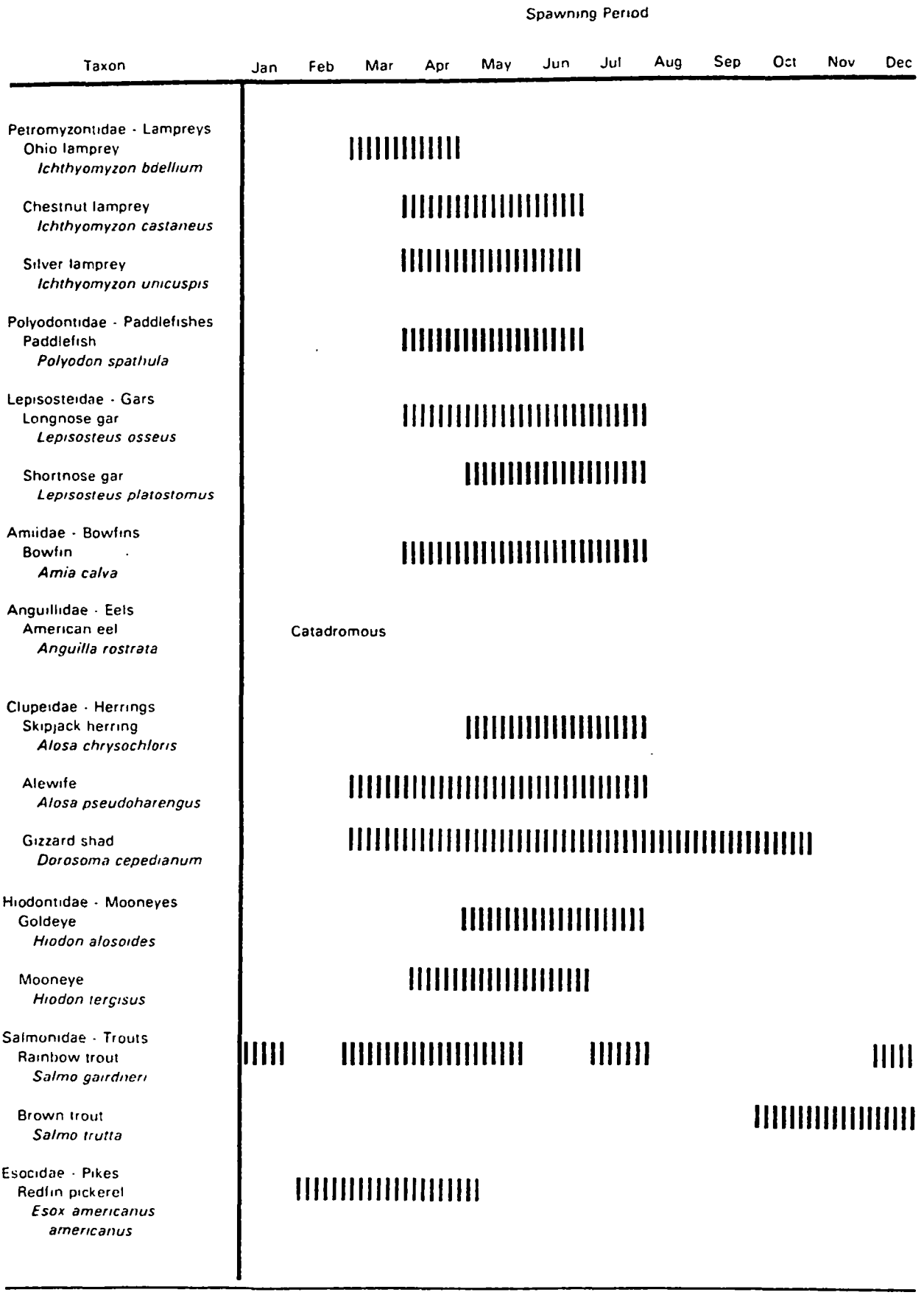


Figure 3-13. The spawning period for the fishes occurring in the Allegheny, Monongahela, and upper Ohio Rivers.

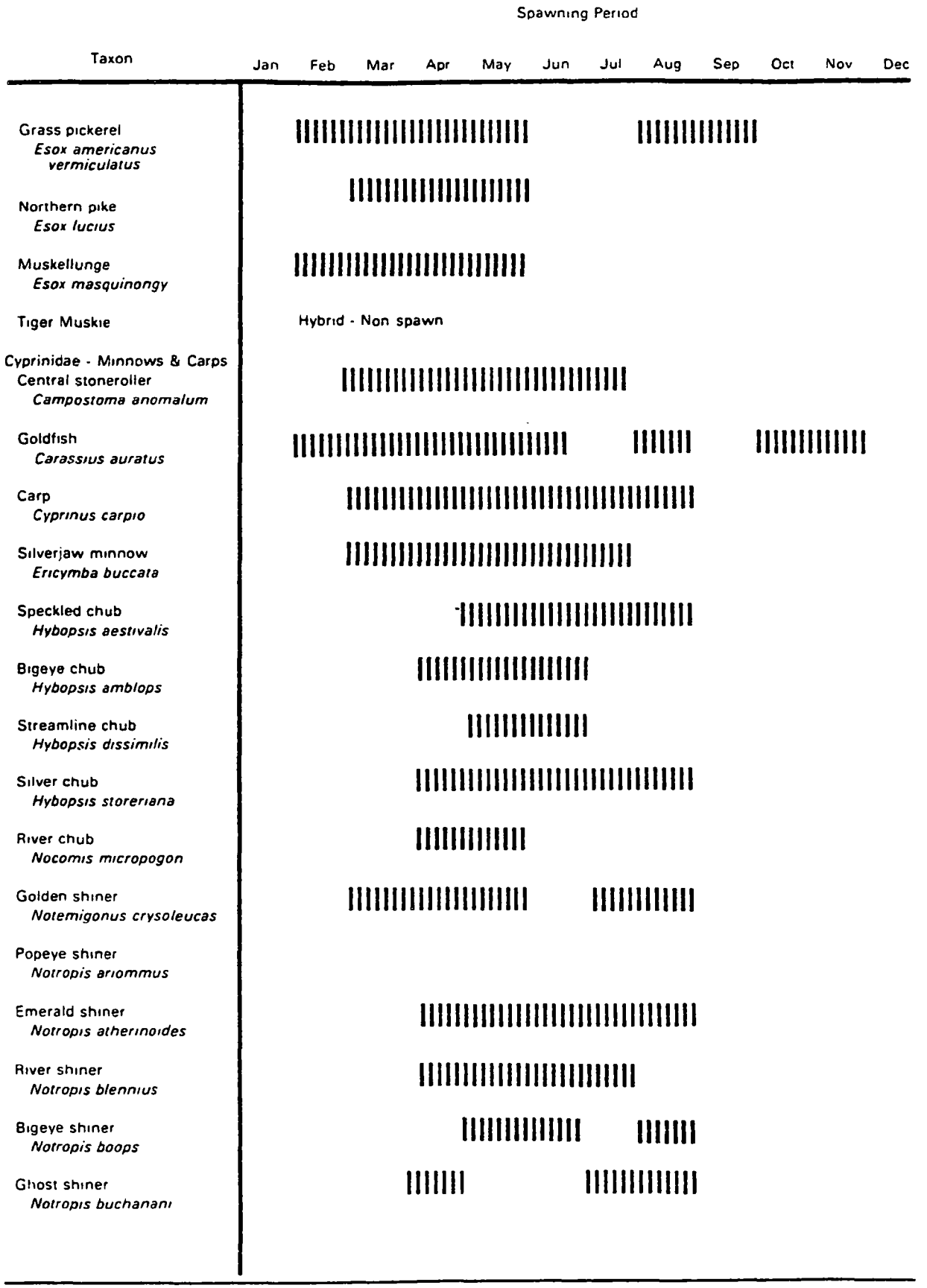


Figure 3-13. (continued)

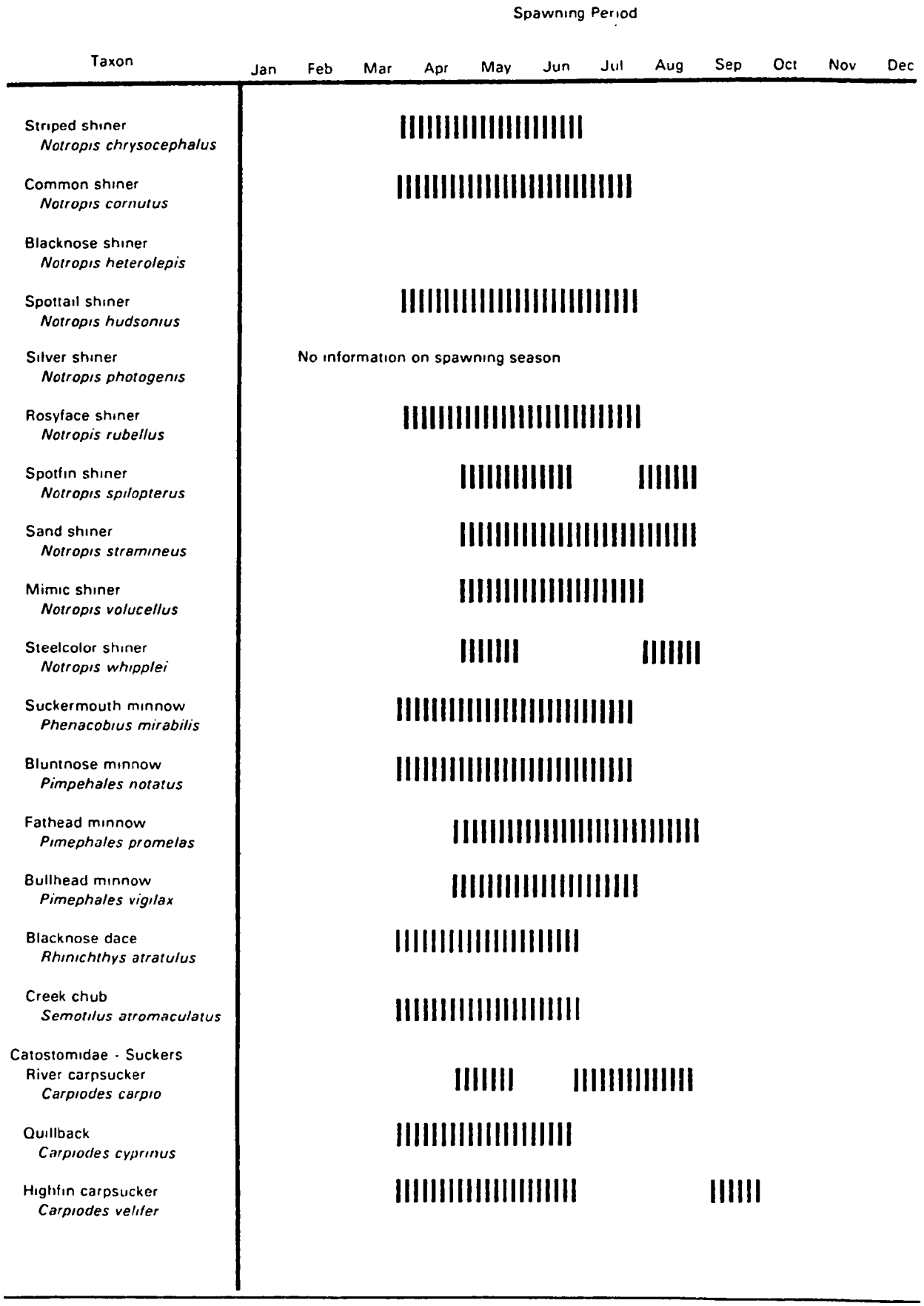


Figure 3-13. (continued)

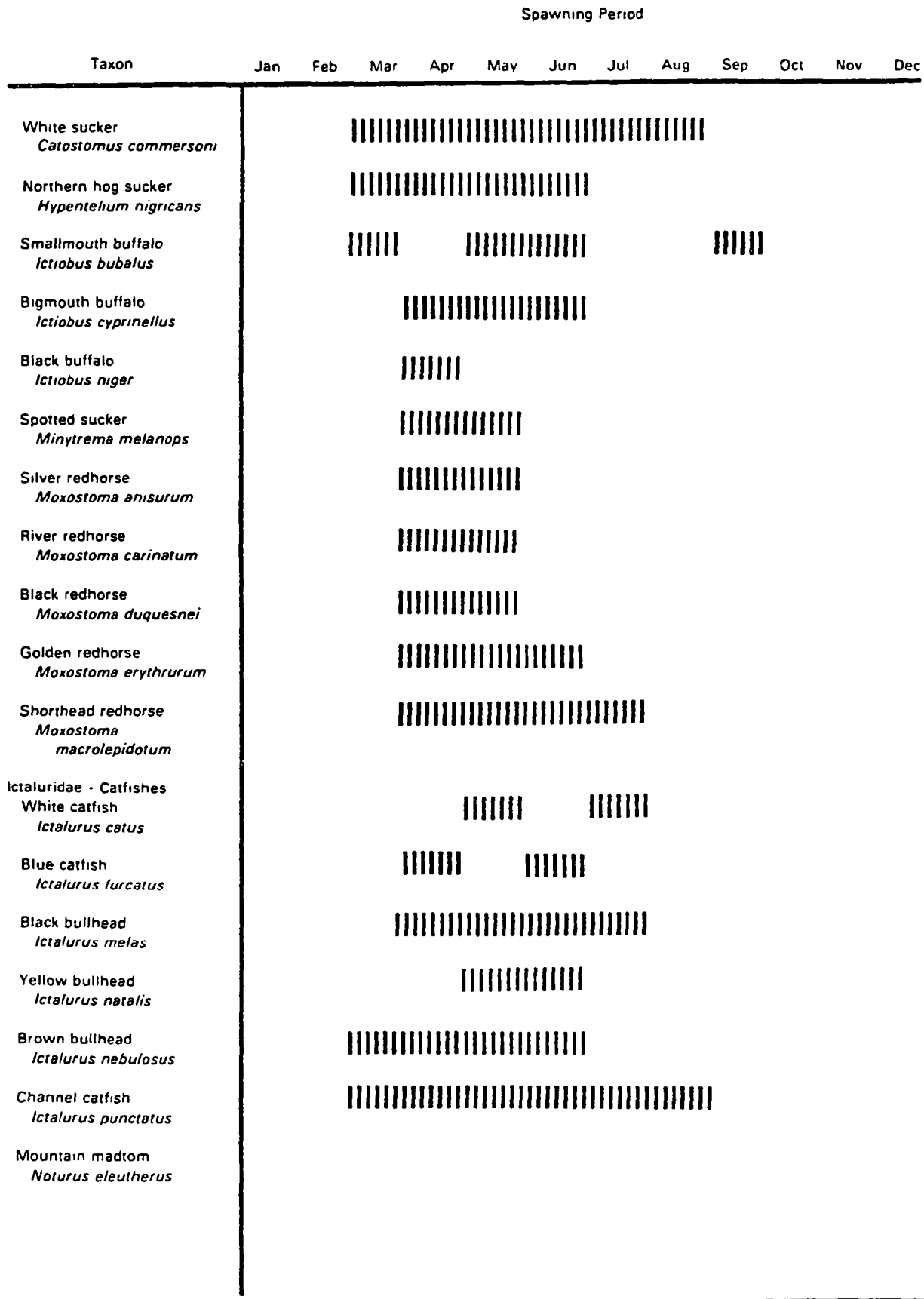


Figure 3-13. (continued)

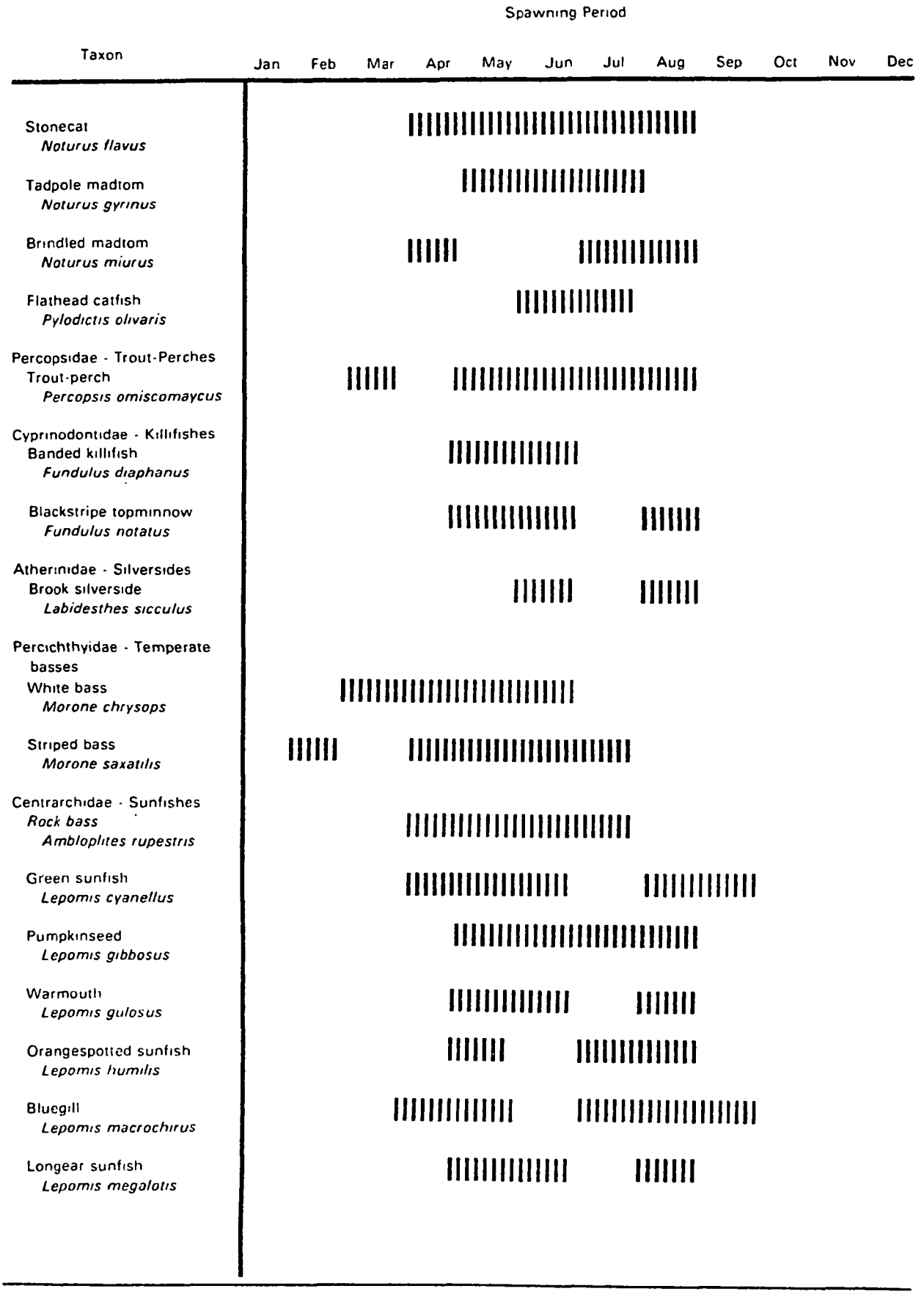


Figure 3-13. (continued)

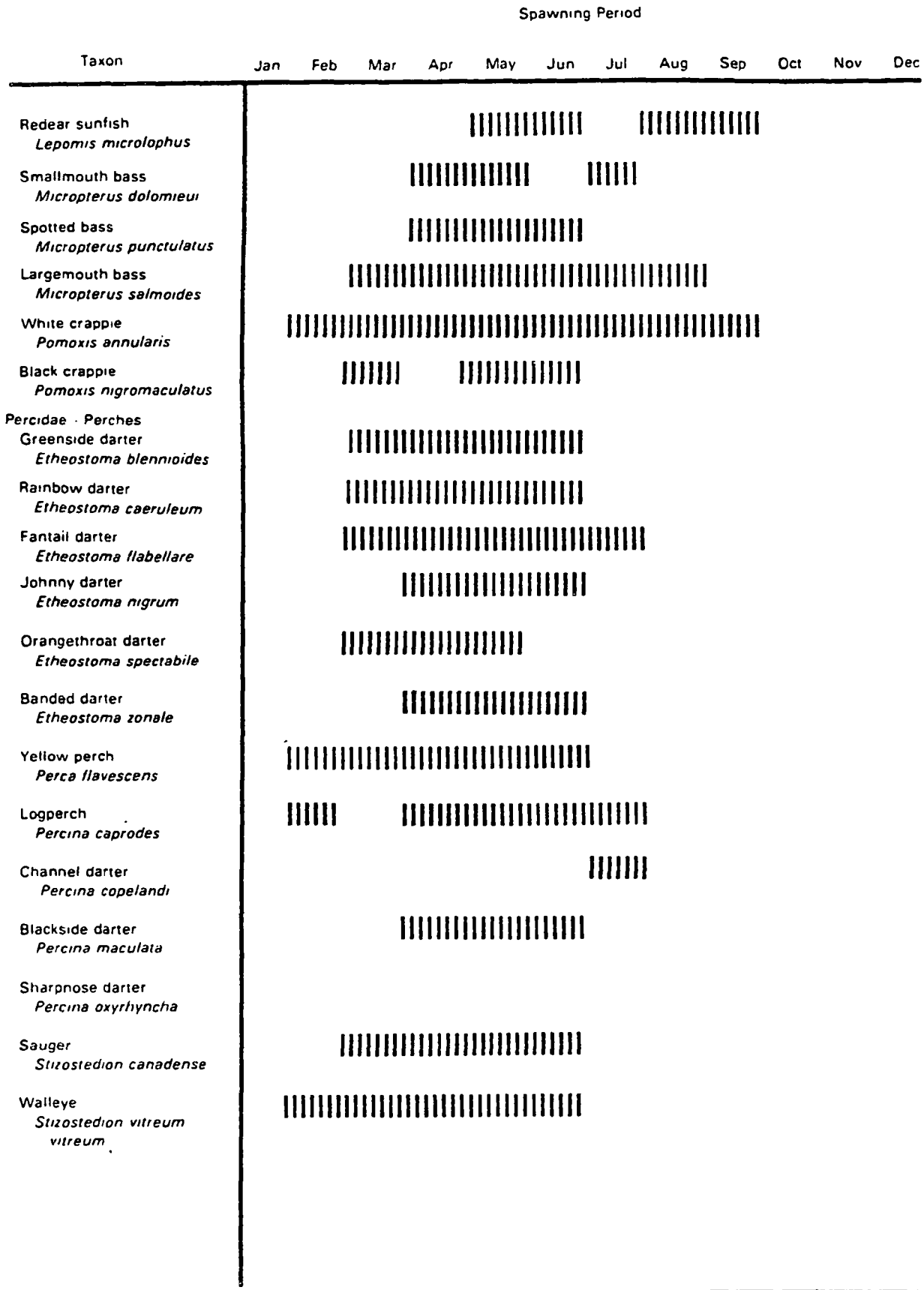


Figure 3-13. (continued)

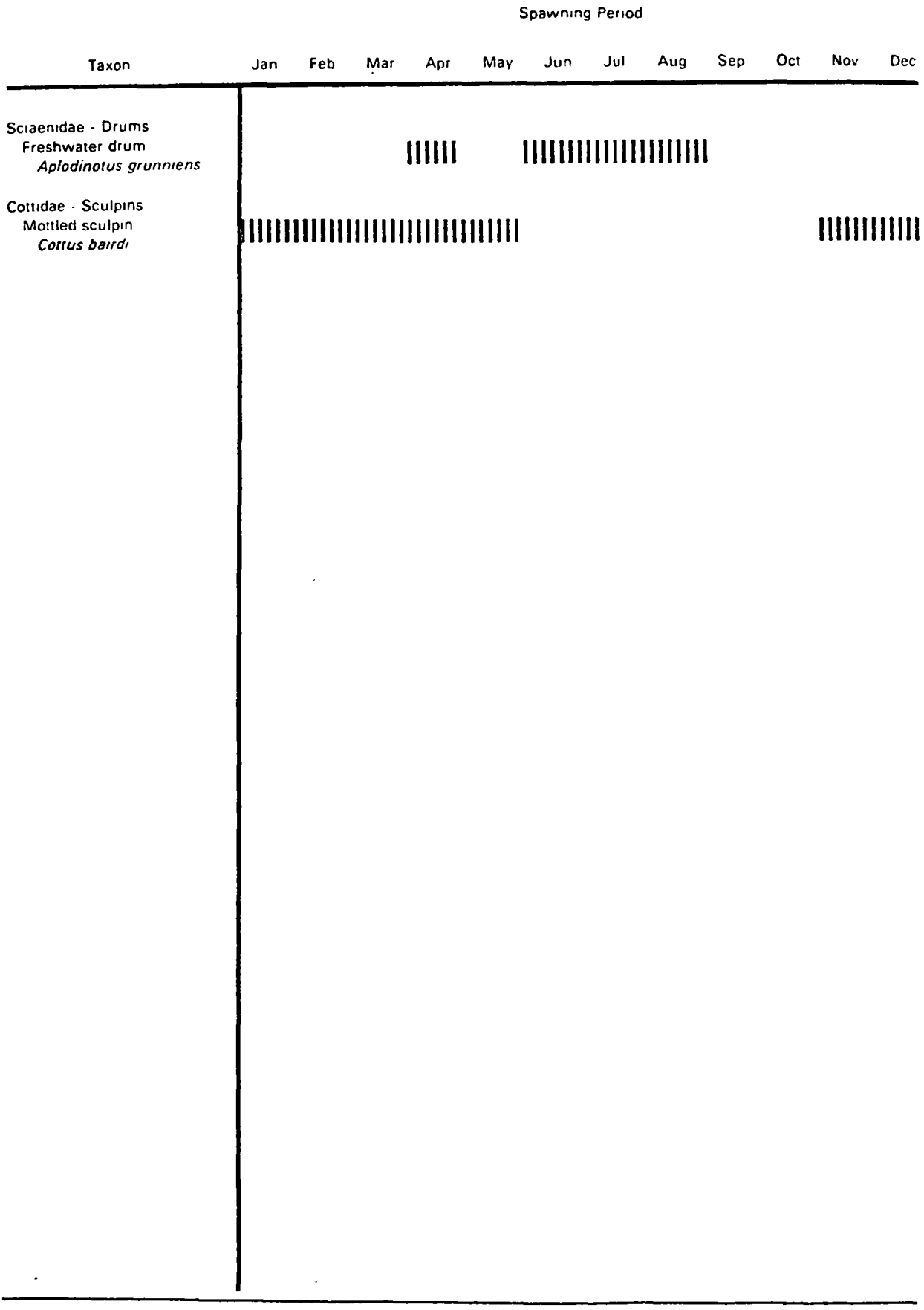


Figure 3-13. (continued)

The habitats available to Ohio River fishes for spawning was reviewed by Pearson and Krumholz (1984). Macro-habitats available to fish include the main channel, main channel border, shore-debris zone, tail waters, side channels, sloughs and embayments, creek mouths and flooded channels. They described each of these as follows:

1. The main channel. This is the area of the river that is negotiated by commercial barge traffic at normal pool elevation and is maintained at least 9' deep and 300' wide by operations of the U.S. Army Corps of Engineers. In most locations and at most seasons, it will be deeper and considerably wider. A current of at least 0.5 ft/sec will always be present. Severe scouring due to both high flows and the constant passing of tow boats is a feature of this zone. The substratum is usually sand, although gravel, rubble, and bedrock may be present. In some locations, and at low water levels, silt and organic debris may also be found. Rooted aquatic plants are absent.

2. Main channel border. This area of the river, between the main channel and the shore-debris zone, is usually very narrow in the upper Ohio River. The substratum is often sand or silt, although occasional extensive deposits of gravel or rubble are found in the study area. Rooted aquatic vegetation is absent, and sunken logs are rare.

3. The shore-debris zone. This zone extends from shoreline riverward from 5 to 150 feet. It is characterized by the presence of dead trees which are floating with the bole resting on the substrate or are rooted in the substrate. The substrate is usually sand or silt, occasionally gravel, with sunken logs and waterlogged branches widely scattered about and partially buried in the bottom. Smaller pieces of vegetable matter often accumulate on the larger pieces. Rooted aquatic vegetation (*Potamogeton* spp.) is rare in the river, but when present it is found in bands 6-20 feet wide in water 4-6 feet deep, and 15-50 feet offshore.

4. Tail waters. These areas are found extending 0.5 mile below each navigation dam. They are characterized by having extensive turbulent

areas, elevated oxygen concentration, and sand, gravel, or bedrock substrates. No rooted aquatic vegetation is usually present.

5. Side channels. These areas usually separate near-shore islands from the river's bank and contain running water at normal pool levels. In the study area they are typically steep-sided, soft-bottomed, and are often lined with eroded, slumping banks. Trees which have slumped into the channel are also present.

6. Sloughs and embayments. These areas are connected to the river at high water but may or may not have a narrow connection with the river at normal water levels (sloughs do not, while embayments do). There is no appreciable current through the area at normal water levels. These areas often contain a great deal of standing and submerged timber, have soft bottoms, and may have rooted aquatic vegetation.

7. Creek mouths and flooded channels. Construction of the navigation dams resulted in the permanent flooding of many creek mouths. The habitat resulting depends largely on the topography of the floodplain crossed by the creek, the gradient of the creek near its mouth, and its mean discharge. If the gradient is low the creek often forms a steep-banked, soft-bottomed, canal of slack water extending from 600 to 3,000 feet up the creek channel. The mouth is often blocked at low water by a silt bar. If the gradient is higher the creek may maintain a noticeable flow and coarser substratum almost to the mouth, and produce a gravel bar extending into the main channel border.

3.4 SPAWNING REQUIREMENTS AND REPRODUCTIVE GUILDS OF OHIO RIVER FISHES

The spawning requirements for each of the species recorded from the study area are presented in Figure 3-14. These data are organized by the most probable riverine habitat type used as a spawning site, substrate type preferred, and fish nesting characteristics. As noted in a previous section, several species have been extirpated, or greatly reduced in abundance, in the upper Ohio River and near Pittsburgh; these include the paddlefish, lake and shovelnose sturgeon, shortnose gar, bowfin, goldeye,

Taxon	Spawning Preference										
	Habitat Type					Substrate Type		Nesting Characteristics			
	Riverine Mid-channel	Riverine Marginal Area	Tributaries	Pools	Riffles	Gravel	Vegetation	Unguarded	Guarded	Broadcast	None
Petromyzontidae - Lampreys											
Ohio lamprey *Ichthyomyzon bdellium*			●		●	●		●			
Chestnut lamprey *Ichthyomyzon castaneus*			●		●	●		●			
Silver lamprey *Ichthyomyzon unicuspis*			●		●	●		●			
Polyodontidae - Paddlefishes											
Paddlefish *Polyodon spathula*			●			●				●	●
Lepisosteidae - Gars											
Longnose gar *Lepisosteus osseus*					●	●	●			●	●
Shortnose gar *Lepisosteus platostomus*				●			●			●	●
Amiidae - Bowfins											
Bowfin *Amia calva*				●			●		●		
Anguillidae - Eels											
American eel *Anguilla rostrata*	Catadromous										
Clupeidae - Herrings											
Skipjack herring *Alosa chrysochloris*						●					●
Alewife *Alosa pseudoharengus*		●				●				●	●
Gizzard shad *Dorosoma cepedianum*		●								●	●
Hiodontidae - Mooneyes											
Goldeye *Hiodon alosoides*							●			●	●
Mooneye *Hiodon tergisus*						●				●	●
Salmonidae - Trouts											
Rainbow trout *Salmo gairdneri*			●		●	●		●			
Brown trout *Salmo trutta*					●	●		●			

Figure 3-14. The spawning requirements for fish species occurring in the Allegheny, Monongahela, and upper Ohio Rivers.

Taxon	Spawning Preference										
	Habitat Type					Substrate Type		Nesting Characteristics			
	Riverine Mid-channel	Riverine Marginal Area	Tributaries	Pools	Riffles	Gravel	Vegetation	Unguarded	Guarded	Broadcast	None
Esocidae - Pikes											
Redfin pickerel *Esox americanus americanus*							●			●	●
Grass pickerel *Esox americanus vermiculatus*		●					●			●	●
Northern pike *Esox lucius*							●			●	●
Muskellunge *Esox masquinongy*							●			●	●
Tiger Muskie											
Cyprinidae - Minnows & *Carps*											
Central stoneroller *Campostoma anomalum*					●	●			●		
Goldfish *Carassius auratus*							●			●	●
Carp *Cyprinus carpio*							●			●	●
Silverjaw minnow *Ericymba buccata*					●	●					●
Speckled chub *Hybopsis aestivalis*										●	●
Bigeye chub *Hybopsis amblops*			●			●	●				●
Streamline chub *Hybopsis dissimilis*			●	●	●	●					●
Silver chub *Hybopsis storeriana*			●			●	●			●	
River chub *Nocomis micropogon*						●		●			
Golden shiner *Notemigonus crysoleucas*							●		●	●	
Popeye shiner *Notropis ariommus*			●	●		●					

Figure 3-14. (continued)

Taxon	Spawning Preference										
	Habitat Type					Substrate Type		Nesting Characteristics			
	Riverine Mid-channel	Riverine Marginal Area	Tributaries	Pools	Riffles	Gravel	Vegetation	Unguarded	Guarded	Broadcast	None
Emerald shiner *Notropis atherinoides*						●				●	
River shiner *Notropis blennius*						●					●
Bigeye shiner *Notropis boops*				●	●	●					●
Ghost shiner *Notropis buchanani*					●	●					●
Striped shiner *Notropis chrysocephalus*						●					●
Common shiner *Notropis cornutus*					●	●		●			
Blacknose shiner *Notropis heterolepis*											
Spottail shiner *Notropis hudsonius*			●		●	●					●
Silver shiner *Notropis photogenis*					●	●					●
Rosyface shiner *Notropis rubellus*		●		●	●	●		●			
Spotfin shiner *Notropis spilopterus*					●	●					●
Sand shiner *Notropis stramineus*		●				●				●	
Mimic shiner *Notropis volucellus*							●			●	●
Steelcolor shiner *Notropis whipplei*							●				●
Suckermouth minnow *Phenacobius mirabilis*					●	●					●
Bluntnose minnow *Pimephales notatus*						●			●		
Fathead minnow *Pimephales promelas*							●		●		

Figure 3-14. (continued)

Taxon	Spawning Preference										
	Habitat Type					Substrate Type		Nesting Characteristics			
	Riverine Mid-channel	Riverine Marginal Area	Tributaries	Pools	Riffles	Gravel	Vegetation	Unguarded	Guarded	Broadcast	None
Bullhead minnow *Pimephales vigilax*						●			●		
Blacknose dace *Rhinichthys atratulus*			●		●	●					●
Creek chub *Semotilus atromaculatus*			●			●			●		
Catostomidae - Suckers											
River carpsucker *Carpiodes carpio*										●	●
Quillback *Carpiodes cyprinus*			●							●	●
Highfin carpsucker *Carpiodes velifer*						●					●
White sucker *Catostomus commersoni*			●	●	●	●				●	●
Northern hog sucker *Hypentelium nigricans*			●	●	●	●				●	●
Smallmouth buffalo *Ictiobus bubalus*							●			●	●
Bigmouth buffalo *Ictiobus cyprinellus*		●		●		●	●			●	●
Black buffalo *Ictiobus niger*		●		●			●			●	●
Spotted sucker *Minytrema melanops*					●						●
Silver redhorse *Moxostoma anisurum*	●	●	●		●	●					●
River redhorse *Moxostoma carinatum*					●						●
Black redhorse *Moxostoma duquesnei*			●		●	●				●	●
Golden redhorse *Moxostoma erythrurum*			●	●	●	●				●	●
Shorthead redhorse *Moxostoma macrolepidotum*		●	●		●	●				●	●

Figure 3-14. (continued)

Taxon	Spawning Preference										
	Habitat Type					Substrate Type		Nesting Characteristics			
	Riverine Mid-channel	Riverine Marginal Area	Tributaries	Pools	Riffles	Gravel	Vegetation	Unguarded	Guarded	Broadcast	None
Ictaluridae - Catfishes											
White catfish *Ictalurus catus*				●	●	●			●		
Blue catfish *Ictalurus furcatus*									●		
Black bullhead *Ictalurus melas*							●		●		
Yellow bullhead *Ictalurus natalis*							●		●		
Brown bullhead *Ictalurus nebulosus*		●	●				●		●		
Channel catfish *Ictalurus punctatus*		●	●	●	●		●		●		
Mountain madtom *Noturus eleutherus*					●	●			●		
Stonecat *Noturus flavus*									●		
Tadpole madtom *Noturus gyrinus*									●		
Brindled madtom *Noturus miurus*	●	●							●		
Flathead catfish *Pylodictis olivaris*									●		
Percopsidae - Trout-Perches											
Trout-perch *Percopsis omiscomaycus*			●			●					●
Cyprinodontidae - Killifishes											
Banded killifish *Fundulus diaphanus*			●				●				●
Blackstripe topminnow *Fundulus notatus*							●		●		
Atherinidae - Silversides											
Brook silverside *Labidesthes sicculus*		●				●	●				●
Percichthyidae - Temperate basses											
White bass *Morone chrysops*			●		●	●				●	●

Figure 3-14. (continued)

Taxon	Spawning Preference										
	Habitat Type					Substrate Type		Nesting Characteristics			
	Riverine Mid-channel	Riverine Marginal Area	Tributaries	Pools	Riffles	Gravel	Vegetation	Unguarded	Guarded	Broadcast	None
Striped bass *Morone saxatilis*											
Centrarchidae - Sunfishes											
Rock bass *Ambloplites rupestris*						●	●		●		
Green sunfish *Lepomis cyanellus*						●			●		
Pumpkinseed *Lepomis gibbosus*						●	●		●		
Warmouth *Lepomis gulosus*							●		●		
Orangespotted sunfish *Lepomis humilis*									●		
Bluegill *Lepomis macrochirus*						●			●		
Longear sunfish *Lepomis megalotis*		●	●			●			●		
Redear sunfish *Lepomis microlophus*						●	●		●		
Smallmouth bass *Micropterus dolomieui*		●		●		●	●		●		
Spotted bass *Micropterus punctulatus*									●		
Largemouth bass *Micropterus salmoides*						●	●		●		
White crappie *Pomoxis annularis*						●	●		●		
Black crappie *Pomoxis nigromaculatus*							●		●		
Percidae - Perches											
Greenside darter *Etheostoma blennioides*			●		●		●				●
Rainbow darter *Etheostoma caeruleum*					●	●			●		
Fantail darter *Etheostoma flabellare*				●	●	●			●		

Figure 3-14. (continued)

Taxon	Spawning Preference										
	Habitat Type					Substrate Type		Nesting Characteristics			
	Riverine Mid-channel	Riverine Marginal Area	Tributaries	Pools	Riffles	Gravel	Vegetation	Unguarded	Guarded	Broadcast	None
Johnny darter *Etheostoma nigrum*									●		
Orangethroat darter *Etheostoma spectabile*			●		●	●					●
Banded darter *Etheostoma zonale*				●			●				●
Yellow perch *Perca flavescens*		●				●	●			●	●
Logperch *Percina caprodes*					●	●				●	●
Channel darter *Percina copelandi*					●	●					●
Blackside darter *Percina maculata*			●		●	●		●			
Sharpnose darter *Percina oxyrhyncha*					●	●					●
Sauger *Stizostedion canadense*						●				●	●
Walleye *Stizostedion vitreum vitreum*		●	●		●	●	●			●	●
Sciaenidae - Drums Freshwater drum *Aplodinotus grunniens*						●				●	●
Cottidae - Sculpins Mottled sculpin *Cottus bairdi*			●			●	●		●		

Figure 3-14. (continued)

gizzard shad, smallmouth and highfin buffaloes, river carpsucker, blue sucker, sturgeon sucker, river shiner, silvery minnow, blue catfish, American eel, sauger, and freshwater drum (Lachner 1956). Other species only rarely captured include the Ohio lamprey, shorthead redhorse, spotted sucker, flathead catfish, slenderhead darter, and warmouth. Spawning requirements for sturgeon, blue sucker, sturgeon sucker, silvery minnow, and slenderhead darter were omitted from Figure 3-14 because lack of recent records and/or improbability of these species becoming re-established in the fishery.

Balon (1975) devised an ecological means of classifying fishes based upon their reproductive behaviors, preferred spawning substrates, and morphological adaptation of the eggs and larvae. Balon's classification scheme provides a framework upon which the known information on spawning habits of Ohio River fish can be arranged and evaluated with regard to availability of habitat. Balon's scheme begins with the premise that two environmental factors are primary determinants of survival during the critical embryological and larval development of fishes: predators and the availability of oxygen.

The fishes of the Ohio River have, therefore, two primary objectives in spawning: (1) to deposit their fertilized eggs where predators cannot destroy them; and (2) to deposit them where they will not be deprived of oxygen due to siltation, lack of current, or bacterial respiration (Pearson and Krumholz 1984).

Pearson and Krumholz (1984) attempted to fit each of the species of fishes reported from the Ohio River into Balon's classification (Table 3-11). Of the 154 species of fishes reported from the mainstem of the Ohio River, the American eel was eliminated from consideration because it spawns in the ocean, and nine introduced species were ignored which have not established reproducing populations. Of the remaining 144 species, inadequate descriptions of the reproductive habits of 18 species were available to permit their assignment to a guild. The 126 species which were assigned to reproductive guilds are listed in Table 3-11 (from Pearson and Krumholz 1984).

Table 3-11. Reproductive guilds of the 126 species of fish which reproduced in the Ohio River, and for which information on spawning habits is available (after Balon 1975). Numbers in ( ) indicate numbers of species within each group. Definitions of the terms are provided in the text.[a]

Balon's (1975) Subsections	Ohio River Fishes
A. NONGUARDERS	
A.1 Open substrate spawners	
A.1.1 Pelagophils (2)	*Notropis atherinoides*
	Aplodinotus grunniens
A.1.2 Litho-pelagophils (5)	*Acipenser fulvescens*
	Dorosoma cepedianum
	Hiodon (2)
	Lota lota
A.1.3 Lithophils (28)	*Scaphirhynchus platorynchus*
	Polyodon spathula
	Alosa (2)
	Clinostomus elongatus
	Hybopsis aestivalis
	Notropis (3)
	Phenacobius mirabilis
	Phoxinus erythrogaster
	Rhinichthys atratulus
	Catostomids (12)
	Percopsis omiscomaycus
	Stizostedion (2)[b]
	Cottus carolinae
A.1.4 Phyto-lithophils (14)	*Dorosoma petenense*
	Hybognathus nuchalis
	Hybopsis (2)
	Notropis (3)
	Carpiodes carpio
	Ictiobus bubalus
	Fundulus notatus
	Labidesthes sicculus
	Morone (2)
	Perca flavescens
A.1.5 Phytophils (17)	*Lepisosteus* (4)
	Esox (3)
	Carassius auratus
	Cyprinus carpio
	Notemigonus crysoleucas
	Notropis (3)
	Erimyzon sucetta
	Ictiobus (2)
	Fundulus diaphanus

Table 3-11. (continued)

Balon's (1975) Subsections	Ohio River Fishes
A.1.6 Psammophils (7)	Ericymba buccata Notropis (3) Carpiodes cyprinus Ammocrypta asprella Percina caprodes
A.2 Brood hiders	
A.2.1 Lithophils (13)	Lampreys (5) Nocomis (2) Semotilus atromaculatus Etheostoma caeruleum Percina (4)
B. GUARDERS	
B.1 Substratum choosers	
B.1.2 Phytophils (1)	Pomoxis annularis
B.2 Nest spawners	
B.2.1 Lithophils (16)	Campostoma anomalum Notropis (4) Ictalurus melas Centrarchids (10)
B.2.2 Phytophils (5)	Amia calva Centrarchids (2) Etheostoma (2)
B.2.5 Speleophils (16)	Pimephales (3) Ictalurids (9) Etheostoma (4)
B.2.6 Polyphils (1)	Lepomis gibbosus
C. BEARERS	
C.2 Internal	
C.2.3 Viviparous (1)	Gambusia affinis

[a]From Pearson and Krumholz 1984.

[b]Recent and convincing evidence indicates that the walleye and sauger belong in the A.1.2, litho-pelagophil guild. (McElman, J.F. 1983. Comparative embryonic ecomorphology and the reproductive guild classifications of walleye, Stizostedion vitreum, white sucker Catostomus commersoni. Copeia 1983(1):256-260).

Balon proposed 32 reproductive guilds divided into three major sections, each with two subsections: (1) nonguarders, which ignore eggs and larvae after spawning and either spawn on open substrates or hide their broods; (2) guarders, which protect and/or aerate eggs and larvae after spawning and either choose the substrate on which the brood is reared, or construct a nest to receive the brood; and (3) bearers, which carry their eggs either on or in the parent's body. Nearly 70 percent of the fishes in the Ohio River (86 species) were placed in the "nonguarders" section (Table 3-11), while 29 percent were placed in the "guarders" section (38 species), and only one species (mosquitofish) was placed in the "bearers" section. Thirteen of Balon's 32 guilds were represented in the Ohio River fish community (Pearson and Krumholz 1984).

Three of the most abundant fishes found in fisheries studies in the upper Ohio River Basin in recent years, the emerald shiner, gizzard shad, and freshwater drum, are either pelagophils (A.1.1) or litho-pelagophils (A.1.2). The eggs and/or larvae of pelagophils and litho-pelagophils are buoyant or semi-buoyant, are adapted to highly oxygenated waters, and have no or poorly-formed embryonic respiratory organs. Apparently, producing pelagic or semi-pelagic eggs and/or larvae has been a most successful strategy in the Ohio River for these three species (Pearson and Krumholz 1984). Four other litho-pelagophils in the Ohio River are today either extirpated (lake sturgeon), rare (burbot), or low in abundance (goldeye and mooneye).

Slightly more than 22 percent of the fishes in the Ohio River (28 species) were considered to be non-guarding lithophils and make up the largest single reproductive guild. Lithophils (A.1.3) deposit their eggs over clean gravel-rock substrates, the larvae are photophobic, and they are adapted for living in well-oxygenated interstitial waters. The embryonic respiratory system is only moderately developed in these fishes. Representative fishes of this guild include redhorses, white sucker, blue sucker, sauger, paddlefish, shovelnose sturgeon, and several minnows (Table 3-11). It seems likely that the overall reproductive success of this guild has declined with canalization and siltation of the Ohio River and its tributaries in the last 80-100 years (Pearson and Krumholz 1984).

The non-guarding phyto-lithophil (A.1.4) guild of fish contains 14 Ohio River species. This guild represents an intermediary group midway between the reproductive modes of the lithophils and the nonguarding phytophils (A.1.5). The phytophils deposit their eggs over either live or dead vegetation, flooded plants, and vegetable debris. The larvae typically are not photophobic, have cement glands on the head to attach themselves to vegetation off the soft bottom, and have highly developed embryonic respiratory structures which adapt them for survival in poorly-oxygenated situations. Seventeen species of Ohio River fishes belong to the phytophil guild. Two members of these two guilds were represented among the most abundant species found in the upper Ohio River: the mimic shiner (phyto-lithophils) and common carp (phytophil). Some other typical and common members of these two guilds include the buffalofishes, river carpsucker, silvery minnow, silver chub, and white bass. It seems likely that the relative reproductive success of members of these two guilds would have increased following canalization and siltation of the Ohio River (Pearson and Krumholz 1984).

The non-guarding psammophils (A.1.6) were represented by just seven species, of which only the sand shiner is very abundant. These fishes spawn over clean, coarse sand substrates. The non-guarding brood hiders (lithophils A.2.1) were represented by 13 species, but none of them are very abundant in the river (Table 3-11).

Members of the "guarder" guilds remain near their spawn and are able to offer protection against predators and provide artificial aeration by cleaning and fanning the eggs. With this strategy fishes are able to reproduce in situations where fine sediments and low oxygen concentrations would otherwise be prohibitive.

The white crappie represents the only Ohio River fish of the guarder-substratum chooser-phytophil (B.1.2) guild. This species spawns over vegetation, fine roots, or vegetable debris. The spawning site is cleaned and guarded, and the newly-hatched larvae swim constantly to avoid the hypoxic substrate beneath the cleaned vegetation.

All of the other guarders in the Ohio River (23 species) are nest spawners, that is, they actually construct a cleaned depression on the substratum or clean a naturally-occurring cavity or crevice, where the eggs are deposited. The nest-spawning lithophils (B.2.1; 16 species) include 10 of the 12 centrarchids in the river, five uncommon minnows, and the black bullhead. The larvae of most fishes in this group hide in the gravel at the bottom of the river, may have cement glands, and their embryonic respiratory organs are moderately- to well-developed. Included in this guild are the spotted and smallmouth basses, bluegill, green sunfish, and longear sunfish. Many of the species in this group prefer to spawn in relatively still backwaters, which are not abundant along the Ohio River.

The nest-spawning phytophil (B.2.2) guild includes just five Ohio River species: the bowfin, two darters, and two centrarchids--the largemouth bass and black crappie. The bowfin and the centrarchids also prefer to nest in the relatively still backwaters. It is possible that one reason these fishes are not abundant in the mainstem area is that they do not nest successfully in shallow areas which are constantly disturbed by tow boat wakes.

The nest-spawning speleophil (B.2.5) guild includes 16 species of Ohio River fishes: the three Pimephales minnows, nine catfish, and four darters (Table 3-11). These fishes guard their eggs after depositing them on the underside of an object or in a natural cavity. The eggs and larvae are fanned by the parents, and consequently, oxygen supply is seldom a problem. The brown bullhead and channel catfish are two members of this successful guild. The pumpkinseed, a relatively uncommon fish of the upper Ohio River, is considered to be a polyphil (B.2.6) because it spawns on nearly any substrate type.

3.5 LARVAL AND JUVENILE FISHES IN THE DRIFT OF THE OHIO, ALLEGHENY, AND MONONGAHELA RIVERS

The previous two sections of this chapter have characterized the fisheries resources of the study area and the spawning requirements of each species. This section will characterize the occurrence of fish eggs and larvae (ichthyoplankton) in the drift of study area rivers. Most data

available regarding the occurrence of ichthyoplankton at various sites along the rivers results from information compiled and presented in fulfillment of the mandates stipulated in the National Environmental Policy Act (NEPA) of 1969 and PL 92-500 of 1972, especially subsections 316(b) of the latter. Electrical utilities located in the upper Ohio River Basin have complied with NEPA and PL 92-500 by monitoring ichthyoplankton in the rivers or by monitoring ichthyoplankton entrained in cooling water passing through generating facilities.

The discussion of larval and juvenile fishes includes data from outside the study area, for comparatively little information was available for the Allegheny and Monongahela Rivers. Considerably more information was available for the upper 260 miles of the Ohio River. Therefore, a compilation of the taxa occurring in the ichthyoplankton of the upper Ohio River (RM 0-260) is included. However, characterization of the relative abundance and absolute density of ichthyoplankton will center on long-term monitoring that has been conducted at Ohio River Mile 53.9, in the New Cumberland Pool, and at Ohio River Mile 76.7, in the Pike Island Pool. Monitoring at these two sites has been conducted from 1976 through 1982 and from 1978 through 1982, respectively (WAPORA, Inc. 1980, Geo-Marine, Inc. 1981, 1982).

Figure 3-15 presents an overview of the taxa that have been identified in ichthyoplankton samples collected from the upper Ohio River Basin. These include the following families of fishes: Clupeidae, Hiodontidae, Umbridae, Cyprinidae, Catostomidae, Ictaluridae, Cyprinodontidae, Atherinidae, Percopsidae, Percichthyidae, Centrarchidae, Percidae, and Sciaenidae. Taxa within the table that have been identified to species represent advanced larval stages or juveniles, both of which have morphological characteristics developed to the point that species determinations can be made. Taxa identified only to the generic or some higher level generally represent larvae in very early stages of development, i.e., prolarvae, for which determination to species level cannot be made with certainty. From the standpoint of taxonomic composition, the Cyprinidae, Catostomidae, Centrarchidae, and Percidae have the greatest number of taxa represented in ichthyoplankton collections (a total of 59 taxa).

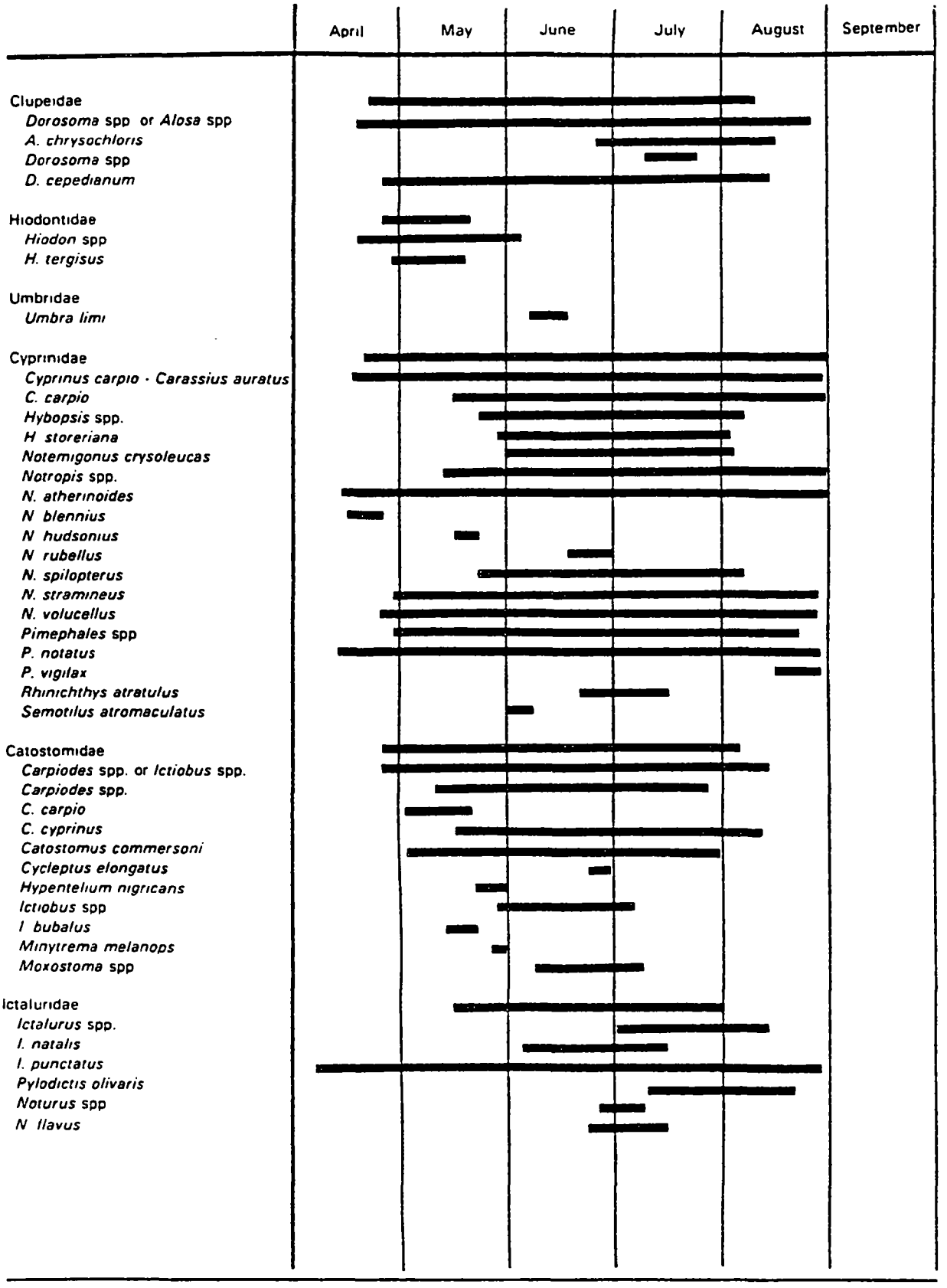


Figure 3-15. The temporal distribution of fish larvae and juveniles in the drift in the Allegheny, Monongahela, and upper Ohio Rivers.

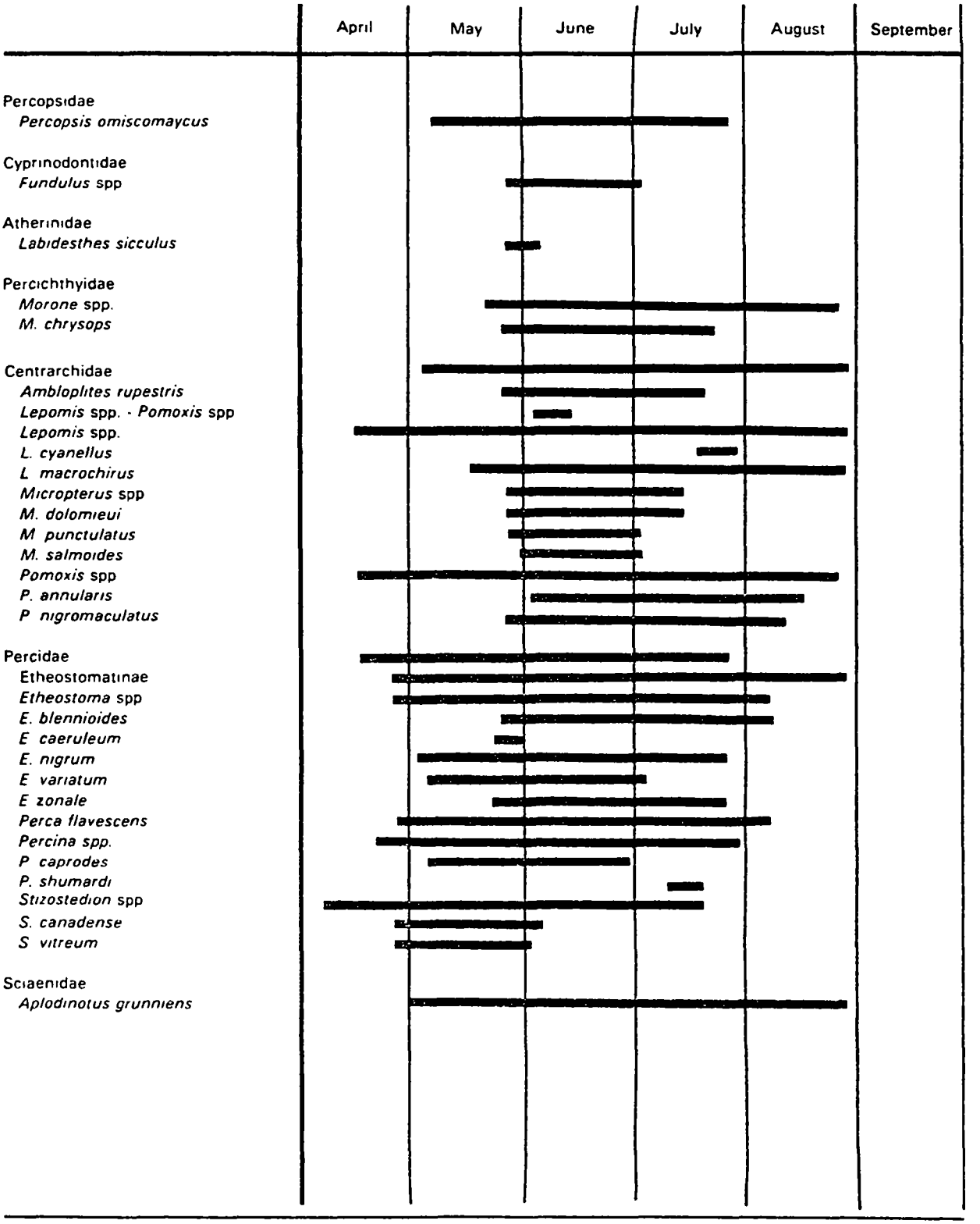


Figure 3-15. (continued)

The seasonal occurrence of each taxon in the ichthyoplankton is presented in Figure 3-15. This summary is probably inclusive of the spawning period for the majority of species that reproduce in the study area, however, some species are known to spawn during other seasons and would not be represented (Figure 3-13). The majority of ichthyoplankton sampling conducted at the various sites has been conducted from mid- to late-April through August. The spawning season is usually initiated in mid to late April and continues into August. However, the latter part of May, June, and early July is the period of spawning activity by the greatest number of species. Ichthyoplankton densities are typically low during April and early May, peak during June or July, and decrease again in August, as the following discussion will illustrate.

Ohio River

Figures 3-16 through 3-19 present an overview of the ichthyoplankton density and species composition that occurs in the New Cumberland and Pike Island Pools of the upper Ohio River. Data presented in Figures 3-16 and 3-17 represent sampling that was conducted in the New Cumberland Pool between 1976 and 1982, whereas Figures 3-18 and 3-19 cover sampling between 1978 and 1982 in the Pike Island Pool. Results from 1976-1980 represent the composite of weighted means of day and night tows with 0.5 meter diameter ichthyoplankton nets (WAPORA, Inc. 1977-1981); 1981 and 1982 data are the results from nighttime tows with 1.0 meter diameter nets (Geo-Marine, Inc. 1982, 1983).

In the New Cumberland and Pike Island Pools, peaks in ichthyoplankton density have occurred in June, July, and August, and May, June, July, and August, respectively. The temporal occurrence of the peak depends upon which species numerically dominate the spawn (Figures 3-16 and 3-18). In the New Cumberland Pool, species numerically dominating the ichthyoplankton during April include the perches, suckers, and minnows and carps; during May the previous three groups continue to dominate the ichthyoplankton assemblage; by June the percids typically decrease in abundance and minnows and carps, suckers, herrings, and "others" numerically dominate; minnows and carp, herrings, drums, and "others" dominate in July and August (Figure

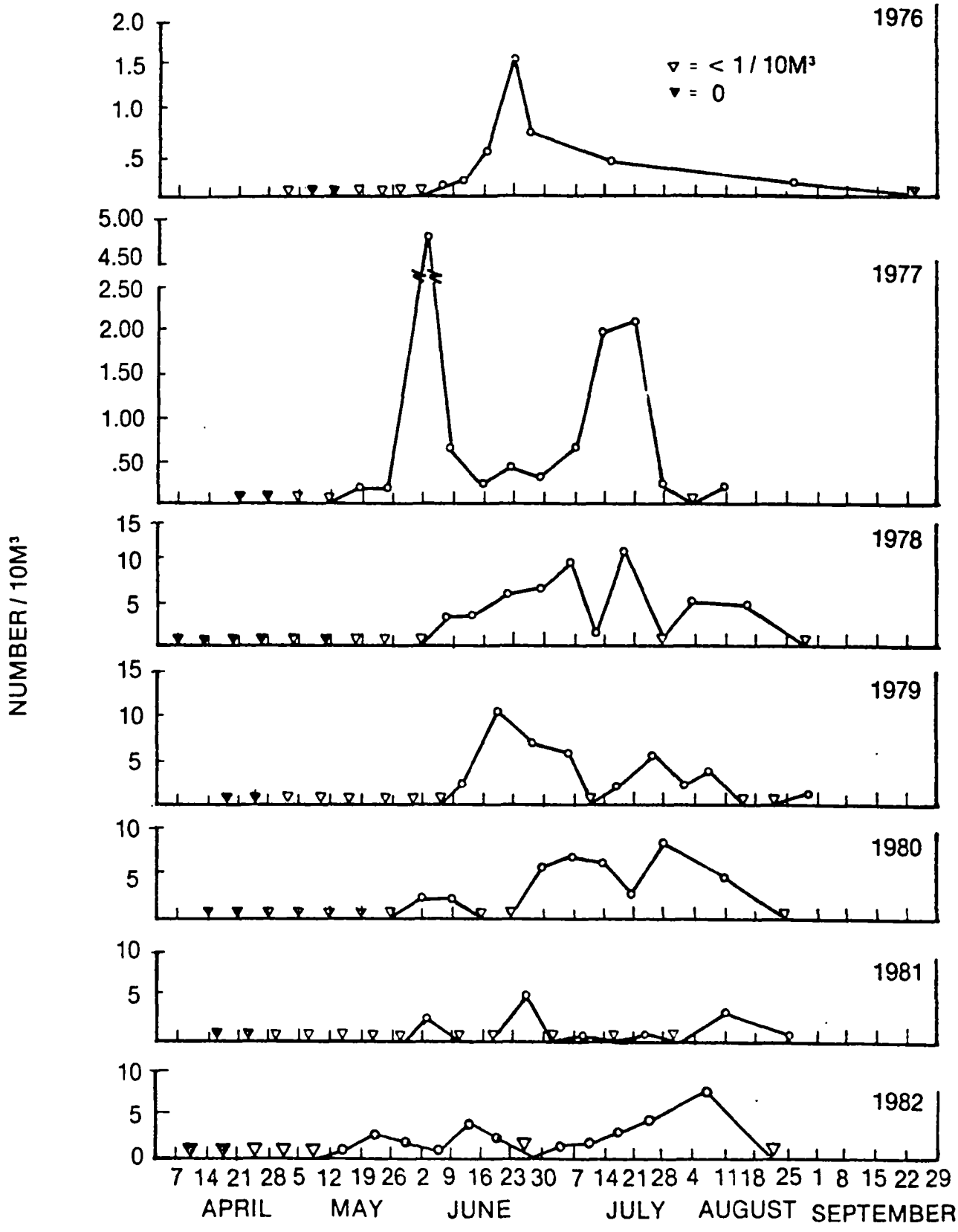


Figure 3-16. Density of ichthyoplankton collected weekly in net tows near the New Cumberland Pool, 1976-1982.

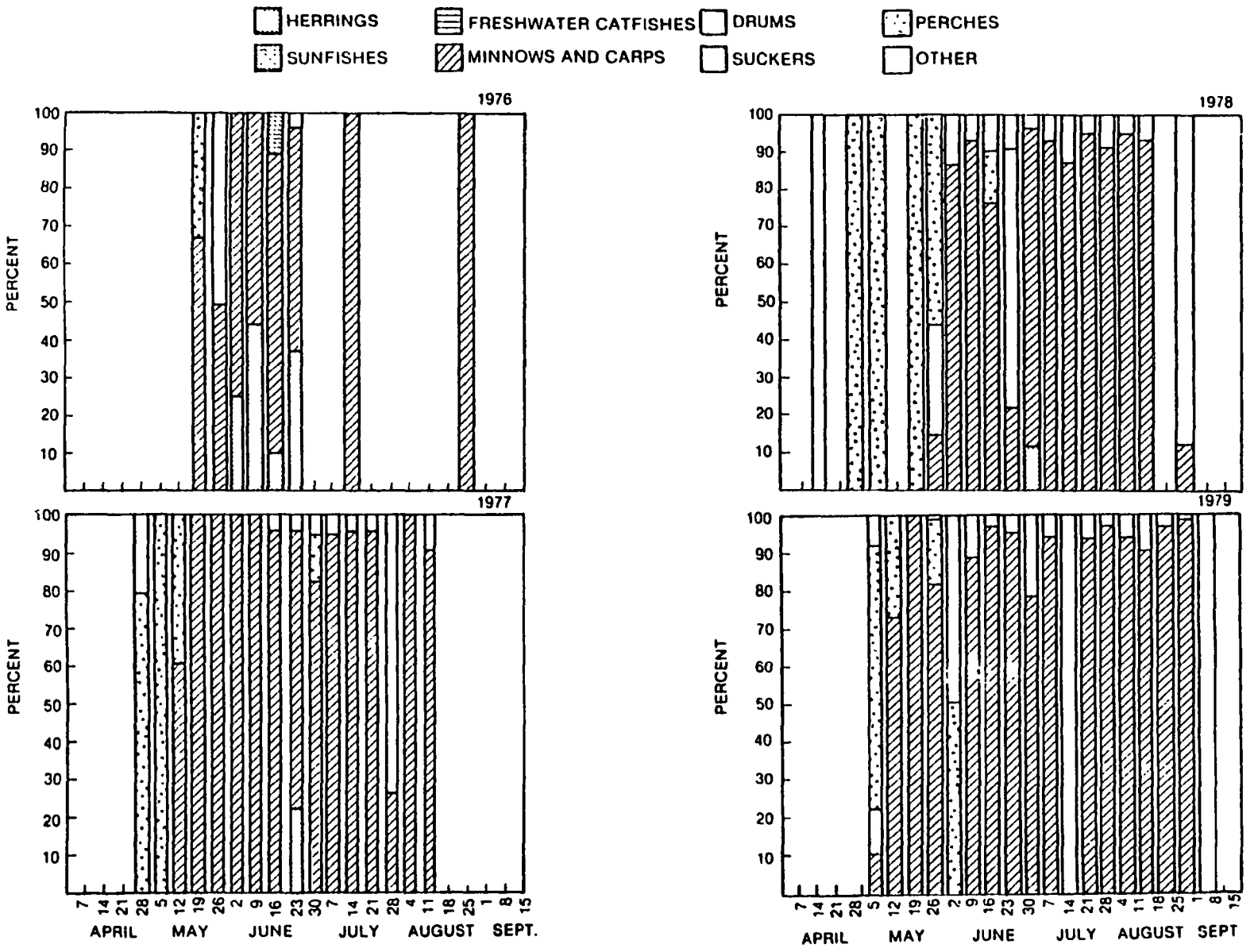


Figure 3-17. Weekly percent composition of all tow samples by dominant families (>10%) near the New Cumberland Pool, 1976-1982.

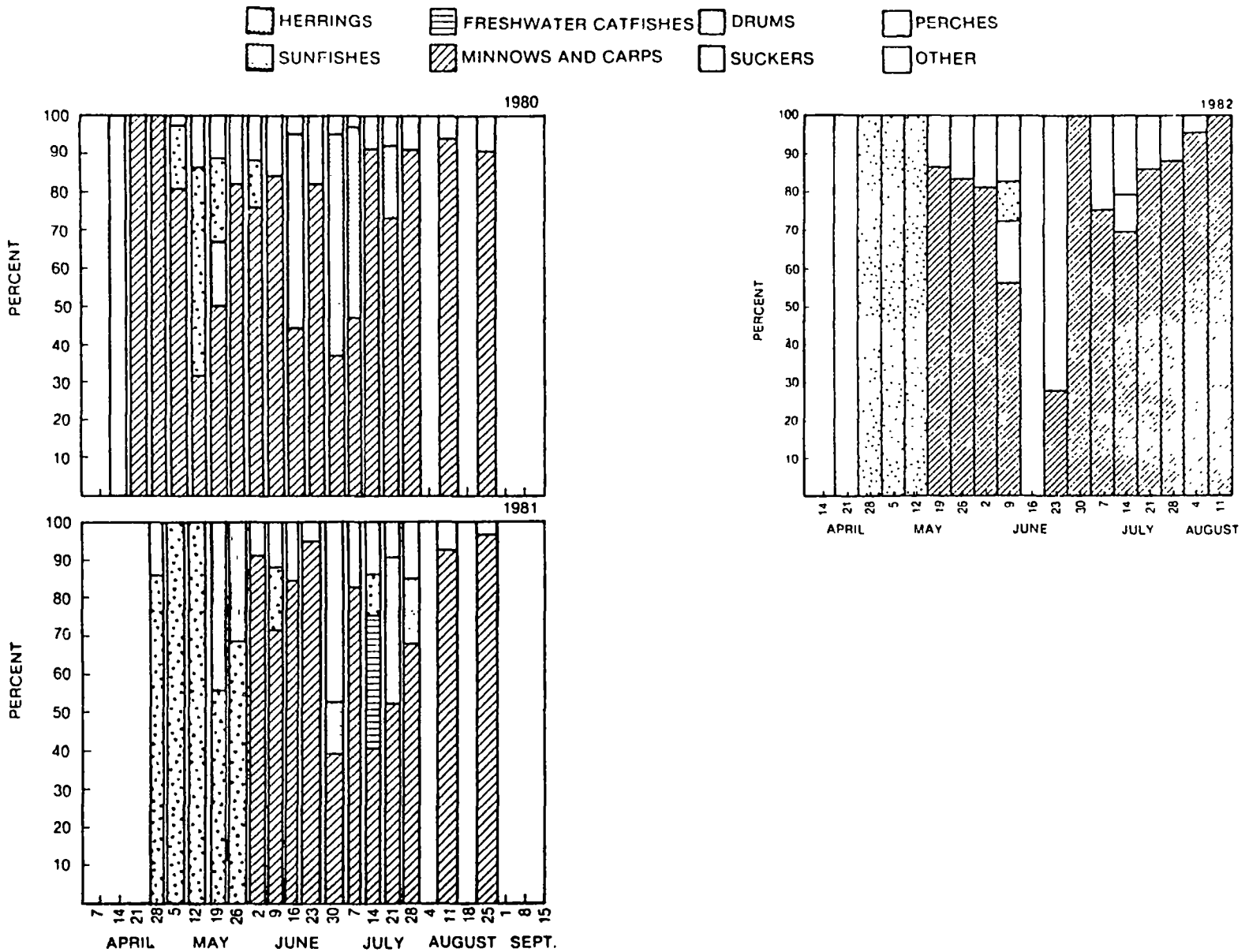


Figure 3-17. (continued)

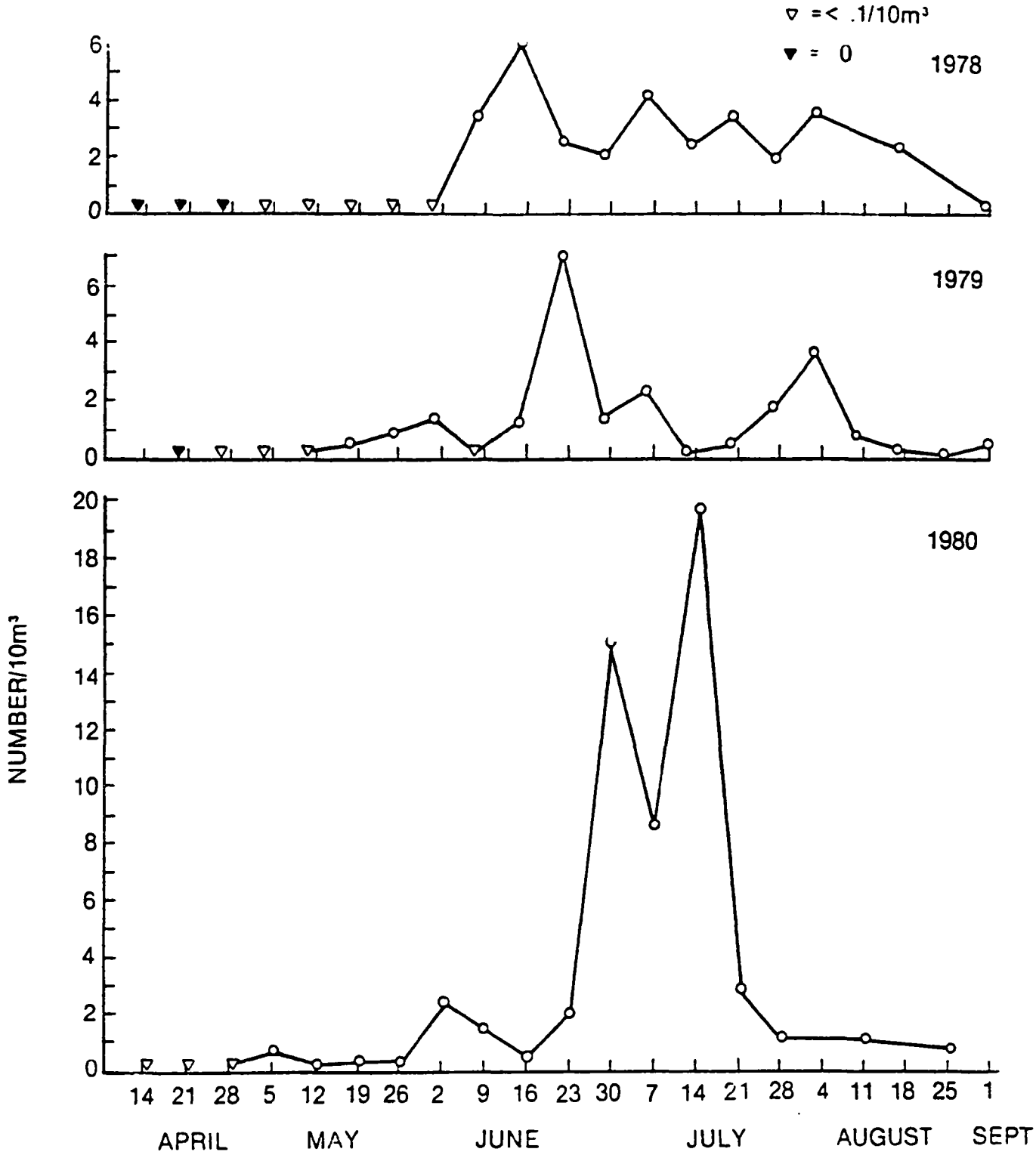


Figure 3-18. Density of ichthyoplankton collected weekly in net tows near the Pike Island Pool, 1978-1982.

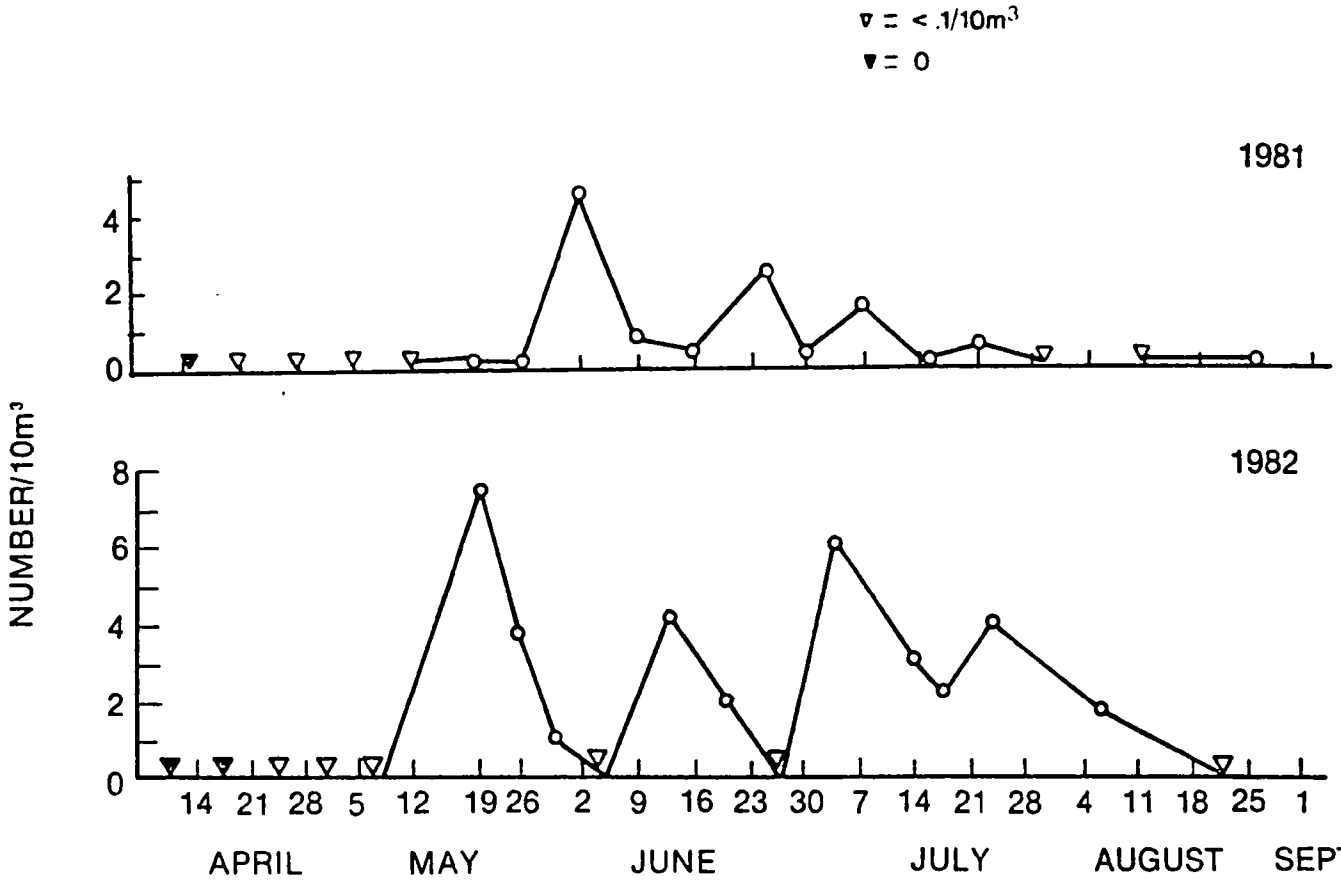


Figure 3-18. (continued)

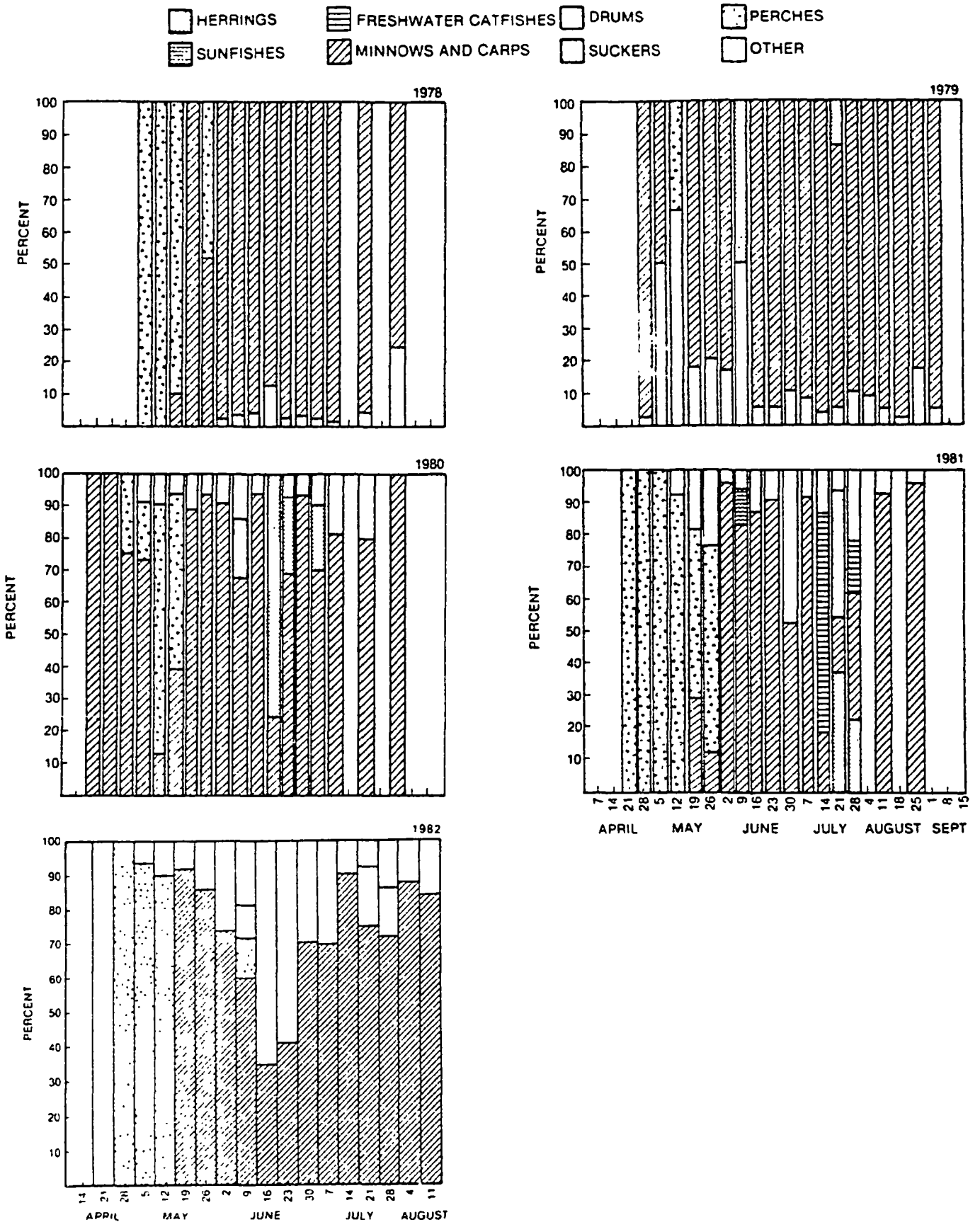


Figure 3-19. Weekly percent composition of all tow samples by dominant families (>10%) near the Pike Island Pool, 1978-1982.

3-17). A similar temporal sequence in species numerically dominating the ichthyoplankton occurs in the Pike Island Pool (Figure 3-18), and at other locations in the upper Ohio River Basin. Exceptions occur, but they reflect the differences that are present in the composition of the fishery at a location rather than the period over which a particular species will spawn. Families of fishes that have many species represented in the community typically have extended spawning periods as not all species spawn simultaneously. Differences in the initiation of spawning during a particular year for a given taxon, i.e., perches in Figures 3-16 and 3-18, may be accounted for by differences in river flow among years and/or differences in the onset of warming of river waters.

Entrainment sampling conducted on three dates in June 1976 at the Bruce Mansfield Power Plant (Ohio River Mile 33.7) resulted in the collection of only fish eggs. The average density during this period was 139 eggs/100 m^3 (Pennsylvania Power Company 1976). Similarly, entrainment sampling during April, May, and June at the Shippingport Atomic Power Station (Ohio River Mile 35.0) yielded no fish eggs and only one cyprinid larvae (Equitable Environmental Health, Inc. 1979).

Ichthyoplankton monitoring in the Ohio River near the Beaver Valley Power Station (River Mile 34.9) from April through July 1976 and 1978 resulted in the collection of 18 taxa distributed among the Clupeidae, Cyprinidae, Catostomidae, Centrarchidae, Percidae, and Sciaenidae. Walleye-sauger and yellow perch larvae were the first taxa in the drift in April and May. By late May, gizzard shad, minnow, crappie, and darter larvae were present. Gizzard shad and minnow and carp larvae numerically dominated collections during June and July each year (NUS Corporation 1976; Duquesne Light Company 1979).

Twelve entrainment collections were made from March 2 to Augut 21, 1978 at the Frank R. Phillips Power Station (Ohio River Mile 15.2). Only 19 larvae and no fish eggs were collected. No eggs or larvae were collected from March 2 to May 4; larvae were collected each biweekly sampling period from May 25 through July 20, and again on August 21. Of the larvae collected, seven were unidentifiable due to mechanical damage. Of the

remaining larvae, 11 were cyprinids (probably Notropis spp.) and one was a clupeid (herring). With so few specimens to compare, identification to family was deemed the most accurate. The greatest number of larvae collected over a 24-hour sampling period was nine on June 8 (average density = 13.7/100 m^3) (Equitable Environmental Health, Inc. 1979).

Monongahela River

Entrainment sampling was conducted at the Mitchell Power Station, located at Monongahela River Mile 29.4, from April 1981 through March 1982. Ichthyoplankton was sampled once every two weeks during the period 15 April through August 1981 and once a month from September 1981 through March 1982. This sampling yielded a total of 3 eggs, 552 larvae, 27 juveniles, and 3 adults of 12 taxa. The taxa collected included the following: gizzard shad, common carp, emerald shiner, mimic shiner, shiners (unidentifiable), bluntnose minnow, minnow (unidentifiable), channel catfish, bullheads (unidentifiable), sunfish (unidentifiable), bass (unidentifiable), darter (unidentifiable), walleye or sauger, and freshwater drum.

Larvae were present in samples collected from April through September, but were most abundant on 22-23 July (56.00/100 m^3), 8-9 July (25.27/100 m^3), and 24-25 June (14.50/100 m^3). Juveniles were collected during four sampling dates, 5-6 August (1.51/100 m^3), 19-20 August (131/100 m^3), 16-17 September (0.38/100 m^3), and 20-21 January (0.73/100 m^3). Adults were taken during two sampling dates 24-25 June (0.18/100 m^3) and 17-18 March (0.32/100 m^3).

Larval catch was dominated by gizzard shad (mean yearly density = 2.61/100 m^3; 35.9% of the total catch), minnow (1.79/100 m^3; 25.4%), common carp (0.26/100 m^3; 3.8%), emerald shiner (0.16/100 m^3; 2.4%), and channel catfish (0.12/100 m^3; 1.4%). Unidentifiable specimens represented 28.1% of the total annual catch (mean = 2.05/100 m^3). Juvenile specimens were dominated by gizzard shad, emerald shiner, and shiners each comprising 22.2% of the total catch (mean = 0.07/100 m^3). Bluntnose minnow (mean = 0.05/100 m^3), mimic shiner (0.02/100 m^3), minnow (0.01/100 m^3), and channel catfish (0.01/100 m^3) were the remaining

juveniles collected. Most juveniles (70.4%) were taken during the 5-6 and 19-20 August sampling surveys. Two emerald shiners and one bluntnose minnow comprised the adult specimens taken during the sampling year (NUS Corporation 1982).

An evaluation of entrainment at the Hatfield Ferry Power Station (Monongahela River Mile 78.9) was conducted during 1979 (Energy Impact Assoc., Inc. 1980). A total of 18 one-hour periods were sampled on three occasions from May through July. No fish eggs or larvae were collected during this sampling.

Entrainment sampling was conducted twice monthly from September through November 1977 and May through September 1977 at the Elrama Power Station (Monongahela River Mile 25.0). Six families of fish--Clupeidae, Cyprinidae, Catostomidae, Ictaluridae, Centrarchidae, and Percidae--were represented in the entrainment samples. Minnows were the most abundant group, and the clupeids (i.e., gizzard shad) were also abundant. Fifteen species of larvae were identified, but most specimens could not be identified below the family level.

Fish eggs and larvae were present primarily from early June to early August 1978, but a few specimens were collected in late April and May and late August and early September 1978. The peak density (99/100 m^3) of eggs and larvae occurred during 28-29 June 1978. The first specimens to appear in the samples were walleye in late April and early May. A mixture of percids (yellow perch and darters) and minnows appeared in late May. In June, minnows, including carp and emerald shiner, and gizzard shad began to dominate the samples. Few specimens were entrained after early August (Ecological Analysts, Inc. 1978).

Allegheny River

During sampling for preparation of a 316(b) demonstration for the Armstrong Power Station (Allegheny River Mile 55.4), ichthyoplankton was sampled between November 1976 and September 1977. Monthly entrainment samples were collected from November through March and again in July,

August, and September. Weekly samples were collected from early April through mid-June. During the 57 one-hour samples, 116 larval and juvenile fish and one fish egg were collected. Larval and juvenile minnows (bluntnose minnow, emerald shiner, mimic shiner, and unidentifiable cyprinids) were the most frequently encountered group (62.1% of the total), followed by larval perch (Johnny darter and unidentifiable perch and darter) (16.4%), and unidentifiable larvae (12.1%). Other taxa collected included the following: spotted sucker (0.8%), unidentifiable sucker (2.6%), unidentifiable sunfish (1.7%), and unidentifiable catfish (1.7%) (Energy Impact Assoc., Inc. 1978).

The number of larval and juvenile fish collected during each sampling period varied seasonally, with entrainment densities ranging from 0/100 to 105.77/100 m^3. Highest numbers of larval and juvenile fish were obtained in June and July when monthly densities averaged 103.04 and 84.14/100 m^3, respectively. Minnows and darters were most abundant at these times.

3.6 DISSOLVED OXYGEN AND ITS INFLUENCE ON FISHES

A possible constraint to the development of hydropower at existing dams in the study area is the potential for depression of dissolved oxygen concentrations. Currently, water passing over dams contributes substantially to reaeration of waters of the study area rivers, and results in a zone of comparatively high dissolved oxygen at the downstream face of dams. Passage of water through turbines installed in dams may circumvent reaeration and may result in a dissolved oxygen sag in a downstream direction. This could cause adverse impacts on fishery resources.

This portion of the literature review will focus on impacts of reduced dissolved oxygen on the fishery. The general consequences of depressed dissolved oxygen concentrations on fish, and more specifically, the levels at which biological impacts could be expected to occur are summarized. This information, when combined with the results of water quality modeling, will enable evaluation of the impacts associated with hydropower development in the study area.

Aerobic organisms utilize the process of diffusion to move dissolved oxygen into their systems by means of an internal-external oxygen pressure gradient. The exchange process is often facilitated by a delivery system (e.g., branchial and opercular pumps in fish) and a transport system (e.g., internal circulatory system) to distribute oxygen within the body. In all aerobic organisms, movement of oxygen to the tissues for metabolism is fundamentally via tension gradients, both inside and out of the body. The oxygen tension gradient between tissues and the external medium is thus critical to the gas exchange process (Davis 1975). Relationships have been established between oxygen consumption of fish and water temperature, water dissolved oxygen content, water carbon dioxide level, size of fish, activity, photoperiod, and other variables (Andrews and Matsuda 1975). Recent comprehensive reviews of the dissolved oxygen requirements of fish have been prepared by Doudoroff and Shumway (1970), Warren et al. (1973), and Davis (1975) and much of the following overview is derived from these sources.

Reduction in the level of available oxygen affects physiological, biochemical, and behavioral processes in fish. Restrictions in the supply of oxygen available for metabolic processes including swimming, migrating, and feeding are caused by hypoxia (Davis 1975). Katz et al. (1959) evaluated the ability of salmon and largemouth bass to swim in water with reduced oxygen content. Largemouth bass were found to display marked seasonal changes in ability to swim at reduced oxygen concentrations. During September, bass were able to swim against a current of 0.8 feet per second (fps) for one day at 25°C in water having a mean dissolved oxygen content of 2.0 mg/l. In early December, at temperatures of 15.5 to 17.0°C, bass could swim against an 0.8 fps current when the water was nearly saturated, but were unable to do so by the time the oxygen level was reduced to 5.0 mg/l. Salmon swimming was impaired at low dissolved oxygen concentrations, a factor that could be important to this migratory species (Katz et al. 1959). Reduction in feeding at reduced dissolved oxygen concentrations has been observed in channel catfish, yellow perch, northern pike, largemouth bass, bluegill, and walleye (Raible 1975, Petit 1973).

Developing fish eggs and larvae show a number of responses to low oxygen including respiratory dependence, retarded growth, reduced yolk sac absorption, developmental deformities, and mortality (Davis 1975, Doudoroff and Shumway 1970). Laboratory studies evaluating the response of warm-water fish species to low dissolved oxygen have been conducted for the following species: white sucker (Siefert and Spoor 1974, Oseid and Smith 1971a), largemouth bass (Dudley and Eipper 1975; Spoor 1977; Carlson and Siefert 1974), walleye (Siefert and Spoor 1974, Oseid and Smith 1971b), black crappie (Siefert and Herman 1977), common carp (Kaur and Toor 1978), channel catfish (Carlson et al. 1980), yellow perch (Carlson et al. 1980), northern pike (Siefert et al. 1973, Adelman and Smith 1970), smallmouth bass (Siefert et al. 1974), and white bass (Siefert et al. 1974). The results of these studies are tabulated in Table 3-12.

Avoidance behavior has been reported for some species in response to low oxygen, although reports of dissolved oxygen thresholds to initiate this behavior vary considerably (Davis 1975). Observed behavior patterns in low O_2 include increased activity, altered phototaxis, and air gulping. Whitmore et al. (1960) demonstrated avoidance of waters containing 1.5 mg/l by largemouth bass and bluegill, and Hill (1969) reported that the American eel consistently selected high over low oxygenated water; the tolerance point for oxygen selection was near 2.5 mg/l at 21°C. The air-water interface may provide a partial means for fish to avoid hypoxia in the underlying water column. The high cost of maintaining aerobiosis in hypoxic water or the lower energy yield of switching to anaerobic metabolism are thus avoided. Not only do the top few millimeters or centimeters of severely hypoxic or even anoxic natural bodies of water have an appreciable oxygen content, but the air itself may also be potentially important as a direct source of oxygen for fish (i.e., "air-gulping" in goldfish) (Burggen 1982). During oxygen depletion, the strength of a negative photoactic response in walleye proved to be largely dependent on the given respiratory situation: during O_2 depletion and during buildup of free CO_2, the response diminished to the point of obliteration. This occurred at levels of O_2 which left mobility and equilibrium of the fish intact (Scherer 1971).

Table 3-12. Summary of lethal levels of dissolved oxygen for fishes occurring in the upper mainstem of the Ohio River and Allegheny and Monongahela Rivers.

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
CLUPEIDAE							
Dorosoma cepedianum Gizzard shad	--	<1.0*	Most	Declining O_2	16	Hart (1945)	*CO_2 tensions 25 mm Hg or less
HIODONTIDAE							
Hiodon alosoides Goldeye	9.4 g	0.7-1.6*	--	Declining O_2	5	Hart (1968)	*Range of lethal levels for individual fish; CO_2 tensions 30 mm Hg or less
	9.4 g	1.2-1.5*	--	"	15	"	*Same as above
ESOCIDAE							
Esox lucius Northern pike	--	3.1	100%	Constant O_2 24 hours*	15	Moore (1942)	*Fish held in a cage submerged in a lake in summer
	--	2.3	100%	Constant O_2 48 hours*	4 or less	"	*Fish held in a cage submerged in a lake in winter
	--	0.2-0.5	100%	Declining O_2	0-20	Privolnev and Koroleva (1953)	
	--	0.3-0.6	First	—	0	Privolnev (1954)	Methods unknown
	1-2 yr	0.5-1.6	About 50%	Declining O_2	15-25	Shkorbatov (1965)	*Water gradually replaced with low O_2 water; averages of individual lethal levels reported
	--	0.7-1.4*	--	--	15-29	Privolnev (1964)	*Reported threshold concentrations; methods unknown
	Fingerlings	1.0-6.0	100% at 1.0 mg/l O_2	Constant O_2 24 hours	21.5	Petit (1973)	All fish survived at 1.5 to 5.0 DO levels. Fish showed signs of stress at 1.5, 2.0, 3.0, and 4.0 mg/l DO levels as compared to control, 6.0 mg/l. Signs of stress: increased opercular movement, color bleaching, air gulping, resting on bottom, lack of feeding.

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Esox lucius Northern pike (cont.)	Fertilized egg to feeding larvae	9.4	43.5%	Constant O_2 at 20 days	15	Siefert et al. (1973)	Significant mortality at DO levels below 4.9 mg/l
	"	4.9	47.6%	"	15	"	
	"	2.6	95.0%	"	15	"	
	"	1.3	100%	"	15	"	
	"	4.9	42%	"	19	Siefert et al. (1973)	Significant mortality at 2.9 mg/l DO
	"	2.9	93.5%	"	19	"	
	Juveniles	7.20	0%	Constant O_2	18.6	Adelman and Smith (1970)	Decreased growth at <4.0 mg/l DO
		5.39	0%	"	18.6	"	
		2.60	0%	"	18.6	"	
		1.74	0%	"	18.6	"	
	Embryo	0.6	23%	Variable O_2 8 hours	10	Peterka and Kent (1976)	Hatching success comparable at all DO levels
		1.8	20%	"	10	"	
		2.6	7%	"	10	"	
		8.0	17%	"	10	"	

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Esox lucius Northern pike (cont.)	Sac larvae	0.3	49%	Variable O_2 8 hours	8-11	Peterka and Kent (1976)	Survival significantly less at 0.3 mg/l DO
		2.0	13%	"	8-11	"	
		4.8	9%	"	8-11	"	
		10.1	8%	"	8-11	"	
	Early feeding larvae	0.5	100%	"	12-14	"	Good survival above 4.0 mg/l DO
		1.6	100%	"	12-14	"	
		4.0	0%	"	12-14	"	
		8.9	7%	"	12-14	"	
CYPRINIDAE							
Campostoma anomalum Stoneroller	--	0.90	100%	Declining O_2*	30	Baker (1941)	*Fish not allowed access to surface
	--	1.4	None	Declining O_2*	30	"	*Fish not allowed access to surface; test discontinued at 12 hours
Carassius auratus Goldfish	1 yr	<2.0	100%	Declining O_2	1-32	Fry et al. (1947)	CO_2 tensions 0-100 mm Hg
	6 g	0.1	100%	Constant O_2 40 min	27-28	Basu (1949)	
	6 g	0.6	None	Constant O_2 9 hours	27-28		

Table 3- 12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Carassius auratus Goldfish (cont.)	6 g	1.0	None	Constant O_2 24 hours	21-27	Basu (1949)	
Cyprius carpio Common carp	8 cm	0.4-0.8	50%	Constant O_2 1 day	10-20	Downing and Merkens (1957)	
	8 cm	0.4-1.2	50%	Constant O_2 7 days	10-16	"	
	8 cm	2.8	50%	"	20	"	
	--	0.2-0.3	First	--	0	Privolnev (1954)	Methods unknown
	2 yr	0.3-0.8*	--	Declining O_2	5-8	Streltsova (1964)	*Lethal O_2 level varied with acclimation to various O_2 levels
	0.5-79 g	0.2-0.7*	--	"	12-18	Opuszynski (1967)	*Range of individual lethal levels; cessation of respiratory movement
	1.6-10 mg	1.1-1.3	50%*	"	21-22	Kumetsova (1958)	*Loss of balance with cessation of respiratory movement (ambiguous)
	245-658 mg	0.6-0.7	50%*	"	19	"	*Same as above
	Embryo	0	100%	Constant O_2	25	Kaur and Toor (1978)	Percentage hatching increased with increasing DO content. Eggs maintained at low DO developed more slowly; time to hatching increased as the DO level decreased. No abnormalities in hatched embryo observed.
	"	1.2	96%	"	25	"	
	"	3.0	60%	"	25	"	

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Cyprinus carpio Commonn carp (cont.)	Embryo	6.0	35%	Constant O_2	25	Kaur and Toor (1978)	
	"	9.0	8%	"	25	"	
	"	12.0	2%	"	25	"	
Notemigonus crysoleucas Golden shiner	--	1.4	None	Constant O_2 48 hours*	4 or less	Moore (1942)	*Fish held in a cage submerged in a lake in winter
	--	<1.0*	Most	Declining O_2	15-16	Hart (1945)	*CO_2 tensions 60 mm Hg or less
Notropis cornutus Common shiner	1-2 yr	1.4-6.2	First*	"	12-27	Cooper (1960)	*Loss of equilibrium
	1-2 yr	0.5-1.0	50%*	"	12-27	"	*Loss of equilibrium
	1-2 yr	0.4-0.6	100%*	"	12-27	"	*Loss of equilibrium
	27.5 g	<2.0*	100%	"	17-22	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg
Notropis whipplei Steelcolor shiner	5 cm	1.0	50%*	"	20-26	Wilding (1939)	*Loss of equilibrium; values obtained by interpolation from graph
Pimephales notatus Bluntnose minnow	4 cm	0.8-1.3	50%*	"	7-24	"	*Same as above
Pimephales promelas Fathead minnow	3.9 g	<2.0*	100%	"	18-21	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Pimephales promelas Fathead minnow (cont.)	3.6 cm	1.0	None*	Constant O_2 18 hours	18-26	Whitworth and Irwin (1961)	*Also in tests with declining CO_2
	Reproduction	1.00-7.92	--	Constant O_2	15-25	Brungs (1971)	No effect on egg production for fish reared at DO concentrations of 3.00 to 7.92 mg/l. Eggs per female lower at 2.0 mg/l, and no eggs were laid at 1.0 mg/l.
	Fry survival and growth	2.02-7.26	--	"	—	"	Fry survival was reduced at <4.0 mg/l; 18% survivors at 4.0 mg/l were deformed. Fry growth was reduced at all DO concentrations below the control (7.26 mg/l).
Semotilus atromaculatus Creek chub	2-3 yr	<2.0*	100%	Declining O_2	17-21	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg
CATOSTOMIDAE							
Catostomus commersoni White sucker	265 g	<2.0*	100%	Declining O_2	17-18	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg
	Fertilization to hatching	7	81.7%	Constant O_2	12.3	Oseid and Smith (1971)	Days to 95% hatch--14; mean length at hatching--10.1 mm
	"	6	80.1%	"	12.9	"	Days to 95% hatch--11; mean length at hatching--8.9 mm
	"	5	73.7%	"	12.3	"	Days to 95% hatch--14; mean length at hatching--10.1 mm
	"	3	71.5-75.8%	"	12.3 & 12.9	"	Days to 95% hatch--13 to 14; mean length at hatching--8.3-9.7 mm
	Embryo to feeding larvae	1.2	100%	Constant O_2 mortality at 22 days	18	Seifert and Spoor (1974)	No harm apparent at 4.5 mg/l. Good hatching at 2.5 mg/l, but growth suppressed. Time to first feeding comparable among control and larvae reared at 4.9 mg/l but extended for larvae reared at 2.5 mg/l.

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Catostomus commersoni White sucker (cont.)		2.5	10.5%	Constant O_2 mortality at 22 days	18	Seifert and Spoor (1974)	
		4.9	4.5%	"	18	"	
		9.1	8.0%	"	18	"	
ICTALURIDAE							
Ictalurus catus White catfish	--	<1.0*	100%	Declining O_2	12-16	Hart (1945)	*CO_2 tensions 100 mm Hg or less
Ictalurus melas Black bullhead	--	3.0	100%	Constant O_2* 24 hours	22	Moore (1942)	*Fish held in a cage submerged in a lake in summer
	--	0.3	100%	Constant O_2* 48 hours	4 or less	"	*Fish held in a cage submerged in a lake in winter
Ictalurus nebulosus Brown bullhead	36 g	<1.0*	100%	Declining O_2	19-22	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg
	--	<1.0	Most	"	12-16	Hart (1945)	*CO_2 tensions 100 mm Hg or less
Ictalurus punctatus Channel catfish	Juvenile	1.0-1.1*	--	Constant O_2 24 hours	25-35	Moss and Scott (1961)	*Estimated average tolerance limits for "normal" fish
	"	2.0*	--	"	30	"	*Estimated average tolerance limits for "excessively fat," overfed fish
	"	0.8-0.9*	--	Gradually declining O_2, reduced daily	25-35	"	*Estimated average 24-hr tolerance limits

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Ictalurus punctatus Channel catfish (cont.)	Juvenile	7.7-2.0	0%	Constant O_2 69 days	25	Carlson et al. (1980)	Growth less at 2.0 and 3.5 mg/l DO, comparable at 5.0, 6.5, and control. Fish at 2.0 mg/l stressed.
	"	6.0-8.0 to 0.4-3.9	0%	Diel fluctuating O_2 69 days	25	"	Growth less than in constant DO test. Only fish reared at lowest DO showed less growth than control.
	Fingerling growth	3.0-6.8	0%	Constant O_2 177 days	27	Raible (1975)	Fish died at DO levels <1.0 mg/l. Weight gain ranged from 706 to 1210% and was highest at 6.0 mg/l and lowest at 3.0 mg/l.
		8.3 5.0 3.0	0%	Constant O_2 for 14 weeks ration fixed	26.6	Andrews et al. (1973)	Growth at 3.0 mg/l ≈ 1/2 that at >5.0 mg/l. Fish at 3.0 mg/l less active.
		8.3 5.0 3.0	0%	Constant O_2 for 6 weeks, fed *ad libitum*	26.6	"	Poor growth in fish at 3.0 mg/l, moderate growth at 5.0 mg/l, best growth at 8.3 mg/l.
	Embryo to first feeding	7.8	33.5%	Constant O_2 19 days	25	Carlson et al. (1974)	Survival significantly less at 2.4 and 4.2 mg/l; growth reduced, hatching and first feeding delayed at all DO levels below 7.8 mg/l.
		5.8	36.0%	"	25	"	
		5.0	44.5%	"	25	"	
		4.2	62.5%	"	25	"	
		2.4	92.5%	"	25	"	
	Embryo to first feeding	7.3	33.0%	"	28	"	Survival significantly less at 2.3 mg/l; other observations same as above testing.

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Ictalurus punctatus Channel catfish (cont.)		5.4	46.0%	Constant O_2 19 days	28	Carlson et al. (1974)	
		4.6	48.0%	"	28	"	
		3.8	47.0%	"	28	"	
		2.3	100%	"	28	"	
CYPRINODONTIDAE							
Fundulus diaphanus Banded killifish	—	0.9	100%	Constant O_2*	4 or less	Moore (1942)	*Fish held in a cage submerged in a lake in winter
GASTEROSTEIDAE							
Culea inconstans Brook stickleback	0.6 g	<2.0*	100%	Declining O_2	20-23	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg
PERCICHTHYIDAE							
Morone chrysops White bass	Fertilization to hatching	9.2	60.5%	Constant O_2 mortality at hatch	16	Siefert et al. (1974)	No trend in survival at hatch with regard to decreasing DO. Larval survival at 7 days post-hatch lower at 1.8 mg/l DO.
		6.9	53.1%	"	16	"	
		5.0	61.0%	"	16	"	
		3.4	58.8%	"	16	"	
		1.8	57.0%	"	16	"	
CENTRARCHIDAE							
Ambloplites rupestris Rock bass	—	2.3	100%	Constant O_2* 48 hours	4 or less	Moore (1942)	*Fish held in a cage submerged in a lake in winter
Lepomis gulosus Warmouth	13 cm	0.4-1.6	100%	Declining O_2*	21-32	Baker (1941)	*Fish not allowed access to surface

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Lepomis gulosus Warmouth (cont.)	13 cm	0.7-1.3	None	Declining O_2*	21-32	Baker (1941)	*Fish allowed access to surface; tests discontinued at 6 to 20 hours
Lepomis cyanellus Green sunfish	--	1.5	100%	Constant O_2 48 hours*	4 or less	Moore (1942)	*Fish held in a cage submerged in a lake in winter
Lepomis gibbosus Pumpkinseed	--	3.1	100%	Constant O_2 24 hours*	15	"	*Fish held in a cage submerged in a lake in summer
	--	0.9	100%	Constant O_2 48 hours*	4 or less	"	*Fish held in a cage submerged in a lake in winter
	24 g	<2.0*	100%	Declining O_2	19-21	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg
Lepomis humilis Orangespotted sunfish	7.6 g	0.9-1.1	100%	Declining O_2*	25-28	Baker (1941)	*Fish not allowed access to surface
	7.6 g	0.2	None	"	22-23	"	*Fish allowed access to surface; test discontinued at 24 hours
	--	1.4	100%	Constant O_2 48 hours*	4 or less	Moore (1942)	*Fish held in a cage submerged in a lake in winter
Lepomis macrochirus Bluegill	2-6 cm	0.6-1.1	100%	Declining O_2*	24-30	Baker (1941)	*Fish not allowed access to surface
	2-7 cm	0.5-1.0	None	"	24-29	"	*Fish allowed access to surface; test discontinued at 12 to 24 hours
	5 cm	0.9	50%	"	30	"	*Fish allowed access to surface

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Lepomis macrochirus Bluegill (cont.)	Juvenile	0.5	100%	Declining O_2	20	McNeil (1956)	
	6-20 g	0.8-1.2*	--	Constant O_2 24 hours	25-35	Moss and Scott (1961)	*Estimated average tolerance limits
	6-20 g	0.7-0.9*	--	Gradually declining O_2, reduced daily	25-35	"	*Estimated average 24 hour tolerance limits
	--	3.1	100%	Constant O_2 24 hours*	15	Moore (1942)	*Fish held in a cage submerged in a lake in summer
	--	0.8	100%	Constant O_2 48 hours*	4 or less	"	*Fish held in a cage submerged in a lake in winter
	--	<1.0*	Most	Declining O_2	15-16	Hart (1945)	*CO_2 tensions 25 mm Hg
	Embryo	0.5	60%	Variable O_2 4 hours	25-28	Peterka and Kent (1976)	Survival comparable at all DO levels
	"	2.1	54%	"	25-28	"	
	"	3.0	50%	"	25-28	"	
	"	7.8	53%	"	25-28	"	
	Sac larvae	0.5	99%	"	21-26	"	Survival comparable at DO levels >1.8 mg/l
	"	1.8	30%	"	21-26	"	
	"	3.7	35%	"	21-26	"	
	"	8.0	31%	"	21-26	"	

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Bluegill (cont.)	Fingerlings	0.8-6.0	100% at 0.8 mg/l	Constant O_2 24 hours	21	Petit (1973)	All survived at 1.0 to 5.0 mg/l levels. Fish stressed at DO levels from 1.0 to 3.0 mg/l.
Lepomis microlophus Redear sunfish	24 g	<1.0*	100%	Declining O_2	20-21	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg
Micropterus dolomieui Smallmouth bass	255 g	<2.0*	100%	"	15-25	"	*CO_2 tensions 0-40 mm Hg
	4 g	0.9-1.6	First*	"	11-27	Burdick et al. (1954)	*Loss of equilibrium
	4 g	0.6-1.2	50%*	"	11-27	"	*Loss of equilibrium
	4 g	0.5-1.0	100%	"	11-27	"	*Loss of equilibrium
	Fertilized egg to feeding larvae	8.7	50.0%	Constant O_2 mortality at 14 days	20	Siefert et al. (1974)	Successful hatching at all DO levels; total mortality of larvae before 14 days at lowest DO levels. At 4.4 mg/l, rate of development approximated control but larval size smaller than control.
	"	4.4	63.5%	"	20	"	
	"	2.5	100%	"	20	"	
	"	1.2	100%	"	20	"	
	"	4.4	70%	"	25	"	Development more rapid than at 20°C, growth was greater, and feeding started earlier.
		2.2	100%	"	25	"	
	Embryo	0.5	100%	Variable O_2 6 hours	20-23	Peterka and Kent (1976)	Mean hatching success comparable at DOs >1.8.

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Micropterus dolomieui Smallmouth bass (cont.)	Embryo	1.8	31%	Variable O_2 6 hours	20-23	Peterka and Kent (1976)	
	"	3.5	13%	"	20-23	"	
	"	7.9	9%	"	20-23	"	
	Sac larva	0.5	100%	Variable O_2 6 hours	17	"	Mean hatching success comparable at DOs >2.2 mg/l
	"	2.2	47%	"	17	"	
	"	4.2	27%	"	17	"	
	"	9.0	17%	"	17	"	
Micropterus salmoides Largemouth bass	4-14 g	0.9-1.4*	--	Constant O_2 24 hours	25-35	Moss and Scott (1961)	*Estimated average tolerance limits
	4-14 g	0.8-1.2*	--	Gradually declining O_2, reduced daily	25-35	"	*Estimated average 24-hour tolerance limits
	--	3.1	100%	Constant O_2 24 hours*	15	Moore (1942)	*Fish held in a cage submerged in a lake in summer
	--	2.3	100%	Constant O_2 48 hours*	4 or less	"	*Fish held in a cage submerged in a lake in winter
	--	<1.0*	100%	Declining O_2*	12-16	Hart (1945)	*CO_2 tensions 50 mm Hg or less
	Fingerling	1.0-6.0	100% at 1.0 mg/l O_2	Constant O_2 24 hours	25	Petit (1973)	All survived at 1.5 to 5.0 mg/l levels. Fish stressed at DO levels from 1.5 to 5.0.

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Micropterus salmoides							
Largemouth bass (cont.)	Fertilized egg to feeding larvae	8.6	10.9%	Constant O_2 20 days	20	Carlson and Siefert (1984)	Control in these experiments; hatching and feeding began at hours 50 and 193, respectively.
	"	6.3	11.8%	"	20	"	Hatching and feeding began at hours 56 and 195, respectively
	"	4.5	11.8%	"	20	"	Hatching and feeding began at hours 49 and 204, respectively
	"	3.1	24.6%	"	20	"	Hatching and feeding began at hours 51 and 216, respectively
	"	1.7	99.6%	"	20	"	Hatching and feeding began at hours 47 and 220, respectively
	"	8.3	25.5%	"	23	"	Control in these experiments; initial feeding at 124 hours
	"	6.0	10.9%	"	23	"	Initial feeding at 124 hours
	"	4.2	38.2%	"	23	"	Initial feeding at 129 hours
	"	3.0	22.8%	"	23	"	Initial feeding at 170 hours
	"	1.7	100%	"	23	"	None fed
	Embryo	2.0		Too Hatching	15	Dudley and Eipper (1975)	Embryo mortality occurred for these DO levels and temperatures (2.0 to 2.8 mg/l; 15 to 25°C)
	"	2.1		"	20	"	
	"	2.8		"	25	"	

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Micropterus salmoides Largemouth bass (cont.)	Embryo and larval	2.0		Too Hatching	15	Dudley and Eipper (1975)	These DO levels produced the same percentage of normally shaped larvae that water at 90% oxygen saturation (i.e., 15°C and 9.13 mg/l, 20°C and 8.25 mg/l, 25°C and 7.54 mg/l) produced
		2.5		"	20	"	
		3.5		"	25	"	
Pomoxis annularis White crappie	23 cm	0.4-0.5	100%	Declining O_2*	27	Baker (1941)	*Fish not allowed access to surface
	23 cm	0.4	50%	Declining O_2*	27	Baker (1941)	*Fish allowed access to surface
Pomoxis nigromaculatus Black crappie	--	4.3	100%	Constant O_2 24 hours*	26	Moore (1942)	*Fish held in a cage submerged in a lake in summer
	--	1.4	100%	Constant O_2 48 hours*	4 or less	Moore (1942)	*Fish held in a cage submerged in a lake in winter
	--	1.0*	Most	Declining O_2	16	Hart (1945)	*CO_2 tensions 30 mm Hg or less
	Adult spawning, embryo, larvae	5 levels, 2.5 to air saturation	--	Constant O_2	20	Siefert and Herman (1977)	Reduce DO concentrations over the range tested had little or no effect on the occurrence of successful spawning or on the number of embryos, viability, hatching success, and survival through swim-up stage
	"	5 levels, 2.6 to air saturation	--	"	Varying 15-21	Carlson and Herman (1978)	Successful spawning occurred in all treatments
	"	4 levels	--	Diurnally fluctuating O_2	"	"	Successful spawning did not occur in lowest fluctuating treatment <1.8 to 4.1 mg/l)

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
PERCIDAE							
Perca flavescens Yellow perch	78 g	<2.0*	100%	Declining O_2	19-24	Black et al. (1954)	*CO_2 tensions 0-40 mm Hg
	89-99 g	0.5-0.8	50%*	Declining O_2	12-21	Burdick et al. (1957)	*Loss of equilibrium
	--	3.1	100%	Constant O_2 24 hours*	15	Moore (1942)	*Fish held in a cage submerged in a lake in summer
	--	1.5	100%	Constant O_2 48 hours*	4 or less	Moore (1942)	*Fish held in a cage submerged in a lake in winter
	7.6 cm	0.9-1.1	50%*	Declining O_2	18-27	Wilding (1939)	*Loss of equilibrium; values obtained by interpolation from graph
	Fingerlings	1.0-6.0	100% at 1.0 mg/l	Constant O_2 24 hours	22.8	Petit (1973)	All fish survived at DO levels of >1.5 mg/l. Stress apparent at <4.0 mg/l.
	"	1.0-6.0	0	"	15.2	"	100% survival at 1.0 mg/l
	Juvenile	8.5-2.0	0	Constant O_2 67 days	20	Carlson et al. (1980)	Growth poor at 2.0 mg/l, comparable at 8.5, 6.5, 5.0, and 3.5 mg/l.
	"	6.8-9.1 to 0.7-5.0	0	Diel fluctuating O_2 67 days	20	"	Growth comparable at all DO levels
Stizostedion vitreum Walleye	Fingerlings	1.4-6.0	100% at 2.0	Constant O_2 24 hours	22.8	Petit (1973)	Fish died at 2.0 and 1.4 mg/l DO, but none died at levels of ≥3.0 mg/l.

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
Stizostedion vitreum Walleye (cont.)	Egg to hatching	2-6	42 to 69% survival to hatching	Constant O_2	12.4-	Oseid and Smith (1971)	Time to hatching was extended, survival was diminished, and mean length was reduced when DO was decreased from 6.0 to 3.0 mg/l.
	Embryo to feeding larvae	1.3	100%	Constant O_2 mortality at 20 days	17	Siefert and Spoor (1974)	Survival in control (8.9 mg/l DO) and at 50% saturation (4.8) comparable; at 35% saturation (3.4 mg/l DO) and below survival markedly reduced. Larval size at hatching comparable in control and 50% saturation; at saturations of <35%, size at hatching reduced. Start of feeding comparable in control and at 50% saturation.
	"	2.0	100%	"	17	"	
	"	2.4	100%	"	17	"	
	"	3.4	85.5%	"	17	"	
	"	4.8	61.5%	"	17	"	
	"	8.9	58.5	"	17	"	
	"	2.3	100%	Constant O_2 mortality at 20 days	20	"	Development faster than at 17°C, but few survivors.
	"	4.5	99.5%	"	20	"	
	"	8.4	98.0%	"	20	"	

Table 3-12. (continued)

Species of Fish Scientific and Common Name	Age or Size	Dissolved O_2 mg/l	Deaths	Exposure	Temp °C	Reference	Remarks
SCIAENIDAE							
Aplodinotus grunniens Freshwater drum	--	4.3	100%	Constant O_2 24 hours*	26	Moore (1942)	*Fish held in a cage submerged in a lake in summer

[a]The symbol < preceding an O_2 concentration value in this column indicates that several or numerous lethal O_2 concentrations reported were all less than (often much less than) the value shown.

[b]"Declining O_2" signifies gradual reduction of O_2; unless otherwise noted under Remarks, O_2 was reduced by respiration of test fish.

[c]References cited dated from 1937 to 1970 inclusive taken from Doudoroff and Shumway 1970. References subsequent to 1970 are included in Literature Cited.

[d]The asterisk (*) is used to indicate to which item or items in the columns at the left the remark pertains or is most pertinent.

Some species show an ability to acclimate to lowered ambient oxygen. However, the advantage gained is not clear. Acclimation can enhance blood oxygen capacity and oxygen utilization somewhat but may not aid active swimming performance. Acclimation may be useful to fish subjected to gradual reductions in oxygen levels, but would be of little advantage to a fish encountering rapid and severe reductions (Davis 1975). Acclimation by study area species may be accommodated by reduction in movements, increasing hematocrit levels, or alteration of heart rate, all adaptations observed in freshwater fishes (Hoss and Peters 1976).

Migration into lower reaches of tributaries is another mechanism by which fish in the study area would be able to escape anoxic or hypoxic conditions. Krumholz and Minckley (1964) suggested that tributaries often provided a refugia for species typically occurring in the upper mainstem of the Ohio River. Gammon and Reidy (1981) observed that a variety of Wabash River fishes concentrated in the mouths of tributaries during an episode of low dissolved oxygen during July and August 1977.

The above information characterizes the responses of and adaptations by fishes to low dissolved oxygen concentrations. The remaining portion of this review is concerned with levels of oxygen that actually result in mortality (Table 3-12). The primary source of information for this summary was Table 1 in Doudoroff and Shumway (1970); information for species occurring in the study area was abstracted from this table and is included herein. Additionally, studies published subsequent to Doudoroff and Shumway's compendium have been added. Habitat suitability information compiled by the U.S. Department of the Interior for several study area species was reviewed, but no data regarding dissolved oxygen requirements for any life stage was available. Species accounts reviewed for which O_2 data were lacking included: blacknose dace (Trail et al. 1983), black bullhead (Stuber 1982), smallmouth buffalo (Edwards and Twomey 1982), bigmouth buffalo (Edwards 1983), creek chub (McMahon 1982), common shiner (Trail et al. 1983), and green sunfish (Stuber et al. 1982). No information on dissolved oxygen tolerance was available for the majority of species in the study area.

The levels of dissolved oxygen shown to be lethal to fish are generally below 4.0 mg/l (Table 3-12). Species that could tolerate dissolved oxygen levels below 3.0 mg/l, with some individuals surviving, including gizzard shad, goldeye, northern pike, stoneroller, goldfish, carp, golden shiner, common shiner, steelcolor shiner, bluntnose minnow, fathead minnow, creek chub, white sucker, white catfish, black bullhead, brown bullhead, channel catfish, banded killifish, brook stickleback, white bass, rock bass, warmouth, green sunfish, pumpkinseed, orangespotted sunfish, bluegill, redear sunfish, smallmouth bass, largemouth bass, white crappie, yellow perch, and walleye. Among these species are several that numerically dominate the fish community of the study area rivers, contribute substantially to the biomass, or are important to the sport catch. Generally, when the same species was tested at high and low temperatures, it had a greater tolerance for low dissolved oxygen levels at low rather than at high water temperatures. Two species that would undergo stress at 4.0 mg/l at summer temperatures are the black crappie and the freshwater drum.

Tolerance of embryonic and larval stages to low dissolved oxygen concentrations for select species was evaluated and survivorship at dissolved oxygen levels above 3.0 mg/l was generally good. Low dissolved oxygen levels and high temperatures in study area rivers typically occur late during summer. Most species occurring in the study area are spring and early summer spawners, therefore, low dissolved oxygen levels resulting from hydroelectric facility operations should not affect embryological development or hatching success. Larval stages and fingerlings, as well as juveniles and adults, would be affected by low dissolved oxygen levels should they occur.

3.7 IMPACTS OF HYDROPOWER PLANT OPERATION ON INDIGENOUS FISH SPECIES

Bell et al. (1967, 1981) provided a comprehensive review of the success of passage of small fish through hydroelectric power generating turbines. His review centered on the anadromous salmonid fisheries of the Columbia River in the Pacific Northwest, but included Canadian and European studies as well. Each location evaluated had either a Francis or Kaplan turbine. Fish losses were attributed to mechanical injuries--abrasions,

contusions, or lacerations; pressure injuries--popped eyes and gill hemorrhages; or shearing action injuries--torn opercula and broken gill arches (Bell et al. 1967, 1981; Turbak et al. 1981). Based upon extensive regression analyses of Francis and Kaplan turbine operational and fish loss data, Bell et al. (1967) concluded that successful passage of fish through turbines was most related to total machine operating efficiency, which is related to wicket gate opening, quantity of water at the head used, and blade angle setting. Generally, highest survival was observed at the point of highest total efficiency for both turbine types. Reported percent survival of fish tested ranged from 0 to 100 percent, but average percent survival was 75 percent in 20 of 32 tests conducted (Bell et al. 1967).

Olson and Kaczynski (1980) reported the results of survival evaluations of downstream migrant coho salmon and steelhead trout through horizontal-axis bulb turbines at Rock Island Dam on the mid-Columbia River. The estimated survival rate for yearling coho salmon smolts passing through the bulb turbine was 93 percent (95 percent confidence intervals equals 90.4 to 95.6 percent); steelhead smolt survival was estimated at 96.9 percent (95 percent confidence interval of 88.0 to 105.9 percent).

The effect of hydropower development on anadromous fishes of the northeast United States was reported by the U.S. Fish and Wildlife Serivce in 1982. In that publication, Kynard et al. discussed the effects of Kaplan turbines on Atlantic salmon smolts, American shad, and blueback herring; Gloss et al. discussed the effects of Ossberger turbines on Atlantic salmon smolts, striped bass, and American shad; and Knight and Kuzmeskus described the potential effects of bulb turbines on Atlantic salmon smolts. The latter study was conducted at Essex Dam along the Merrimack River at Lawrence, Massachusetts. Knight and Kuzmeskus reported 98 percent survival of salmon smolt five hours after plant passage.

The preceding studies reveal that few bulb turbine equipped hydroplant fish mortality studies have been conducted. Those completed have dealt with anadromous, cold water fisheries in coastal areas. A field study that will document fish survival at a bulb turbine equipped hydroplant located along a warm-water, midwestern river remains to be conducted.

4.0 DISCUSSION

4.1 EVALUATION OF WATER QUALITY MODEL PREDICTIONS

The modeling analyses included the development of the calibrated model, the verification of the model accuracy under another set of conditions, sensitivity analyses for key parameters, and analysis of various hydropower development scenarios. Based on the calibration and verification results, a high level of confidence in the model accuracy is indicated. The available data were sufficiently detailed to provide a level of resolution suitable for the purpose of the study. The dissolved oxygen profile predictions compare very well to the shape of the observed data profiles, and except for the inability of the model to completely demonstrate the supersaturated condition on the Ohio River, the dissolved oxygen levels show good agreement.

The sensitivity analyses indicated that the model is fairly insensitive to small changes in the parameter values selected. The greatest sensitivity appears to be with the light extinction coefficient effect on algal populations and consequent impacts on dissolved oxygen levels.

The results of the hydropower development scenarios indicated there would be a cumulative impact on dissolved oxygen levels at the LTMA flow rate, but that this impact would not be of sufficient magnitude to cause water quality violations (depression of dissolved oxygen levels below 5.0 mg/l) in the study area. The extreme case of no reaeration at the locks and dams (i.e., 100 percent flow through the turbines with no reaeration from the dam) indicated reduced dissolved oxygen levels just downstream of each dam, but these predicted levels are well above the stream standard of 5.0 mg/l. The results from the 50 percent flow condition show reduced impacts from hydropower development. Based on the planned hydropower development announced for these locks and dams, the flow through the turbines would never be 100 percent, and would most likely be around 80 percent at the LTMA condition. Therefore, it is expected that the cumulative dissolved oxygen deficit within the study area from complete hydro-

power development would fall somewhere between the 50 percent and 100 percent scenarios.

The results from the LFE analysis are similar to the results from the LTMA. There is a stronger indication of a dissolved oxygen deficit at the lower reaches of the Ohio River, but no water quality violation is predicted to occur within the study area.

The down river impact of hydropower development (i.e., below Ohio River Mile 40) was not included in the scope of this study. There would be concern in these lower reaches, based on the trend of the dissolved oxygen levels predicted in this study and the indication that the deficits will be cumulative. There also have been a higher number of dissolved oxygen water quality criteria violations in the lower Ohio River reaches (ORSANCO 1980, 1982, 1984), which could be exacerbated by hydropower development. If this were the situation, then the slightly reduced dissolved oxygen levels at the lower study boundary (Ohio River Mile 40) could be significant.

A limitation in evaluating these results is the condition upstream of the study area. The large number of potential development sites on the upper Allegheny and upper Monongahela Rivers could change the upstream conditions as used in this study (i.e., the headwater conditions). An investigation of these upper reaches for cumulative impacts of hydropower development could result in a lower dissolved oxygen predicted as a headwater condition for this study. This would then affect the predictions for the Allegheny and Monongahela Rivers.

4.2 EVALUATION OF BIOLOGICAL IMPACTS ASSOCIATED WITH LOW DISSOLVED OXYGEN VALUES

The upper Ohio River and Allegheny and Monongahela Rivers have a fish community composed of 122 species distributed among 20 families. Biological monitoring has been conducted in the study area during the past 30 years, resulting in a fairly detailed characterization of the fish fauna for recent times. Following the categorization of fishes provided by Preston and White (1978), the fish fauna of the study area is dominated, either numerically or in biomass, by species in the following categories:

Category	Species Included
Forage A	Emerald shiner, bigeye shiner, ghost shiner, striped shiner, rosyface shiner, spotfin shiner, sand shiner, mimic shiner, and bluntnose minnow
Forage B	Gizzard shad
Sport A	White bass, rock bass, green sunfish, pumpkinseed, warmouth, bluegill, smallmouth bass, largemouth bass, spotted bass, and white crappie
Sport B	Yellow perch and walleye
Commercial	White catfish, channel catfish, flathead catfish, quillback, and freshwater drum
Rough	Longnose gar, carp, goldfish, white sucker, northern hogsucker, golden redhorse, black bullhead, yellow bullhead, and brown bullhead
Miscellaneous	Trout-perch, Johnny darter, and logperch

Many other species typically accompanied the above dominants in fish collections, however, the others occurred at low density, typically have low biomass, but added richness to the community.

The study area provides seven different habitats for spawning, (1) the main channel, (2) main channel border, (3) the shore-debris zone, (4) tail waters, (5) side channels, (6) sloughs and embayments, and (7) creek mouths and flooded channels. Some or all of these areas are used as spawning sites, for larvae and juveniles of 13 of the 20 families occurring in the study area have been collected in ichthyoplankton tows or in entrainment samples, 59 taxa in all.

Spawning occurs primarily during spring and early summer. Thus, most species and the peak period(s) of ichthyoplankton density preceed adverse conditions that could be associated with the late summer high temperature-low river flow period. With locks and dams in the study area being retrofit for hydropower production, the potential exists for dissolved oxygen levels to be depressed during the late summer high temperature-low flow condition. However, model predictions suggest that oxygen values will remain high, average >5.0 mg/l per day, therefore, no sustained impact to the study area fishery is anticipated as a result of low dissolved oxygen values. Tolerance of fishes to low dissolved oxygen levels suggest that only minor impacts would occur so long as dissolved oxygen values remained above 4.0 mg/l.

5.0 CONCLUSIONS

The conversion of the locks and dams to hydropower will reduce the reaeration in the study area. The complete removal of this reaeration will be demonstrated as a reduction in dissolved oxygen levels in the study area. The total reduction at the downriver location in this study area is predicted to be about 1.4 mg/l (at complete removal of reaeration) for the lowest expected monthly average flow (LTMA). The reduction in dissolved oxygen for the lowest flow expected (LFE) is also predicted to be about 1.4 mg/l.

The reduction in dissolved oxygen levels appears to be cumulative, and appears to be more significant at the downriver reaches than at the upriver locations. It appears that the natural reaeration at the upriver locations compensates for the loss of reaeration at the upper locks and dams, but that this natural reaeration is less adequate downriver.

The complete conversion of the locks and dams in the study area is not predicted to create a water quality violation for dissolved oxygen. The complete conversion could cause a violation downriver. However, this was not evaluated in this study.

Under the conditions evaluated, dissolved oxygen values will remain above 5.0 mg/l and should be sufficient to protect aquatic life.

6.0 RECOMMENDATIONS

The evaluation of hydropower impacts on dissolved oxygen should be continued. It should include upriver evaluations on the Allegheny and Monongahela Rivers to determine if a degraded water quality condition is expected at the headwaters for this study. The study should be extended downriver to determine if the cumulative dissolved oxygen deficit observed in this study continues to be demonstrated.

The evaluation of each hydropower conversion proposal on the study area rivers should include an evaluation of the existing lock and dam reaeration. The result of the investigation should be compared to the conditions in this study and evaluated to determine the potential impact on these conclusions. In particular, the reaeration of the turbine tailrace should be estimated. The reaeration of the turbine flow should be evaluated as a mitigation requirement.

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