Part I: Monroe Facility Case Study

Chapter I1: Background

This case study presents the results of an analysis performed by EPA to assess the potential benefits of reducing impingement and entrainment (I&E) at cooling water intake structures (CWIS) at the Detroit Edison Monroe Power plant, located at the mouth of the River Raisin on the western shore of Lake Erie (Figure I1-1). Section I1-1 of this background chapter provides a brief description of the facility, Section I1-2 describes the environmental setting, and Section I1-3 presents information on the area's socioeconomic characteristics.

CHAPTER CONTENTS

I1-1 OVERVIEW OF MONROE FACILITY

The Detroit Edison Monroe Power Plant is a four-unit, 3,293 MW fossil fuel, steam electric power plant (Cole, 1978; Goodyear, 1978; Jude et al., 1983). The facility is located where the River Raisin enters Lake Erie, just north of the J.R. Whiting facility, evaluated in Part H of this case study document (Figure I1-1). The first unit went online in 1971, and all four generating units were completed by 1974. Each unit has four circulating water pumps, each of which is capable of a flow of 7.3 m^3/sec (116,000 gpm). Monroe is one of the largest fossil fuel burning power plants in the United States (Detroit Edison, 2002).

Monroe operates a once-through cooling system (Goodyear, 1978). The cooling water intake draws a maximum flow of 85 m^3/sec (3,000 cfs) (Cole, 1978). The 100 m (328 ft) long cooling water intake channel is located about 650 m (2,133 ft) upstream from the mouth of the River Raisin (Goodyear, 1978). The intake has two screenhouses and 12 circulating water pumps (Jude et al., 1983). Each pump is equipped with trash racks with vertical bars spaced 7.6 cm (3in.) apart, and a traveling screen with 1 cm (0.4in.) openings (Goodyear, 1978). The traveling screens normally rotate once each 8 hours, but will rotate at a higher speed when debris restricts flow (Jude, et al., 1983). The cooling water discharge canal, which is 1.8 km (1.1 mi) long and 171 m (561 ft) wide, empties into Plum Creek just upstream of its confluence with Lake Erie approximately 2.5 km (1.6 mi) south-southwest of the mouth of the River Raisin (Goodyear, 1978).

Monroe uses a fish return system to divert fish from the intake channel (Jude et al., 1983; Dodge, 1998), reducing impingement by an estimated 60 percent (Dodge, 1998). Fish and debris are diverted by the traveling screens to a pump, and transported into a series of pipes that discharge into Lake Erie east of the plant.

> ❖ ***Ownership Information***
> Monroe is a regulated utility plant owned by Detroit Edison, a subsidiary of DTE Energy Company. DTE Energy is an energy holding company with over 9,100 employees. The firm owns or controls over 11 million megawatts of electric generating capability. In 2001, DTE Energy posted sales of $7.8 billion. 2000 electricity sales were 55 million MWh (Hoover's Online, 2002; DTE Energy, 2002).

The cooling water design flow of the Monroe plant of 1,975 MGD is 4 times greater than the River Raisin's average flow (Dodge, 1998). During most of the year, the entire flow of the river is withdrawn, and Lake Erie water is drawn upstream to the plant to provide the additional water required, reversing the flow of the river at its mouth (Goodyear, 1978; Cole, 1978).

It began commercial service in 1969 and currently operates four coal-fired steam-electric units and five oil-fired internal combustion turbines. Monroe had 345 employees in 1999 and generated 18.3 million megawatt hours (MWh) of electricity. Estimated baseline revenues in 1999 were $1.4 billion, based on the plant's 1999 estimated electricity sales of 17.2 million MWh and the 1999 company-level electricity revenues of $81.59 per MWh. Monroe's 1999 production expenses totaled $284 million, or 1.553 cents per KWh, for an operating income of $1.1 billion.

Figure I1-1: Location of Monroe Power Plant on the River Raisin and Lake Erie. J.R. Whiting Power Plant is just south of Monroe Power Plant

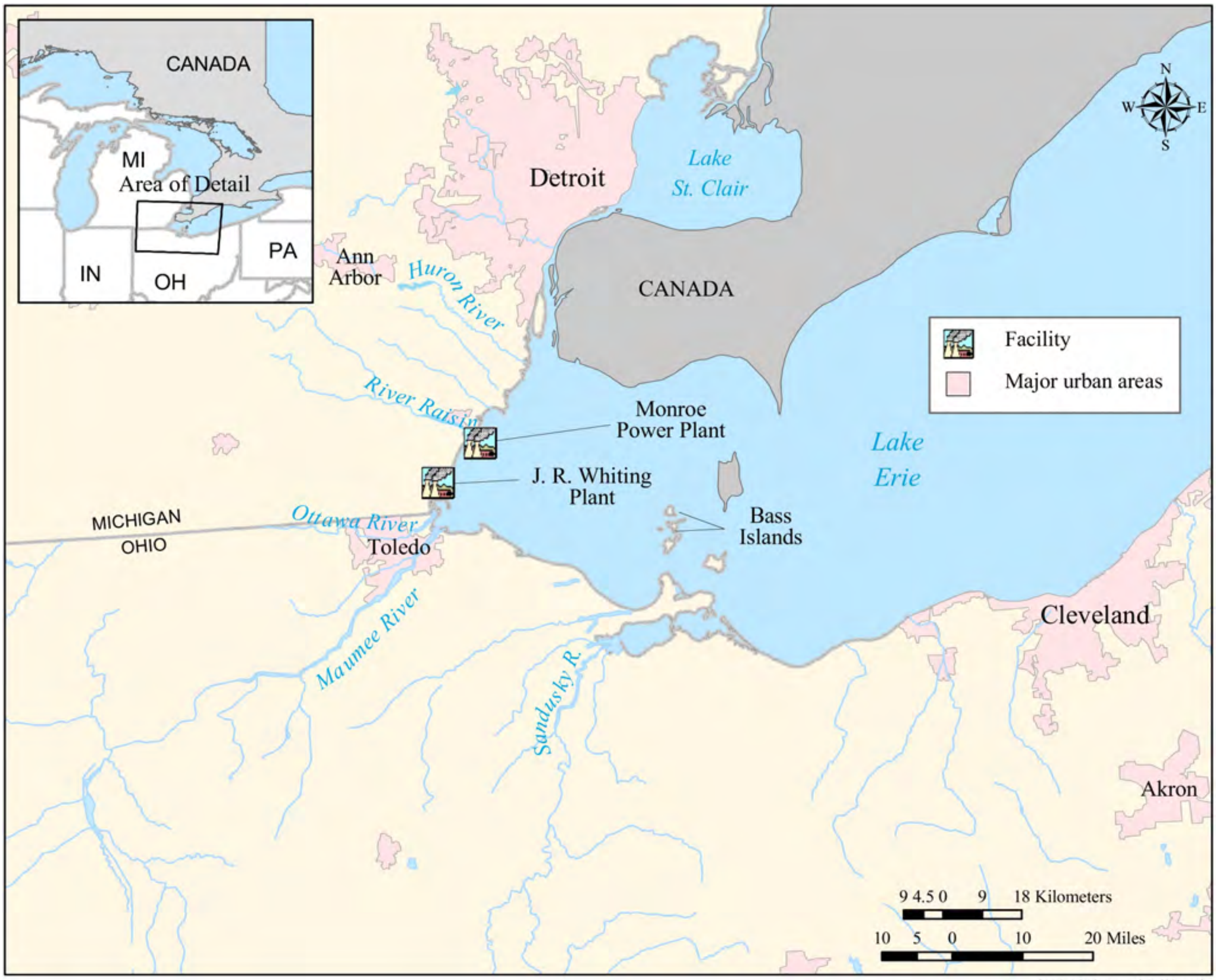


Table I1-1 below summarizes the plant characteristics of the Monroe plant.

Table I1-1: Summary of Monroe Plant Characteristics (1999)

	Monroe
Plant EIA Code	1733
NERC Region	ECAR
Total Capacity (MW)	3,293
Primary Fuel	Coal
Number of Employees	345
Net Generation (million MWh)	18.3
Estimated Revenues (billion)	$1.4
Total Production Expense (million)	$284
Production Expense (¢/KWh)	1.553¢
Estimated Operating Income (billion)	$1.1

Notes: NERC = North American Electric Reliability Council
ECAR = East Central Area Reliability Coordination Agreement
Dollars are in $2001.
Source: Form EIA-860A (NERC Region, Total Capacity, Primary Fuel); FERC Form-1 (Number of Employees, Net Generation, Total Production Expense).

I1-2 Environmental Setting

The Monroe plant withdraws water from both the River Raisin and Lake Erie. The following section focuses on the River Raisin to avoid repetition of information in Part H, the case study of J.R. Whiting. Readers seeking more information on Lake Erie are referred to Chapter H1 of Part H of this document.

I1-2.1 The River Raisin

The River Raisin drains approximately 2,770 km^2 (1,070 mi^2) in Michigan and northwestern Ohio (Dodge, 1998; USGS, 2001b). The mainstem of the river is about 240 km (150 mi) long, and the drop in elevation is about 146 m (480 ft) from the headwaters to the mouth (Dodge, 1998). The average discharge measured at a station approximately 19 km (12 mi) upstream from the mouth is 21 m^3/sec (741 cfs). The annual flow pattern is representative of a snowmelt-fed river, with high flows in March and April and low flows in July through October. It is believed that the river was named "Raisin" by French explorers who discovered plentiful grapevines growing along its banks.

The River Raisin has been affected by many factors over time (Dodge, 1998). Agricultural activity has contributed to flow instability and erosion, which in turn have altered the channel structure. In addition, agricultural land use contributes to sedimentation problems, altered temperature regimes, and nutrient loading. Point source pollution from industrial and municipal sources was a problem for many years, but has been dramatically reduced since the 1970's. Despite the potential for recreational use, public perception of the river as polluted, with limited access and poor fishery management mean that it is not heavily used.

The lower portion of the River Raisin was identified by the International Joint Commission as one of Michigan's 14 Areas of Concern (AOCs) because of polychlorinated biphenyl (PCB) and metal contamination of fish and sediments (Dodge, 1998). The River Raisin AOC is defined as the lower portion of the river from the Winchester Bridge Dam in Monroe, extending 0.8 km (0.5 mi) out into Lake Erie, and 1.6 km (1 mi) north and south along the nearshore zone of the lake (Dodge, 1998; U.S. EPA, 2001b).

I1-2.2 Aquatic Habitat and Biota

The lower River Raisin has an average gradient of 0.91 m per km (3.0 ft per mi), and a firm stream bed composed of cobble, rock, sand and limestone bedrock (Dodge, 1998). Because of the bedrock substrate, much of the river is usually shallow and wide. Overall, the river has a diversity of benthic macroinvertebrate and fish species. The northern clearwater crayfish (*Orconectes propinquus*) is found throughout the river. The lower River Raisin once supported 20 species of mussels, but a recent survey found only four species.

A survey conducted by the Michigan Department of Natural Resources in 1985 identified 36 fish species in the lower reach of the river (Dodge, 1998). Smallmouth bass were abundant, although they are not found in the middle reaches because of the shallow gradient there. Lake Erie fish are not typically found in the River Raisin, because access is restricted by a series of dams.

Many of the fish identified in I&E studies at the Monroe Plant (see Table I3-1) are common to the River Raisin (Dodge, 1998). These species include spotfin shiner (*Cyprinella spiloptera*), emerald shiner (*Notropis atherinoides*), common carp (*Cyprinus carpio*), bluntnose minnow (*Pimephales notatus*), white sucker (*Catostomus commersoni*), northern hog sucker (*Hypentelium nigricans*), bullheads (*Ameiurus* spp.), northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), rainbow trout (*Oncorhynchus mykiss*), pumpkinseed (*Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), crappies (*Pomoxis* spp.), yellow perch (*Perca flavescens*), logperch (*Percina caprodes*), and walleye (*Stizostedion vitreum*).

Other species, particularly those impinged and entrained most frequently at the plant, are most likely drawn from Lake Erie (Dodge, 1998). These species include gizzard shad (*Dorosoma cepedianum*), alewife (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), burbot (*Lota lota*), freshwater drum (*Aplodinotus grunniens*), and white bass (*Morone chrysops*).

Species of special concern identified by the Michigan Natural Features Inventory (MNFI) found in the River Raisin include the black redhorse (*Moxostoma duquesnei*), brindled madtom (*Noturus miurus*), and pugnose shiner (*Notropis anogenus*). Threatened species identified by MNFI are creek chubsucker (*Erimyzon oblongus*), eastern sand darter (*Ammocrypta pellucida*), silver shiner (*Notropis photogenis*), and southern redbelly dace (*Phoxinus erythrogaster*).

I1-2.3 Major Environmental Stressors

Human activity in the River Raisin basin has led to a number of major stresses on the aquatic environment (Dodge, 1998). Dam construction and habitat alteration have affected habitat quality on the river. Prior to the 1970's, extensive point source pollution from municipal and industrial sources, particularly paper mills, resulted in PCB and metal contamination of the sediments and biota in the river. Fish communities have also been affected by stocking of species such as common carp and rainbow trout, as well as accidental introductions of invasive species.

a. Habitat alteration

The River Raisin has experienced extensive modification over time (Dodge, 1998). There are 22 dams on the river mainstem, 38 dams on tributaries, and numerous small dams on smaller streams. The construction of dams has altered the flow regime of the river and eliminated much of the highest gradient habitat in the mainstem. Approximately 94 percent of the River Raisin basin is devoted to agricultural use. Activities associated with the extensive agricultural development in the basin such as deforestation, channelization and wetland drainage have reduced the quality and diversity of aquatic habitat. Although urban land use is minimal (estimates range from 2 to 3 percent), development is increasing and affects the flow regime of the river.

River Raisin habitat for *potamodromous* fish (fish that migrate from lakes up rivers, like salmon, walleye, and white bass) has been eliminated by the combination of the large water withdrawals by the Monroe power plant and the series of dams in the lower river (Dodge, 1998). While spring spawning runs of walleye and white bass have increased dramatically in other western Lake Erie tributaries, they are absent in the River Raisin.

b. Introduction of nonnative species

The introduced zebra mussel became established in large numbers in Lake Erie and its tributaries in the late 1980's and early 1990's (U.S. EPA, 2000). Zebra mussels have altered habitat, food web dynamics, energy transfer, and nutrient cycles in the lakes. However, filtering by zebra mussels has apparently contributed to a dramatic increase in Lake Erie's water clarity. A preferred course of action on how to deal with the zebra mussels has not yet been established by the Lake Erie Lakewide

Management Plan Committee (U.S. EPA, 2000). Zebra mussels have been found in headwater lakes of the River Raisin (Dodge, 1998).

Another invasive species of concern in the River Raisin is the rusty crayfish (*Oronectes rusticus*), an aggressive species that outcompetes native crayfish and is a predator of fish eggs. Although sea lamprey (*Petromyzon marinus*) is an invasive species of concern in Lake Erie, it has not been found in the River Raisin (Dodge, 1998).

c. Overfishing

Overfishing is not a significant stressor on the River Raisin (Dodge, 1998). While major sport fish like largemouth bass are present and other species like smallmouth bass, muskellunge, rainbow trout, and walleye are stocked, fishing pressure on the lower River Raisin is only light to moderate. This may be because river fishing is more difficult than nearby lake fishing, because there are competing uses, and because of the number of dams along the river, which impede passage of boats.

d. Pollution

Discharges to Lake Erie and its tributaries of persistent toxic chemicals were banned in the 1970's, but effects of these historical discharges continue to linger (U.S. EPA, 2000). Water quality in the River Raisin was historically affected by both industrial point source pollution and agricultural nonpoint source pollution. Today, sediments, water, and biota are contaminated with PCBs and metals such as zinc, chromium, and copper (Dodge, 1998; U.S. EPA, 2001b).

The presence of PCBs has resulted in fish consumption advisories being issued for the River Raisin and Lake Erie (see Table I1-2; MDCH, 2001).

Table I1-2: State of Michigan Fish Consumption Advisories for the River Raisin and Lake Erie, 2001[a]

	Fish Length (in.)								
	6-8	**8-10**	**10-12**	**12-14**	**14-18**	**18-22**	**22-26**	**26-30**	**30+**
River Raisin (below Monroe Dam)									
Carp	◆	◆	◆	◆	◆	◆	◆	◆	◆
Freshwater drum	▲/■	▲/■	▲/■	▲/■	▲/■	▲/■	▲/■	▲/■	▲/■
Smallmouth bass					▼/❖	▼/❖	▼/❖	▼/❖	
White bass	▲/❖	▲/❖	▼/❖	◆	◆	◆			
Lake Erie									
Carp	◆	◆	◆	◆	◆	◆	◆	◆	◆
Catfish	◆	◆	◆	◆	◆	◆	◆	◆	◆
Chinook salmon			▲/■	▲/■	▲/■	▲/■	▲/■	▲/■	▲/■
Coho salmon			▲/■	▲/■	▲/■	▲/■	▲/■	▲/■	▲/■
Freshwater drum	▲/▼	▲/▼	▲/▼	▲/▼	▲/▼	▲/▼	▲/▼	▲/▼	▲/▼
Lake trout			▲/❖	▲/❖	▲/❖	▲/❖	▲/❖	▲/❖	▲/❖
Rainbow trout			▲/■	▲/■	▲/■	▲/■	▲/■	▲/■	▲/■
Smallmouth bass					▲/■	▲/■	▲/■	▲/■	
Walleye				▲/▼	▲/▼	▲/▼	▲/■	▲/■	▲/■
White bass	▲/■	▲/■	▲/■	▲/■	▲/■	▲/■			
Whitefish	▼/◆	▼/◆	▼/◆	▼/◆	▼/◆	▼/◆	◆	◆	◆
White perch	▲/■	▲/■	▲/■	▲/■					
Yellow Perch	▲/▼	▲/▼	▲/▼	▲/▼	▲/▼	▲/▼			

◆ = No consumption.
❖ = Limit consumption to 6 meals (½ pound) per year.
■ = Limit consumption to 1 meal (½ pound) per month.
▼ = Limit consumption to 1 meal (½ pound) per week.
▲ = Unlimited consumption

[a] If there is only one symbol it is the advice for the whole population. When two symbols are shown, the first is the advice for the "general population" and the second is the advice for "children age 15 and under and women who are pregnant, nursing, or expect to bear children."

Source: MDCH, 2001.

e. Surface water withdrawals by CWIS

Steam electric power generation accounts for 68 percent of all surface water withdrawals from Lake Erie and its surrounding watersheds in the United States (USGS, 1995). The watersheds draining into the western Lake Erie hydrologic subregion are more heavily used by cooling water intake structures, which represent 92 percent of all surface water withdrawals.

I1-3 SOCIOECONOMIC CHARACTERISTICS

The Monroe plant is located in Monroe County, Michigan, a rural county bordered to the east by Lake Erie and to the north and south by more urban counties (Wayne County, Michigan, and Lucas County, Ohio). In 2000, Monroe had a population of 145,945, a high rate of home ownership, and a higher median income than surrounding counties (U.S. Census Bureau, 2001). The socioeconomic characteristics of Monroe and neighboring counties are summarized in Table I1-3.

Table I1-3: Socioeconomic Characteristics of Monroe and Neighboring Counties

	Monroe County, MI	Wayne County, MI	Lucas County, OH
Population in 2000	145,945	2,061,162	455,054
Land area in 2000, km^2 (mi^2)	1,427 (551)	1,590 (614)	881 (340)
Persons per square mile, 2000	265	3,357	1,338
Metropolitan Area	Detroit, MI	Detroit, MI	Toledo, OH
Median household money income, 1997 model-based estimate	$48,607	$35,357	$37,064
Persons below poverty, percent, 1997 model-based estimate	7.60%	18.00%	13.60%
Housing units in 2000	56,471	826,145	196,259
Homeownership rate in 2000	81.00%	66.60%	65.40%
Households in 2000	53,772	768,440	182,847
Persons per household in 2000	2.69	2.64	2.44
Households with persons under 18 years in 2000	39.10%	37.70%	34.10%
High school graduates, 25 and older in 1990	60,968	926,603	221,052
College graduates, 25 and older in 1990	8,655	180,822	49,393

Source: U.S. Census Bureau, 2001.

I1-3.1 Major Industrial Activities

Monroe County produces agricultural products such as soybeans, grains, corn, sugar beets, potatoes, and alfalfa, and industrial processes such as auto parts manufacturing, metal fabrication, cement, packaging, and glass production (InfoMI, 2001). The city of Monroe is the county seat and the largest city in the county. Industrial activity in the city is dominated by steel production, paper products, furniture, electrical power and auto parts.

I1-3.2 Commercial Fisheries

There is no commercial fishing on the River Raisin. In Lake Erie, commercial fishing generated between $2 million and $3 million of revenue per year over the last decade (USGS, 2001c). A small share of this catch comes from Michigan waters. Tables I1-4 and I1-5 show the pounds harvested and the revenue generated for the Michigan Lake Erie commercial fishery from 1985 to 1999. Despite fish consumption advisories, carp is the most important commercial species, comprising 72 percent of the catch and 51 percent of revenues over this 15-year period. Channel catfish, quillback, and bigmouth buffalo make up most of the remaining harvest and revenue (USGS, 2001c).

Table I1-4: Pounds of Commercial Landings in the Michigan Waters of Lake Erie, 1985-1999

Species	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gizzard shad	878,000							2,845	395	2,103	23	36,996	24,494	4,988	6,200
Brown bullhead	7,340	7,687	4,462	5,421	3,572	488	704	444	844	659	827	828	744	2,139	7,050
Channel catfish	9,253	11,183	39,603	15,208	11,481	2,025	1,941	2,929	9,152	5,760	16,168	24,969	17,936	16,573	7,561
White perch							8	10			64	45	4		
White bass	4,764	1,397	4,142	1,049	991		19	357	1,180	1,819	1,850	2,923	7,306	1,326	23
Freshwater drum	905	2,032	1,825	1,180				290	4,206	111	39,673	48,218	8,823	24,507	265
Gars									441	68		27	90	279	
Suckers	1,378	123	88								436	4,286	72	6,180	1,945
Goldfish			551	188	2,951	877	8,416	1,025	501	111	517	7,138	10,497	6,862	
Carp	738,857	367,310	685,395	417,365	194,320	158,151	198,294	251,365	238,805	94,662	329,262	387,671	325,433	620,015	211,055
Quillback	87,326	2,217	1,062	1,380	568		6,894	30,204	28,175	8,930	66,013	73,662	33,937	22,990	
Bigmouth buffalo	577	14,732	17,814	9,471	19,549	40,064						104	91,877	15,721	25,894
Totals	1,728,400	406,681	754,942	451,262	233,432	201,605	216,276	289,469	283,699	114,223	454,833	586,867	521,213	721,580	259,993

Source: USGS, 2001c.

Table I1-5: Revenue from Commercial Landings in the Michigan Waters of Lake Erie, 1985-1999

Species	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gizzard shad	$241,450							$342	$40	$274	$1	$4,809	$1,714	$350	$744
Brown bullhead	$1,834	$1,888	$1,076	$1,355	$895	$123	$171	$122	$213	$185	$189	$209	$253	$599	$1,904
Channel catfish	$5,364	$6,453	$23,201	$9,114	$6,898	$1,215	$1,138	$1,569	$5,580	$3,628	$10,189	$14,236	$9,684	$9,281	$4,461
White perch							$4	$5			$42	$28	$2		
White bass	$1,219	$1,073	$3,209	$629	$488		$18	$374	$1,191	$1,474	$1,702	$2,661	$6,213	$1,074	$18
Freshwater drum	$89	$185	$187	$472				$28	$462	$22	$7,538	$7,714	$1,411	$4,168	$48
Gars										$17		$11	$45	$112	
Suckers	$155	$7	$6								$26	$256	$5	$371	$253
Goldfish			$827	$47	$495	$201	$1,689	$308	$126		$130	$2,929	$3,466	$2,745	
Carp	$85,409	$38,937	$79,199	$63,611	$26,000	$19,590	$23,794	$30,612	$31,044	$12,306	$36,222	$46,521	$45,562	$80,601	$27,438
Quillback	$5,086	$170	$106	$139	$227		$2,661	$12,856	$10,144	$3,130	$22,446	$26,516	$6,449	$4,598	
Bigmouth buffalo	$292	$6,060	$7,148	$3,975	$8,332	$16,358						$47	$40,425	$8,018	$11,913
Totals	$340,898	$54,773	$114,959	$79,342	$43,335	$37,487	$29,475	$46,216	$48,800	$21,036	$78,485	$105,937	$115,229	$111,917	$46,779

Source: USGS, 2001c.

I1-3.3 Recreational Fisheries

Recreational fishing is minimal in the lower portion of the River Raisin, and most fishing is concentrated in the lakes of the upper basin (Dodge, 1998). A combination of factors such as limited access and a public perception of the river as polluted contributes to the lack of recreational fishing in the river. The lower River Raisin does have good smallmouth bass habitat and experiences light to moderate fishing pressure. Because of logjams and other obstacles, bank and wading fishing tends to be more popular than boat fishing.

Recreational fishing in Lake Erie is more predominant. Recreational anglers spent about 175,000 noncharter days fishing the Michigan waters of Lake Erie in 1994 (Rakoczy and Svoboda, 1997). Their most commonly caught species were yellow perch and walleye (44 percent and 35 percent of the total harvest, respectively; Table I1-6). White bass, channel catfish, freshwater drum, and white perch made up most of the remaining catch. Total recreational hours averaged approximately 2 million between 1986 and 1994 (Table I1-6).

Table I1-6: Michigan Lake Erie Boat Fishery Angler Effort and Primary Species Catch April Through October, 1986 to 1998

	Angler Hours	Number of Yellow Perch Harvested	Number of Walleye Harvested
1986[a]	2,068,779	834,310	605,666
1987	2,455,903	619,112	902,378
1988[b]	4,362,452	318,786	1,996,824
1989	3,799,067	1,466,442	1,092,289
1990	2,482,242	770,507	780,508
1991[a]	805,294	378,716	132,322
1992	836,216	255,747	249,713
1993	935,249	473,580	270,376
1994	1,012,595	246,327	216,040
1995	na	343,240	107,909
1996	na	635,233	174,607
1997	na	529,435	112,400
1998	na	586,277	114,607

[a] May through October.
[b] May through September.
na = not available.
Sources: Rakoczy and Svoboda, 1997; Thomas and Haas, 2000.

I1-3.4 Other Water-Based Recreation

The River Raisin is used for other recreational activities such as canoeing, power boating, and hunting (Dodge, 1998). Although passage is complicated by six low-head dams in Monroe, canoeing activity occurs just upstream of Monroe. The current is gentle for easy nonpower boating, although flow may be too low at some times of the year. The town of Blissfield sponsors a canoe race each September. Motor boating is concentrated in the lakes of the upper portion of the River Raisin watershed and at the mouth of the River Raisin. Many private marinas are located downstream of the last dam on the river, and boaters access Lake Erie from the river.

Although limited, some hunting occurs along the River Raisin. The Sharonville State Game Area, located in Jackson and Washtenaw Counties, is managed for deer, small mammal, and fowl hunting. Waterfowl hunting includes wood duck and Canada goose. Other game areas managed for similar hunting opportunities are the Onsted State Game Area, the Somerset State Game Area, and the Lake Hudson State Recreation Area. In Monroe County, The Michigan Department of Natural Resources manages the Petersburg State Game area for deer and small game hunting.

❖ The Linesville, PA Spillway at Pymatuning State Park:---"Where Ducks Walk on Fishes' Backs"

Carp swarm above and below the spillway. They compete with ducks and Canada geese for slices of bread tossed to them by visitors. The ducks clamor over the seemingly endless school of carp to get their share. The ducks actually walk on the back of the carp.

The Spillway is a popular recreational site where visitors bring old bread or buy it at a nearby concession stand. Birds and fish compete for the bread. The spillway is the outflow of a secondary impoundment at the 2500 acre Pymatuning reservoir / sanctuary that serves as fish propagation waters for the Linesville Fish Culture Station.

Source: http://www.sideroads.com/outdoors/spillway.html
Photos: © Lynne G. Tudor

Chapter I2: Technical Description of Monroe

This chapter presents technical information related to the case study facility. Section I2-1 presents detailed Energy Information Administration (EIA) data on the generating units addressed by this case study and in scope of the Phase II rulemaking. Section I2-2 describes the configuration of the facility's intake structures.

CHAPTER CONTENTS

I2-1 OPERATIONAL PROFILES

Baseline operational characteristics

The Monroe power plant operates nine units. Four are coal-fired steam electric units (Units 1-4) that use cooling water withdrawn from the River Raisin while five units (Units IC1-IC5) are oil-fired internal combustion turbines that do not require cooling water. The internal combustion turbines began operation in 1969 while the four coal units began operation between June 1971 and May 1974.

Monroe's total net generation in 1999 was 18.3 million MWh. The four steam turbine units (Units 1-4) had capacity utilization rates between 50.4 and 73.3 percent. Table I2-1 presents details for Monroe's nine units.

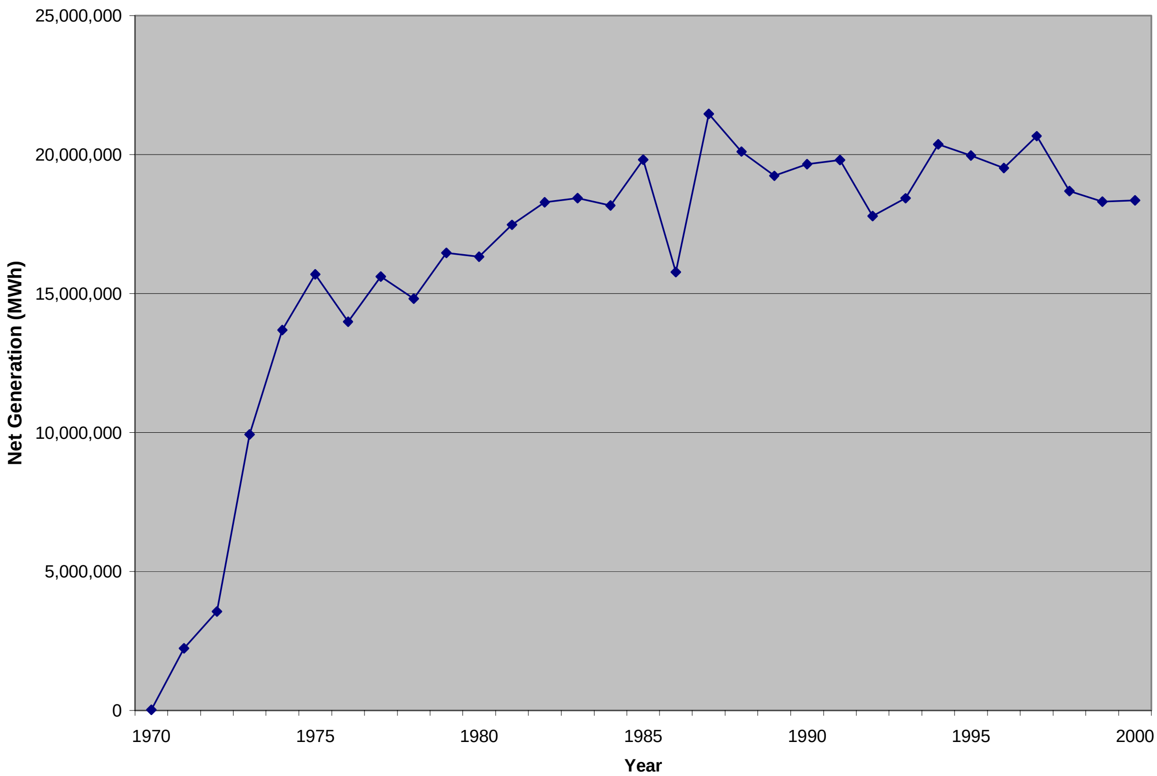
Table I2-1: Generator Detail of the Monroe Plant (1999)

Generator ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status	Net Generation (MWh)	Capacity Utilization[c]	ID of Associated CWIS
1	817	ST	BIT	June 1971	Operating	4,667,517	65.2%	1
2	823	ST	BIT	March 1973	Operating	3,633,349	50.4%	2
3	823	ST	BIT	May 1973	Operating	4,755,872	66.0%	3
4	817	ST	BIT	May 1974	Operating	5,249,776	73.3%	4
IC1	2.8	IC	FO2	Nov. 1969	Operating	1,916	1.6%	Not Applicable
IC2	2.8	IC	FO2	Dec. 1969	Operating			
IC3	2.8	IC	FO2	Nov. 1969	Operating			
IC4	2.8	IC	FO2	Dec. 1969	Operating			
IC5	2.8	IC	FO2	Nov. 1969	Operating			
Total	**3,293**					**18,308,430**	**63.5%**	

[a] Prime mover categories: ST = steam turbine; IC = internal combustion turbine.
[b] Energy source categories: BIT = bituminous coal; FO2 = No. 2 fuel oil.
[c] Capacity utilization was calculated by dividing the unit's actual net generation by the potential generation if the unit ran at full capacity all the time (i.e., capacity * 24 hours * 365 days).
Source: U.S. Department of Energy, 2001a, 2001b, 2001d.

Figure I2-1 below presents Monroe's electricity generation history between 1970 and 2000.

Figure I2-1: Monroe Net Electricity Generation 1970 -2000 (in MWh)



Source: Form EIA-906.

I2-2 CWIS Configuration and Water Withdrawal

The Monroe Power Station is located at the mouth of the River Raisin, approximately 2000 ft upstream from the open water of western Lake Erie. Monroe currently employs two intake structures that supply cooling water to the facility's once-through cooling system. Water from the River Raisin is diverted down a man-made intake canal to the intake structures. The first intake structure is 330 feet from the canal opening, while the second structure is 880 feet from the opening. Both structures share the same design and technology configuration.

Intake water drawn into one of the two structures passes through trash racks consisting of vertical bars spaced 7.6 cm apart and under a skimmer wall to one of the eight intake bays. Each intake bay contains fish collecting pans and guide screens that divert most impingeable organisms to a fish pump. Fish pumped out of the intake canal are deposited in a fish return pipe 20 cm in diameter. The return pipe expands to 66 cm in diameter downstream from the diversion point. Diverted fish are returned to Lake Erie at the end of a rocky jetty. Intake water not diverted with pumped fish passes through a vertical traveling screen to the circulating pumps and through the condenser. Traveling screens are rotated every eight hours, except during periods of high impingement. Heated water returns to the River Raisin via a discharge canal located to the west of the main powerhouse.

At maximum capacity, the Monroe Power Plant can withdraw 1,975 MGD through its two cooling water intake structures, representing 4 times the mean annual flow of the source water, the River Raisin. Because of the proximity of the intake canal to Lake Erie (~2000 ft.) and the large volume of water required for cooling operations at the facility, Monroe often draws water from Lake Erie up the mainstem of the river to the intake canal. Seasonal variations (spring flood) prevent this from occurring on a daily basis.

During the 1970s, Detroit Edison evaluated a fish pump and return system at its Monroe facility for its ability to reduce the impingement of aquatic organisms. Data from a 1977 316(b) demonstration study indicate a diversion rate associated with the fish pumps of 95 percent, meaning 95 percent of the fish passing through the trash racks into the main portion of the intake structure were successfully diverted through the return system to Lake Erie. The survival rate of diverted fish is unclear. Given the nature of the diversion (mechanical pumps), the distance of the return pipe (~2000 ft.), and the differences between the original and terminal environments (River Raisin vs. Lake Erie), it is reasonable to assume that some number of diverted fish do not survive for an extended period of time after the return to Lake Erie. However, there have been no studies of long-term survival.

No technologies are currently in place to reduce entrainment mortality.

Chapter I3: Evaluation of I&E Data

EPA evaluated impacts to aquatic organisms resulting from the CWIS of the Monroe facility using the assessment methods described in Chapter A5 of this document. EPA focused its evaluation on data collected when the facility was operated as it is currently configured. Section I3-1 lists fish species that are impinged and entrained at Monroe, Section I3-2 presents life histories of the most abundant species in the facility's I&E collections, and Section I3-3 summarizes the facility's I&E collection methods. Section I3-4 presents annual I&E data, and Section I3-5 summarizes the results of EPA's evaluation of Monroe's I&E data.

Chapter Contents

I3-1 Species Impinged and Entrained at Monroe

Table I3-1 lists species known to be impinged and entrained at Monroe, and their classification as recreational, commercial, or forage species. In general, EPA evaluated only those species with impingement and entrainment numbers greater than 1 percent of the total at the facility. However, species that were uncommon in I&E collections were still included if they had commercial or recreational value and there was available site specific life history information.

Table I3-1: Species Vulnerable to I&E by Monroe

Common Name	Scientific Name	Recreational	Commercial	Forage
Alewife	*Alosa pseudoharengus*			X
Black bass	*Micropterus dolomieui*	X		
Black bullhead	*Ameiurus melas*		X	
Black crappie	*Pomoxis nigromaculatus*	X		
Bluegill	*Lepomis macrochirus*	X		
Bluntnose minnow	*Pimephales notatus*			X
Bowfin	*Amia calva*	X		
Brown bullhead	*Ameiurus nebulosus*		X	
Burbot	*Lota lota*	X	X	
Carp	*Cyprinus carpio carpio*		X	
Central mudminnow	*Umbra limi*			X
Channel catfish	*Ictalurus punctatus*	X	X	
Chinook salmon	*Oncorhynchus tshawytscha*	X	X	
Coho salmon	*Oncorhynchus kisutch*	X	X	
Emerald shiner	*Notropis atherinoides*			X
Fathead minnow	*Pimephales promelas*			X
Flathead catfish	*Pylodictis olivaris*	X		
Freshwater drum	*Aplodinotus grunniens*		X	

Table I3-1: Species Vulnerable to I&E by Monroe (cont.)

Common Name	Scientific Name	Recreational	Commercial	Forage
Gizzard shad	*Dorosoma cepedianum*		X	
Golden redhorse	*Moxostoma erythrurum*			X
Goldfish	*Carassius auratus auratus*		X	
Green sunfish	*Lepomis cyanellus*	X		
Hornyhead chub	*Nocomis biguttatus*		X	
Largemouth bass	*Micropterus salmoides*	X		
Logperch	*Percina caprodes*			X
Longnose gar	*Lepisosteus osseus*			X
Mottled sculpin	*Cottus bairdii*			X
Muskellunge	*Esox masquinongy*	X		
Northern hog sucker	*Hypentelium nigricans*		X	
Northern pike	*Esox lucius*	X		
Pumpkinseed	*Lepomis gibbosus*	X		
Quillback	*Carpiodes cyprinus*		X	
Rainbow smelt	*Osmerus mordax mordax*	X	X	
Rainbow trout	*Oncorhynchus mykiss*	X	X	
Rock bass	*Ambloplites rupestris*	X		
Silver lamprey	*Icthyomyzon unicuspis*			X
Smallmouth bass	*Micropterus dolomieui*	X		
Spotfin shiner	*Cyprinella spiloptera*			X
Spottail shiner	*Notropis hudsonius*			X
Sunfish species	Centrarchidae	X		
Tadpole madtom	*Noturus gyrinus*			X
Troutperch	*Percopsis omiscomaycus*			X
Walleye	*Stizostedion vitreum*	X		
White bass	*Morone chrysops*	X	X	
White crappie	*Pomoxis annularis*	X		
White perch	*Morone americana*	X		
White sucker	*Catostomus commersoni*		X	
Whitefish species	Coregoninae	X	X	
Yellow bullhead	*Ameiurus natalis*		X	
Yellow perch	*Perca flavescens*	X		

Sources: (Andrew Nuhfer, Michigan Department of Natural Resources, Fisheries Division, personal communication, 2/13/02; Jude et al., 1983; Cole, 1978; Goodyear, 1978)

I3-2 Life Histories of Major Species Impinged and Entrained

Alewife *(Alosa pseudoharengus)*

Alewife is a member of the herring family, Clupeidae, and ranges along the Atlantic coast from Newfoundland to North Carolina (Scott and Crossman, 1998). Alewives entered the Great Lakes region through the Welland Canal, which connects Lake Erie and Lake Ontario; by 1949, they were present in Lake Michigan (University of Wisconsin Sea Grant Institute, 2001). Because alewives are not a freshwater species, they are particularly susceptible to osmotic stress associated with freshwater. Freshwater fish have larger kidneys, which they use to constantly pump water from their bodies. Since alewives lack this physiological adaptation, they are more susceptible to environmental disturbances.

In the Great Lakes, alewives spend most of their time in deeper water. During spawning season, they move to shallower inshore waters to spawn. Although alewives generally do not die after spawning, the fluctuating temperatures that the adults are exposed to when they move to inshore waters often results in mortality due to osmotic stress. In some years, temperature changes caused by upwelling may result in a massive die-off of spawning alewives (University of Wisconsin Sea Grant Institute, 2001).

Alewife has been introduced to a number of lakes to provide forage for sport fish (Jude et al., 1987b). Ecologically, alewife is an important prey item for many fish.

Spawning is driven by water temperature, beginning in the spring as water temperatures reach 13 to 15 ˚C (55.4 to 59.0 ˚F), and ending when they exceed 27 ˚C (80.6 ˚F) (Able and Fahay, 1998). In their native coastal habitats, alewives spawn in the upper reaches of coastal rivers, in slow-flowing sections of slightly brackish or freshwater. In the Great Lakes, alewives move inshore to the outlets of rivers and streams to spawn (University of Wisconsin Sea Grant Institute, 2001).

In coastal habitats, females lay demersal eggs in shallow water less than 2 m (6.6 ft) deep (Wang and Kernehan, 1979). They may lay from 60,000 to 300,000 eggs at a time (Kocik, 2000). The demersal eggs are 0.8 to 1.27 mm (0.03 to 0.05 in.) in diameter. Larvae hatch at a size of approximately 2.5 to 5.0 mm (0.1 to 0.2 in.) total length (Able and Fahay, 1998). Larvae remain in the upstream spawning area for some time before drifting downstream to natal estuarine waters. Juveniles exhibit a diurnal vertical migration in the water column, remaining near the bottom during the day and rising to the surface at night (Fay et al., 1983a). In the fall, juveniles move offshore to nursery areas (Able and Fahay, 1998).

Maturity is reached at 3 to 4 years for males, and 4 to 5 years for females (Able and Fahay, 1998). The average size at maturity is 265 to 278 mm (10.4 to 10.9 in.) for males and 284 to 308 mm (11.2 to 12.1 in.) for females (Able and Fahay, 1998). Alewife can live up to 8 years, but the average age of the spawning population tends to be 4 to 5 years (Waterfield, 1995; PSEG, 1999c).

ALEWIFE
(Alosa pseudoharengus)

Family: Clupeidae (herrings).

Common names: River herring, sawbelly, kyak, branch herring, freshwater herring, bigeye herring, gray herring, grayback, white herring.

Similar species: Blueback herring.

Geographic range: Along the western Atlantic coast from Newfoundland to North Carolina.[a] Arrived in the Great Lakes via the Welland Canal.[b]

Habitat: Wide-ranging, tolerates fresh to saline waters, travels in schools.

Lifespan: Generally 4-5 years but may live up to 8 years.[c,d]

Fecundity: Females may lay from 60,000 to 300,000 eggs at a time.[e]

Food source: Small fish, zooplankton, fish eggs, amphipods, mysids.[d]

Prey for: Striped bass, weakfish, rainbow trout.

Life stage information:

Eggs: *demersal*
- Found in waters less than 2 m (6.6 ft) deep.[e]
- Are 0.8 to 1.27 mm (0.03 to 0.05 in.) in diameter.[f]

Larvae:
- Approximately 2.5 to 5.0 mm (0.1 to 0.2 in) at hatching.[f]
- Remain in upstream spawning area for some time before drifting downstream to natal estuarine waters.

Juveniles:
- Stay on the bottom during the day and rise to the surface at night.[g]
- Emigrate to ocean in summer and fall.[f]

Adults: *anadromous*
- Reach maturity at 3-4 years for males and 4-5 years for females.[f]
- Average size at maturity is 265-278 mm (10.4-10.9 in.) for males and 284-308 mm (11.2-12.1 in.) for females.[f]
- Overwinter along the northern continental shelf.[f]

[a] Scott and Crossman, 1998.
[b] University of Wisconsin Sea Grant Institute, 2001.
[c] PSEG, 1999c.
[d] Waterfield, 1995.
[e] Kocik, 2000.
[f] Able and Fahay, 1998.
[g] Fay et al., 1983a.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

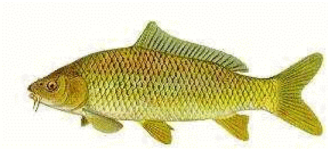
Carp (*Cyprinus carpio carpio*)

Carp is a member of the family of carps and minnows, Cyprinidae, and is abundant in Lake Erie. Carp were first introduced from Asia to the United States in the 1870's and 1880's, and by the 1890's were abundant in the Maumee River and in the west end of Lake Erie (Trautman, 1981). Carp are most abundant in low-gradient, warm streams and lakes with high levels or organic matter, but tolerate all types of bottom and clear to turbid waters (Trautman, 1981). Carp overwinter in deeper water and migrate to shallow water, preferably marshy environments with submerged aquatic vegetation in advance of the spawning season (McCrimmon, 1968). Adults feed on a wide variety of plants and animals, and juveniles feed primarily on plankton.

Carp are often considered a nuisance species because of their habit of uprooting vegetation and increasing turbidity when feeding (McCrimmon, 1968; Scott and Crossman, 1973). Carp are not widely popular fishes for anglers, although carp fishing may be an important recreational activity in some parts of the United States (Scott and Crossman, 1973). They are occasionally harvested commercially and sold for food (Scott and Crossman, 1973).

Male carp reach sexual maturity between ages 3 and 4, and the females reach maturity between ages 4 and 5 (Swee and McCrimmon, 1966). Spawning can occur at water temperatures between 16 and 28 ˚C (60.8 and 82.4 ˚F) with optimum activity between 19 and 23 ˚C (66.2 and 73.4 ˚F) (Swee and McCrimmon, 1966). Fecundity in carp can range from 36,000 eggs for a 39.4 cm (15.5 in.) fish to 2,208,000 in a 85.1 cm (33.5 in.) fish (Swee and McCrimmon, 1966), but individuals may spawn only about 500 eggs at a given time (Dames and Moore, 1977a). Eggs are demersal and stick to submerged vegetation.

Eggs hatch 3 to 6 days after spawning and larvae tend to lie in shallow water among vegetation (Swee and McCrimmon, 1966). The lifespan of a typical carp in North America is less than 20 years (McCrimmon, 1968). Adult carp can reach 102-122 cm (40-48 in.) long, and weigh 18-27 kg (40-60 lb) (Trautman, 1981).



CARP
(*Cyprinus carpio carpio*)

Family: Cyprinidae (minnows or carp).

Common names: Carp.

Similar species: Goldfish, buffalofishes, carpsuckers.[a]

Geographic range: Wide-ranging throughout the United States.

Habitat: Low-gradient, warm streams and lakes with high levels or organic carbon. Tolerates relatively wide range of turbidity. Often associated with submerged aquatic vegetation.[b]

Lifespan: Less than 20 years.[b]

Fecundity: 36,000 to 2,208,000 eggs per season.[c]

Food source: Omnivorous; diet includes invertebrates, small molluscs, ostracods, and crustaceans as well as roots, leaves, and shoots of water plants.[b]

Prey for: Juveniles provide limited forage for northern pike, smallmouth bass, striped bass, and longnosed gar, as well as green frogs, bullfrogs, turtles, snakes, mink.[b]

Life stage information:

Eggs: *demersal*
- During spawning, eggs are released in shallow, vegetated water. Eggs are demersal and stick to submerged vegetation.
- Eggs hatch in 3-6 days.[c]

Larvae:
- Larvae are found in shallow, weedy, and muddy habitats.[d]

Adults:
- May reach lengths of 102-122 cm (40-48 in.).[a]

[a] Trautman, 1981.
[b] McCrimmon, 1968.
[c] Swee and McCrimmon, 1966.
[d] Wang, 1986a.
Fish graphic from North Dakota Game and Fish Department, 2002.

Channel catfish (*Ictalarus punctatus*)

Channel catfish is a member of the Ictaluridae (North American freshwater catfish) family. It is found from Manitoba to southern Quebec, and as far south as the Gulf of Mexico (Dames and Moore, 1977a). Channel catfish can be found in freshwater streams, lakes, and ponds. They prefer deep water with clean gravel or boulder substrates and low to moderate currents (Ohio Department of Natural Resources, 2001b).

Channel catfish reach sexual maturity at ages 5-8, and females will lay 4,000-35,000 eggs dependent on body weight (Scott and Crossman, 1998). Spawning begins when water temperatures reach 24-29 °C (75-85 °F) in late spring or early summer. Spawning occurs in natural nests such as undercut banks, muskrat burrows, containers, or submerged logs. Eggs approximately 3.5 mm (0.1 in) in diameter are deposited in a large, flat, gelatinous mass (Wang, 1986a). After spawning, the male guards the nest and fans it to keep it aerated. Eggs hatch in 7-10 days at 24-26 °C (75-79 °F), and the newly hatched larvae remain near the nest for several days (Wang, 1986a). Young fish prefer to inhabit riffles and turbulent areas. Channel catfish are very popular with anglers and are relatively prized as a sport fish (Dames and Moore, 1977a).

CHANNEL CATFISH
(*Ictalarus punctatus*)

Family: Ictaluridae (North American freshwater catfish).

Common names: Channel catfish, graceful catfish.[a]

Similar species: Blue and white catfishes.[b]

Geographic range: South-central Canada, central United States, and northern Mexico.[a]

Habitat: Freshwater streams, lakes, and ponds. Prefer deep water with clean gravel or boulder substrates.[c]

Lifespan: Maximum reported age: 16 years.[a]

Fecundity: 4,000 to 35,000 eggs depending on body weight.[e]

Food source: Small fish, crustaceans, clams, snails.[a]

Prey for: Chestnut lamprey.[a]

Life stage information:

Eggs: *demersal*
- 3-4 mm (0.12-0.16 in.) in diameter.[d]
- Hatch in 7-10 days.[d]

Larvae:
- Remain near nest for a few days then disperse to shallow water.[d]
- Approx. 6.4 mm (0.25 in.) upon hatching.[d]

Adults: *demersal*
- Average length: 30-36 cm (12-14 in.).[c]
- Maximum length: up to 104 cm (41 in.).[c]

[a] Froese and Pauly, 2001.
[b] Trautman, 1981.
[c] Ohio Department of Natural Resources, 2001b.
[d] Wang, 1986a.
[e] Scott and Crossman, 1998.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Emerald shiner (*Notropis atherinoides*)

Emerald shiner is a member of the family Cyprinidae. It is found in large open lakes and rivers from Canada south throughout the Mississippi Valley to the Gulf Coast in Alabama (Scott and Crossman, 1973). Emerald shiner prefer clear waters in the mid- to upper sections of the water column, and are most often found in deep, slow moving rivers and in Lake Erie (Trautman, 1981). The emerald shiner is one of the most prevalent fishes in Lake Erie, although populations may fluctuate dramatically from year to year (Trautman, 1981). Because of its small size, it is an important forage fish for many species.

Spawning occurs from July to August in Lake Erie (Scott and Crossman, 1973). Females lay anywhere from 870 to 8,700 eggs (Campbell and MacCrimmon, 1970), which hatch within 24 hours (Scott and Crossman, 1973). Young-of-year remain in large schools in inshore waters until the fall, when they move into deeper waters to overwinter (Scott and Crossman, 1973). Young-of-year average 5.1 to 7.6 cm (2 to 3 in.) in length (Scott and Crossman, 1973).

Emerald shiner are sexually mature by age 2, though some larger individuals may mature at age 1 (Campbell and MacCrimmon, 1970). Most do not live beyond 3 years (Fuchs, 1967). Adults typically range from 6.4 to 8.4 cm (2.5 to 3.3 in.) (Trautman, 1981).

EMERALD SHINER
(*Notropis atherinoides*)

Family: Cyprinidae (herrings).

Common names: Emerald shiner.

Similar species: Silver shiner, rosyface shiner.[a]

Geographic range: From Canada south throughout the Mississippi valley to the Gulf Coast in Alabama.[b,c]

Habitat: Large open lakes and rivers.[b]

Lifespan: Emerald shiner live to 3 years.[a,d]

Fecundity: Mature by age 2. Females can lay anywhere from approximately 870 to 8,700 eggs.[3]

Food source: Microcrustaceans, midge larvae, zooplankton, algae.[d]

Prey for: Gulls, terns, mergansers, cormorants, smallmouth bass, yellow perch, and others.[d]

Life stage information:

Eggs: *demersal*
- Eggs hatch in less than 24 hours.[d]

Larvae: *pelagic*
- Individuals from different year classes can have varying body proportions and fin length, as can individuals from different localities.[a]

Adults:
- Typically range in size from 6.4 to 8.4 cm (2.5 to 3.3 in.).[a]

[a] Trautman, 1981.
[b] Froese and Pauly, 2000.
[c] Campbell and MacCrimmon, 1970.
[d] Scott and Crossman, 1973.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Freshwater drum (*Aplodinotus grunniens*)

Freshwater drum is a member of the drum family, Sciaenidae. Possibly exhibiting the greatest latitudinal range of any North American freshwater species, its distribution ranges from Manitoba, Canada, to Guatemala, and throughout the Mississippi River drainage basin (Scott and Crossman, 1973). The freshwater drum is found in deep pools of rivers and in Lake Erie at depths between 1.5 and 18 m (5 and 60 ft) (Trautman, 1981). Drum is not a favored food item of either humans or other fish; however, it supports a minor commercial fishery (Edsall, 1967; Trautman, 1981; Bur, 1982).

Based on studies in Lake Erie, the spawning season peaks in July (Daiber, 1953), although spent females have been found as late as September (Scott and Crossman, 1973). Females in Lake Erie produce anywhere from 43,000 to 508,000 eggs (Daiber, 1953). The eggs are buoyant, floating at the surface of the water (Daiber, 1953; Scott and Crossman, 1973). This unique quality may be one explanation for the freshwater drum's exceptional distribution (Scott and Crossman, 1973). Yolk-sac larvae are buoyant as well, floating inverted at the surface of the water with the posterior end of the yolk sac and tail touching the surface (Swedberg and Walburg, 1970).

Larvae develop rapidly over their first year. Maturity appears to be reached earlier in freshwater drum females from the Mississippi River than in females from Lake Erie. Daiber (1953) found Lake Erie females begin maturing at age 5, and 46 percent reach maturity by age 6. Lake Erie males begin maturing at age 4, and by age 5, 79 percent had reached maturity.

The maximum age for fish in western Lake Erie is 14 years for females and 8 years for males (Edsall, 1967). Adults tend to be between 30 to 76 cm (12 to 30 in.) long.

FRESHWATER DRUM
(*Aplodinotus grunniens*)

Family: Sciaenidae.

Common names: freshwater drum, white perch, sheepshead.[a]

Similar species: white bass, carpsuckers.[a]

Geographic range: From Manitoba, Canada, to Guatemala. They can be found throughout the Mississippi River drainage basin.

Habitat: Bottoms of medium to large sized rivers and lakes.[b]

Lifespan: The maximum age for fish in western Lake Erie is 14 years for females and 8 years for males.[c]

Fecundity: Females in Lake Erie produce from 43,000 to 508,000 eggs.[e]

Food sources: Juveniles: Cladocerans (plankton), copepods, dipterans.[d] Adults: Dipterans, cladocerans,[d] darters, emerald shiner.[e]

Prey for: Very few species.

Life stage information:

Eggs: *pelagic*
- The buoyant eggs float at the surface of the water, possibly accounting for the species' high distribution.[e]

Larvae:
- Prolarvae float inverted at the surface of the water with the posterior end of the yolk sac and their tail touching the surface.[f]

Adults:
- The species owes its name to the audible "drumming" sound that it is often heard emitting during summer months.[e]
- Tend to be between 30 to 76 cm (12 to 30 in.) long.[a]

[a] Trautman, 1981
[b] Froese and Pauly, 2001.
[c] Edsall, 1967.
[d] Bur, 1982.
[e] Scott and Crossman, 1973.
[f] Swedberg and Walburg, 1970.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Gizzard shad (*Dorosoma cepedianum*)

Gizzard shad is a member of the family Clupeidae. Its distribution is widespread throughout the eastern United States and into southern Canada, with occurrences from the St. Lawrence River south to eastern Mexico (Miller, 1960; Scott and Crossman, 1973). Gizzard shad are found in a range of salinities from freshwater inland rivers to brackish estuaries and marine waters along the Atlantic Coast of the United States (Miller, 1960; Carlander, 1969). Gizzard shad often occur in schools (Miller, 1960). Young-of-year are considered an important forage fish (Miller, 1960), though their rapid growth rate limits the duration of their susceptibility to many predators (Bodola, 1966). In Lake Erie, gizzard shad are most populous in the shallow waters of western Lake Erie, around the Bass Islands, and in protected bays and mouths of tributaries (Bodola, 1966).

Spawning occurs from late winter or early spring to late summer, depending on temperature. Spawning has been observed in early June to July in Lake Erie (Bodola, 1966), and in May elsewhere in Ohio waters (Miller, 1960). The spawning period generally lasts 2 weeks (Miller, 1960). Males and females release sperm and eggs while swimming in schools near the surface of the water. Eggs sink slowly to the bottom or drift with the current, and adhere to any surface they encounter (Miller, 1960). Females have been reported to release an average of 378,990 eggs annually (Bodola, 1966), which average 0.75 mm (0.03 in.) in diameter (Wallus et al., 1990).

Hatching time can be anywhere from 36 hours to 1 week, depending on water temperature (Bodola, 1966). Young shad may remain in upstream natal waters if conditions permit (Miller, 1960). By age 2 all gizzard shad are sexually mature, though some may mature as early as age 1 (Bodola, 1966). Unlike many other fish, fecundity in gizzard shad declines with age (Electric Power Research Institute, 1987).

Gizzard shad generally live up to 6 years in Lake Erie, but individuals up to 10 years have been reported in southern locations (Scott and Crossman, 1973). Mass mortalities have been documented in several locations during winter months, due to extreme temperature changes (Williamson and Nelson, 1985).

GIZZARD SHAD
(***Dorosoma cepedianum***)

Family: Clupeidae (herrings).

Common names: Gizzard shad.

Similar species: Threadfin shad.[a]

Geographic range: Eastern North America from the St. Lawrence River to Mexico.[b,c]

Habitat: Inhabits inland lakes, ponds, rivers, and reservoirs to brackish estuaries and ocean waters.[b,c]

Lifespan: Gizzard shad generally live 5 to 6 years, but have been reported up to 10 years.[b]

Fecundity: Maturity is reached by age 2; females produce average of 378,990 eggs.[b]

Food sources: Larvae consume protozoans, zooplankton, and small crustaceans.[c] Adults are mainly herbivorous, feeding on plants, phytoplankton, and algae. They are one of the few species able to feed solely on plant material.[b]

Prey for: Walleye, white bass, largemouth bass, crappie, among others (immature shad only).[b]

Life stage information:

Eggs: *demersal*
- During spawning, eggs are released near the surface and sink to the bottom, adhering to any surface they touch.

Larvae: *pelagic*
- Larvae serve as forage to many species.
- After hatching, larvae travel in schools for the first few months.

Adults:
- May grow as large as 52.1 cm (20.5 in.).[a]
- May be considered by some to be a nuisance species because of sporadic mass winter die-offs.[3]

[a] Trautman, 1981.
[b] Miller, 1960.
[c] Scott and Crossman, 1973.
Fish graphic from Iowa Dept. of Natural Resources, 2001.

Lake whitefish (*Coregonus clupeaformis*)

Lake whitefish are a member of the whitefish family, Salmonidae (Coregoninae subfamily). They are distributed widely in fresh water from Alaska, through Canada and south into the Great Lakes and northern New England (Scott and Crossman, 1998). They are a valuable commercial and recreational fish and are prized for their fine tasting meat as well as their eggs, which are prepared and marketed as caviar. Their liver is also used for paté.

Lake whitefish spawn in the autumn, usually in November and December, in the Great Lakes (Scott and Crossman, 1998). They deposit demersal eggs in shallow water of less than 7.6 m (25 ft) over rocky, hard, or sandy substrate. Fecundity is estimated at 16,100 eggs per pound of fish. The eggs are initially about 2.3 mm (0.09 in.) in diameter, but increase to up to 3.2 mm (0.13 in.) after 24 hours in the water. Eggs do not hatch right away, but overwinter and hatch in April or May when water temperatures rise (approximately 140 days; Froese and Pauly, 2001). The optimal temperature range for development is 0.6-6.1 ˚C (33-43 ˚F; Scott and Crossman, 1998).

Young whitefish develop rapidly, and reach the commercial size of 0.9 kg (2 lb) at age 3 in Lake Erie (Scott and Crossman, 1998). They may reach a length of 676 mm (26.6 in.) in Lake Erie. Males generally mature and die earlier than females.

LAKE WHITEFISH
(*Coregonus clupeaformis*)

Family: Salmonidae, subfamily Coregoninae (whitefish).[a]

Common names: Whitefish, Great Lakes whitefish, humpback whitefish.[b]

Geographic range: Alaska and Canada to Great Lakes and New England.[a]

Habitat: Lakes and large rivers.[b]

Lifespan: Maximum reported age: 28 years. In Lake Erie, live to approximately 16 years.[a]

Fecundity: 16,100 eggs per pound in Lake Erie.[a]

Food source: Young consume copepods, cladocerans, and insect larvae. Adults consume eggs and small fish such as darter, alewife, minnow, and stickleback.[a]

Prey for: Lake trout, northern pike, burbot, yellow walleye, whitefish. Parasitized by sea lamprey.[a]

Life stage information:

Eggs: *demersal*
- 2.3-3.2 mm (0.09-0.13 in.) in diameter.[a]
- Hatch in 140 days.[b]

Larvae:
- Approx. 12 mm (0.47 in.) at 1 week.[a]
- Concentrate in shallow water of about 30 cm (12 in.).[c]

Adults: *demersal*
- Maximum length in Lake Erie: up to 67.6 cm (26.6 in.).[a]

[a] Scott and Crossman, 1998.
[b] Froese and Pauly, 2001.
[c] University of Saskatchewan, 2002.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Walleye (*Stizostedion vitreum*)

Walleye is a member of the perch family, Percidae. It is found in freshwater from as far north as the Mackenzie River near the Arctic Coast to as far south as Georgia, and is common in the Great Lakes. Walleye are popular sport fish both in the summer and winter.

Walleye spawn in spring or early summer, although the exact timing depends on latitude and water temperature. Spawning has been reported at water temperatures of 5.6 to 11.1 ˚C (42 to 52 ˚F), in rocky areas in white water or shoals of lakes (Scott and Crossman, 1998). They do not fan nests like other similar species, but instead broadcast eggs over open ground, which reduces their ability to survive environmental stresses (Carlander, 1997). Females typically produce between 48,000 and 614,000 eggs in Lake Erie, and the eggs are 1.4 to 2.1 mm (0.06 to 0.08 in.) in diameter (Carlander, 1997). Eggs hatch in 12-18 days (Scott and Crossman, 1998). Larvae are approximately 6.0 to 8.6 mm (0.23 to 0.33 in.) at hatching (Carlander, 1997).

Walleye develop more slowly in the northern extent of their range; in Lake Erie they typically are 8.9 to 20.3 cm (3.5 to 8.0 in.) by the end of the first growing season. Males generally mature at 2-4 years and females at 3-6 years (Scott and Crossman, 1998), and females tend to grow faster than males (Carlander, 1997). Walleye may reach up to 78.7 cm (31 in.) long in Lake Erie (Scott and Crossman, 1998).

WALLEYE
(*Stizostedion vitreum*)

Family: Percidae (perch).

Common names: Blue pike, glass eye, gray pike, marble eye, yellow pike-perch.[a]

Similar species: Sauger.[b]

Geographic range: Canada to southern United States.[c]

Habitat: Large, shallow, turbid lakes; large streams or rivers.[c]

Lifespan: Maximum reported age: 12 years.[b]

Fecundity: Broadcast spawners; in Lake Erie, 48,000 to 614,000 eggs per spawn.[b]

Food source: Insects, yellow perch, freshwater drum, crayfish, snails, frogs.[a]

Prey for: Sea lamprey, northern pike, muskellunge, sauger.[a]

Life stage information:

Eggs: *demersal*
- 1.4-2.1 mm (0.06-0.08 in.) in diameter.[b]
- Hatch in 12-18 days.[c]

Larvae: *pelagic*
- Approx. 6.2-7.3 mm (0.24-0.29 in.) upon hatching.[b]

Adults: *demersal*
- Maximum length: up to 78.7 cm (31 in.).[c]

[a] Froese and Pauly, 2001.
[b] Carlander, 1997.
[c] Scott and Crossman, 1998.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

White bass (*Morone chrysops*)

White bass is a member of the temperate bass family, Moronidae. It ranges from the St. Lawrence River south through the Mississippi valley to the Gulf of Mexico, though the species is most abundant in the Lake Erie drainage (Van Oosten, 1942). White bass has both commercial and recreational fishing value.

Spawning take place in May in Lake Erie and may extend into June, depending on water temperatures. Spawning bouts can last from 5 to 10 days (Scott and Crossman, 1973). Adults typically spawn near the surface, and eggs are fertilized as they sink to the bottom. Fecundity increases directly with size in females; the average female lays approximately 565,000 eggs. Eggs hatch within 46 hours at a water temperature of 15.6 ˚C (60 ˚F) (Scott and Crossman, 1973).

Larvae grow rapidly, and young white bass reach lengths of 13 to 16 cm (5.1 to 6.3 in.) by the fall (Scott and Crossman, 1973). They feed on microscopic crustaceans, insect larvae, and small fish. As adults, the diet switches to fish. Yellow perch are an especially important prey species for white bass (Scott and Crossman, 1973).

Most white bass mature at age 3 (Van Oosten, 1942). Upon reaching sexual maturation, adults tend to form unisexual schools, traveling up to 11.1 km (6.9 mi) a day. Adults occupy the upper portion of the water column, maintaining depths of 6 m (19.7 ft) or less (Scott and Crossman, 1973). On average, adults are between 25.4 to 35.6 cm (10 to 14 in.) long (Ohio Department of Natural Resources, 2001b). White bass rarely live beyond 7 years (Scott and Crossman, 1973).

WHITE BASS
(*Morone chrysops*)

Family: Moronidae.

Common names: White bass, silver bass.

Similar species: White perch, striped bass.[a]

Geographic range: St. Lawrence River south through the Mississippi valley to the Gulf of Mexico, highly abundant in the Lake Erie drainage.[b]

Habitat: Occurs in lakes, ponds, and rivers.[c]

Lifespan: White bass may live up to 7 years.[d]

Fecundity: The average female lays approximately 565,000 eggs.[b]

Food source: Juveniles consume microscopic crustaceans, insect larvae, and small fish.[b] Adults have been found to consume yellow perch, bluegill, white crappie,[b] and carp.[b,d]

Prey for: Other white bass.[a]

Life stage information:

Eggs: *demersal*
- Eggs are approximately 0.8 mm (0.03 in.) in diameter.[b]

Larvae: *pelagic*
- White bass experience their maximum growth in their first year.[b]

***Adults*:**
- Travel in schools, traveling up to 11.1 km (6.9 mi) a day.[b]
- Most mature at age 3.[e]
- Adults prefer clear waters with firm bottoms.[a]

[a] Trautman, 1981.
[b] Scott and Crossman, 1973.
[c] Froese and Pauly, 2000.
[d] Carlander, 1997.
[e] Van Oosten, 1942.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Yellow perch (*Perca flavescens*)

The yellow perch is a member of the Percidae family and is found in fresh waters in the northern and eastern United States and across eastern and central Canada. Yellow perch are also occasionally seen in brackish waters (Scott and Crossman, 1973). They are typically found in greatest numbers in clear waters with low gradients and abundant vegetation (Trautman, 1981). The Great Lakes are a major source of yellow perch for the commercial fishing industry. Perch feed during the day on immature insects, larger invertebrates, fishes, and fish eggs (Scott and Crossman, 1973).

Sexual maturity is reached at age 1 for males and at ages 2 and 3 for females (Saila et al., 1987). Perch spawn in the spring in water temperatures ranging from 6.7 to 12.2 ˚C (44 to 54 ˚F) (Scott and Crossman, 1973). Adults move to shallower water to spawn, usually near rooted vegetation, fallen trees, or brush. Spawning takes place at night or in the early morning. Females lay all their eggs in a single transparent strand that is approximately 3 cm (1.2 in.) wide (Saila et al., 1987) and up to 2.1 m (7 ft) long (Scott and Crossman, 1973). These egg cases are semi-buoyant and attach to submerged vegetation or occasionally to the bottom and may contain 2,000-90,000 eggs (Scott and Crossman, 1973). In western Lake Erie, fecundities for yellow perch were reported to range from 8,618 to 78,741 eggs (Saila et al., 1987).

Yellow perch larvae hatch within about 8-10 days and are inactive for about 5 days until the yolk is absorbed (Scott and Crossman, 1973). Young perch are initially pelagic and found in schools, but become demersal after their first summer (Saila et al., 1987).

Adult perch are inactive at night and rest on the bottom (Scott and Crossman, 1973). Females generally grow faster than males and reach a greater final length (Scott and Crossman, 1973). In Lake Erie, perch may reach up to approximately 31 cm (12 in.) in total length and have been reported to live up to 11 years.

YELLOW PERCH
(*Perca flavescens*)

Family: Percidae (perches).

Common names: Yellow perch, perch, American perch, lake perch.[a]

Similar species: Dusky darter.[b]

Geographic range: Northern and eastern United States.[c]

Habitat: Lakes, ponds, creeks, rivers. Found in clear water near vegetation.[a,b]

Lifespan: Up to 11 years.[c]

Fecundity: 8,618 to 78,741 eggs.[c]

Food source: Immature insects, larger invertebrates, fishes, and fish eggs.[c]

Prey for: Almost all warm to cool water predatory fish, including bass, sunfish, crappies, walleye, sauger, northern pike, muskellunge, and other perch, as well as a number of birds.[c]

Life stage information:

Eggs: *semi-buoyant*
- Eggs laid in long tubes containing 2,000-90,000 eggs.[c]
- Eggs usually hatch in 8-10 days.[c]

Larvae: *pelagic*
- Larvae are 4.1-5.5 mm (0.16-0.22 in.) upon hatching.[d]
- Found in schools with other species.[c]
- Become demersal during the first summer.[d]

Adults: *demersal*
- Reach up to 31 cm (12 in.) in Lake Erie.[c]
- Found in schools near the bottom.

[a] Froese and Pauly, 2001.
[b] Trautman, 1981.
[c] Scott and Crossman, 1973.
[d] Saila et al., 1987.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

I3-3 METHODS FOR ESTIMATING I&E AT MONROE

EPA examined I&E data from a variety of facility and agency monitoring reports. Impingement data were collected in 1972, 1973, and 1975 by the U.S. Fish and Wildlife Service (Goodyear, 1978), in 1982-83 by the University of Michigan Great Lakes Research Division (Jude et al., 1983), and in 1985-86 by the Michigan Department of Natural Resources (Andrew Nuhfer, Michigan Department of Natural Resources, Fisheries Division, personal communication, 2/13/02). Entrainment data were collected in 1973, 1974, and 1975 by the U.S. EPA (Cole, 1978) and in 1982-83 by the University of Michigan Great Lakes Research Division (Jude et al., 1983). For this benefits case study, EPA determined that only the data for the 1980's are relevant for an evaluation of the facility as it is currently operated and configured. The methods used to collect these data are summarized below.

I3-3.1 Impingement Monitoring

University of Michigan, Great Lakes Research Division, 1982-1983

Impingement was sampled by scientists from the University of Michigan, Great Lakes Research Division once per week from February 18, 1982, to February 7, 1983 (Jude et al., 1983). Samples were collected once a week for the 52 week sampling period, and one additional sample was collected on February 25, 1982, to sample a large gizzard shad impingement event. Sampling lasted for 24 hours and was conducted on Monday to Tuesday, or Tuesday to Wednesday (if Monday was a holiday).

Samples were collected from the two screenhouses via a conveyor belt, which delivered impinged fish from the traveling screens to a dump truck. Trucks were checked to ensure that they were not switched during the sampling period. After the 24 hour sampling period, either all of the fish were counted or, if the collection was too large to count, a subsample was collected. Subsampling was done by leveling the collected fish in the truck bed, visually dividing the bed into square sections, assigning a number to each section, and randomly selecting a subset of sections (usually two). The remaining fish were spread evenly again, and the length, width, and depth of the pile were measured. The volume of unsampled fish was converted to an estimated weight using a conversion factor of 0.758 g/cm^3, which was derived from 10 replicates of 20 kg (44.09 lb) samples of alewives. This conversion was checked on several dates by comparing the volume of the fish sampled to the volume of the unsampled fish. When the resulting relationship from the volume comparison was consistently different from that calculated by the conversion factor because of variations in fish size and percentage of nonfish debris, the volume comparison was used to determine the percentage of fish subsampled. Estimates of the total number of fish impinged in a sampling period were made from subsampled counts by scaling up to the total amount for a sampling period.

During the large gizzard shad impingement event on February 25, 1982, the sampling method had to be altered because the fish were filling up trucks too quickly to be subsampled according to the usual protocol. A subsample of gizzard shad was collected from each truck, with an attempt made to collect a representative size distribution. Fish other than gizzard shad that were seen were also collected. The time to fill each truck and the volume of fish in the truck were recorded. A subset of the trucks was measured and the information applied to other truckloads collected that day.

The University of Michigan calculated average daily impingement rates by dividing the sum of impingement during all sampling days in the month by the number of sampling days. They then calculated monthly impingement by multiplying the average daily impingement by the number of days in the month. Annual impingement was the sum of all 12 months in the study.

Michigan Department of Natural Resources, 1985-1986

Impingement was also sampled by the Michigan Department of Natural Resources (DNR) from May 16, 1985, to May 6, 1986.

Samples were collected on 3 days in May and June 1985, 5 days per month in July and August 1985, and 4 days per month from September 1985 through April 1986, so that a total of 49 samples were collected. The day of sampling was randomly selected from weekdays (Monday through Friday). The duration of sampling was approximately 24 hours, although shorter periods were sampled when impingement was high and longer periods were sampled when there were few fish.

Samples were collected from the two screenhouses via a conveyor belt, which delivered impinged fish from the traveling screens to a dump truck. When the number of fish collected could be processed in less than 5 hours, the entire sample was counted. When this was not the case, the collection was subsampled. Subsampling was done by leveling the collected fish in the truck bed, visually dividing the bed into square sections, assigning a number to each section, and randomly selecting a subset of sections (approximately 40 percent). Equal numbers of buckets of debris and fish were collected from each selected section to draw a subsample. The subsamples and the remaining fish were weighed to determine what percentage of the total of the subsamples represented. On days when subsamples were taken, they represented an average of 26 percent by weight of the total collection. Subsamples were extrapolated to the total amount by multiplying by an expansion factor (calculated by dividing the weight of the total collection by the weight of the subsample).

The Michigan DNR calculated daily impingement values for each species by standardizing the collection rate to a 24 hour period. Periodic estimates were derived by multiplying the daily estimate by the number of days in a period of time represented by that sampling event (approximately 7). They then calculated monthly totals by summing the periodic rates for a given month. Final annual estimates are representative of both screenhouses combined.

I3-3.2 Entrainment Monitoring

University of Michigan, Great Lakes Research Division, 1982-1983

Entrainment sampling was also conducted from February 1982 to February 1983 (Jude et al., 1983). Samples were taken weekly from March through August; twice a month in January, February, September, and October; and once per month in November and December.

Lake and river water in the intake canal was often stratified because of temperature differences. Thus, samples used to estimate entrainment were collected in the discharge canal, because the water was well mixed. Larvae were collected using a 0.5 m (1.6 ft), 363 μm (0.0014 in) mesh net. A flowmeter was used to measure the volume of water per sample, usually between 20 and 55 m^3 (706 and 1,942 ft^3). Four replicate samples were collected in each of four daily periods on each sampling date.

In their calculations, the Michigan DNR first multiplied the mean density in each of the four daily periods by the total weekly volume of water that passed through the plant during the corresponding daily period. Then these estimates for each daily time period were summed to estimate a weekly total across all time periods. Annual estimates were calculated by Michigan DNR by summing all of the weekly estimates.

I3-4 Annual Impingement and Entrainment

EPA evaluated annual I&E at Monroe using the methods presented in Chapter A5 of Part A of this document. The species-specific life history values used by EPA for its analyses are presented in Appendix I1. Table I3-2 displays estimates of annual impingement (numbers of organisms) at Monroe for the years of monitoring (1982 and 1985). Table I3-3 presents these numbers expressed as age 1 equivalents, Table I3-4 displays annual impingement of fishery species as pounds of lost fishery yield, and Table I3-5 displays annual impingement expressed as production foregone. Tables I3-6 through I3-9 display the same information for entrainment at Monroe for 1982.

The results of EPA's analysis indicate that both impingement and entrainment collections at Monroe are dominated by gizzard shad, followed by white bass, yellow perch, and freshwater drum. Impingement rates are about 4.5 times entrainment rates. However, more commercial and recreational species are entrained than impinged. About 34.3 million gizzard shad, 0.7 million white bass, 0.3 million yellow perch, and 0.15 million freshwater drum age 1 equivalents are impinged per year. Annual age 1 equivalents entrained average about 8.7 million gizzard shad, 0.8 million white bass, 0.6 million yellow perch, and 0.15 million freshwater drum. Impingement and entrainment of all species combined results in over 2 million pounds of lost fishery yield per year.

I3-5 Summary

Table I3-10 summarizes EPA's estimates of annual I&E at Monroe. Results indicate that, on average, nearly 21 million organisms are impinged at Monroe each year. This represents 35.8 million age 1 equivalents, 1.4 million pounds of lost fishery yield, and 0.7 million pounds of production foregone. Over 4.6 billion organisms are entrained per year, representing about 11.6 million age 1 equivalents, 0.6 million pounds of lost fishery yield, and 3.5 million pounds of production foregone. The economic value of these losses is discussed in Chapter I4, and the potential benefits of reducing these losses with the proposed rule are discussed in Chapter I5.

Table I3-2: Estimates of Annual Impingement (numbers of organisms) at Monroe, 1982 and 1985

Year	Alewife	Blue-gill	Bluntnose Minnow	Bullhead spp.	Carp	Central Mudminnow	Channel Catfish	Coho Salmon	Crappie	Fathead Minnow	Freshwater Drum	Gizzard Shad	Golden Redhorse	Hornyhead Chub	Log-perch
1982	250	750	6	1,732	7,100	12	1,333	18	1,310	170	160,000	30,000,000	12	210	96,800
1985	0	0	0	0	0	0	0	0	0	0	96,847	9,310,023	0	0	137,854
Mean	125	375	3	866	3,550	6	666	9	655	85	128,424	19,655,012	6	105	117,327
Minimum	0	0	0	0	0	0	0	0	0	0	96,847	9,310,023	0	0	96,800
Maximum	250	750	6	1,732	7,100	12	1,333	18	1,310	170	160,000	30,000,000	12	210	137,854
SD	177	530	4	1,225	5,020	8	943	13	926	120	44,656	14,630,023	8	148	29,030
Total	250	750	6	1,732	7,100	12	1,333	18	1,310	170	256,847	39,310,023	12	210	234,654

0=Sampled, but none collected.
Fri Feb 15 13:29:27 MST 2002 Raw.losses. IMPINGEMENT; Plant:monroe; PATHNAME:P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/raw.losses.imp.monroe.csv

Table I3-2: Estimates of Annual Impingement (numbers of organisms) at Monroe, 1982 and 1985 (cont.)

Year	Longnose Gar	Mottled Sculpin	Muskel-lunge	Northern Pike	Rainbow Trout	Shiner spp.	Silver Lamprey	Smallmouth Bass	Smelt	Suckers	Sunfish	Tadpole Madtom	Walleye	White Bass	Yellow Perch	Other
1982	140	60	7	86	68	320,012	270	194	2,300	8,278	7,412	580	26,000	530,000	370,000	0
1985	0	0	0	0	0	40,491	0	0	6,221	0	0	0	7,374	567,550	78,246	24,817
Mean	70	30	4	43	34	180,252	135	97	4,260	4,139	3,706	290	16,687	548,775	224,123	12,408
Minimum	0	0	0	0	0	40,491	0	0	2,300	0	0	0	7,374	530,000	78,246	0
Maximum	140	60	7	86	68	320,012	270	194	6,221	8,278	7,412	580	26,000	567,550	370,000	24,817
SD	99	42	5	61	48	197,651	191	137	2,773	5,853	5,241	410	13,171	26,552	206,301	17,548
Total	140	60	7	86	68	360,503	270	194	8,521	8,278	7,412	580	33,374	1,097,550	448,246	24,817

0=Sampled, but none collected.
Fri Feb 15 13:29:27 MST 2002 Raw.losses. IMPINGEMENT; Plant:monroe; PATHNAME:P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/raw.losses.imp.monroe.csv

Table I3-3: Annual Impingement at Monroe Expressed as Numbers of Age 1 Equivalents, 1982 and 1985

Year	Alewife	Blue-gill	Bull-head spp.	Carp	Channel Catfish	Crappie	Fresh-water Drum	Gizzard Shad	Log-perch	Muskel-lunge	Shiner spp.	Small-mouth Bass	Smelt	Suckers	Sun-fish	Wall-eye	White Bass	Yellow Perch
1982	311	894	2,014	7,783	1,718	1,586	184,603	52,388,535	129,361	8	378,718	281	2,770	9,916	12,353	35,303	639,692	436,069
1985	0	0	0	0	0	0	111,739	16,257,949	184,225	0	47,919	0	7,493	0	0	10,013	685,014	92,218
Mean	156	447	1,007	3,891	859	793	148,171	34,323,242	156,793	4	213,319	141	5,132	4,958	6,177	22,658	662,353	264,144
Minimum	0	0	0	0	0	0	111,739	16,257,949	129,361	0	47,919	0	2,770	0	0	10,013	639,692	92,218
Maximum	311	894	2,014	7,783	1,718	1,586	184,603	52,388,535	184,225	8	378,718	281	7,493	9,916	12,353	35,303	685,014	436,069
SD	220	632	1,424	5,503	1,215	1,121	51,523	25,548,182	38,794	5	233,910	199	3,340	7,011	8,735	17,883	32,047	243,139
Total	311	894	2,014	7,783	1,718	1,586	296,342	68,646,484	313,586	8	426,637	281	10,264	9,916	12,353	45,316	1,324,706	528,287

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A5, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.
0=Sampled, but none collected.
Fri Feb 15 13:35:00 MST 2002 ;Results; I Plant: monroe ; Units: equivalent.sums Pathname:
P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/I.equivalent.sums.monroe.csv

Table I3-4: Annual Impingement of Fishery Species at Monroe Expressed as Yield Lost to Fisheries (in pounds), 1982 and 1985

Year	Bullhead spp.	Carp	Channel Catfish	Crappie	Freshwater Drum	Gizzard Shad	Smallmouth Bass	Smelt	Suckers	Sunfish	Walleye	White Bass	Yellow Perch
1982	44	3,761	54	13	9,806	2,067,893	11	24	123	4	520	48,743	465
1985	0	0	0	0	5,936	641,738	0	64	0	0	148	52,196	98
Mean	22	1,880	27	7	7,871	1,354,816	6	44	62	2	334	50,469	282
Minimum	0	0	0	0	5,936	641,738	0	24	0	0	148	48,743	98
Maximum	44	3,761	54	13	9,806	2,067,893	11	64	123	4	520	52,196	465
SD	31	2,659	38	9	2,737	1,008,444	8	29	87	3	263	2,442	259
Total	44	3,761	54	13	15,742	2,709,631	11	88	123	4	668	100,939	563

0=Sampled, but none collected.
Fri Feb 15 13:35:17 MST 2002 ;Results; I Plant: monroe ; Units: yield Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/I.yield.monroe.csv

Table I3-5: Annual Impingement at Monroe Expressed as Production Foregone (in pounds), 1982 and 1985

Year	Alewife	Blue-gill	Bull-head spp.	Carp	Channel Catfish	Crappie	Fresh-water Drum	Gizzard Shad	Log-perch	Muskel-lunge	Shiner spp.	Small-mouth Bass	Smelt	Suckers	Sun-fish	Wall-eye	White Bass	Yellow Perch
1982	5	11	53	2,426	90	54	17,556	936,779	645	4	4,654	20	31	1,057	21	6,388	59,868	4,761
1985	0	0	0	0	0	0	10,627	290,714	918	0	589	0	85	0	0	1,812	64,109	1,007
Mean	2	5	26	1,213	45	27	14,091	613,747	781	2	2,621	10	58	529	10	4,100	61,988	2,884
Minimum	0	0	0	0	0	0	10,627	290,714	645	0	589	0	31	0	0	1,812	59,868	1,007
Maximum	5	11	53	2,426	90	54	17,556	936,779	918	4	4,654	20	85	1,057	21	6,388	64,109	4,761
SD	3	8	37	1,716	63	38	4,900	456,837	193	3	2,874	14	38	747	15	3,236	2,999	2,655
Total	5	11	53	2,426	90	54	28,183	1,227,494	1,563	4	5,243	20	116	1,057	21	8,199	123,977	5,768

0=Sampled, but none collected.
Fri Feb 15 13:35:09 MST 2002 ;Results; I Plant: monroe ; Units: annual.prod.forg Pathname:
P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/I.annual.prod.forg.monroe.csv

Table I3-6: Estimates of Annual Entrainment (numbers of organisms) at Monroe, 1982

Year	Burbot	Carp	Channel Catfish	Crappie	Freshwater Drum	Gizzard Shad	Logperch	Shiner spp.
1982	2,770,000	79,700,000	4,160,000	580,000	158,000,000	4,080,000,000	2,983,000	30,420,000

Fri Feb 15 13:29:29 MST 2002 Raw.losses. ENTRAINMENT; Plant:monroe;
PATHNAME:P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/raw.losses.ent.monroe.csv

Table I3-6: Estimates of Annual Entrainment (numbers of organisms) at Monroe, 1982 (cont.)

Year	Smallmouth Bass	Smelt	Suckers	Sunfish	Walleye	White Bass	Whitefish	Yellow Perch	Unknown
1982	599,000	11,000,000	6,204,000	923,000	2,080,000	156,000,000	190,000	128,000,000	38,300,000

Fri Feb 15 13:29:29 MST 2002 Raw.losses. ENTRAINMENT; Plant:monroe;
PATHNAME:P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/raw.losses.ent.monroe.csv

Table I3-7: Annual Entrainment at Monroe Expressed as Numbers of Age 1 Equivalents, 1982

Year	Burbot	Carp	Channel Catfish	Crappie	Fresh-water Drum	Gizzard Shad	Log-perch	Shiner spp.	Small-mouth Bass	Smelt	Suckers	Sunfish	Walleye	White Bass	White-fish	Yellow Perch
1982	1,765	394,554	20,594	23,517	143,558	8,747,005	115,373	276,928	48,283	89,543	89,117	311,090	16,749	772,277	81	567,330

Fri Feb 15 13:34:58 MST 2002 ;Results; E Plant: monroe ; Units: equivalent.sums Pathname:
P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/E.equivalent.sums.monroe.csv

Table I3-8: Annual Entrainment of Fishery Species at Monroe Expressed as Yield Lost to Fisheries (in pounds), 1982

Year	Burbot	Carp	Channel Catfish	Crappie	Freshwater Drum	Gizzard Shad	Smallmouth Bass	Smelt	Suckers	Sunfish	Walleye	White Bass	Whitefish	Yellow Perch
1982	206	190,659	643	195	7,626	345,264	1,972	766	1,108	113	247	58,845	73	605

Fri Feb 15 13:35:15 MST 2002 ;Results; E Plant: monroe ; Units: yield Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/E.yield.monroe.csv

Table I3-9: Annual Entrainment at Monroe Expressed as Production Foregone (in pounds), 1982

Year	Burbot	Carp	Channel Catfish	Crappie	Freshwater Drum	Gizzard Shad	Logperch	Shiner spp.	Smallmouth Bass	Smelt	Suckers	Sunfish	Walleye	White Bass	Yellow Perch
1982	<1	578,130	6,789	20,614	101,515	970,508	8,873	83,324	7,469	5,350	95,408	1,645	28,802	1,185,004	354,467

Fri Feb 15 13:35:07 MST 2002 ;Results; E Plant: monroe ; Units: annual.prod.forg Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/E.annual.prod.forg.monroe.csv

Table I3-10: Average Annual Impingement and Entrainment at Monroe (sum of annual means of all species evaluated)

	Impingement	Entrainment
Raw losses (# of organisms)	20,889,043	4,663,609,000
Age 1 equivalents (# of fish)	35,814,243	11,617,765
Fishery yield (lb of fish)	1,415,820	608,321
Production foregone (lb of fish)	702,141	3,447,899

mixed.rollup.chap3.ent Fri Feb 15 14:09:44 MST 2002
P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/flowchart.chap3.ENT.csv
mixed.rollup.chap3.imp Fri Feb 15 14:09:42 MST 2002
P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/flowchart.chap3.IMP.csv

Chapter I4: Economic Value of I&E Losses Based on Benefits Transfer Techniques

This chapter presents the results of EPA's evaluation of the economic losses associated with I&E at the Detroit Edison Monroe Power Plant using benefits transfer techniques. Section I4-1 provides an overview of the valuation approach, Section I4-2 discusses the value of recreational fishery losses, Section I4-3 discusses commercial fishery values, Section I4-4 discusses the value of forage species losses, Section I4-5 discusses nonuse values, and Section I4-6 summarizes the benefits transfer results.

Chapter Contents

I4-1 Overview of Valuation Approach

Fish losses from I&E at Monroe affect recreational and commercial fisheries as well as forage species that contribute to the biomass of recreational and commercial species. EPA evaluated all of these species groups to capture the total economic impact of I&E at Monroe.

Recreational fishery impacts are based on benefits transfer methods, applying the results from nonmarket valuation studies. Commercial fishery impacts are based on commodity prices for the individual species. The economic value of forage species losses is determined by estimating the replacement cost of these fish if they were to be restocked with hatchery fish, and by considering the foregone biomass production of forage fish resulting from I&E losses and the consequential foregone production of commercial and recreational species that use the forage species as a prey base. All of these methods are explained in further detail in the Chapter A9 of Part A of this document.

Many of the fish species impacted by I&E at Monroe are harvested both recreationally and commercially. To avoid double-counting the economic impacts of I&E on these species, EPA determined the proportion of total species landings attributable to recreational and commercial fishing, and applied this proportion to the impacted fishery catch. For example, if 30 percent of the landed numbers of one species are harvested commercially at a site, then 30 percent of the estimated catch of I&E-impacted fish are assigned to the increase in commercial landings. The remaining 70 percent of the estimated total landed number of I&E-impacted adult equivalents are assigned to the recreational landings.

The National Marine Fisheries Service (NMFS) provides both recreational and commercial fishery landings data by state. To determine what proportions of total landings per state occur in the recreational or commercial fishery, EPA summed the landings data for the recreational and commercial fishery, and then divided by each category to get the corresponding percentage. The percentages applied in this analysis are presented in Table I4-1.

As discussed in Chapters A5 and A9 of Part A of this document, the yield estimates presented in Chapter I3 are expressed as total pounds for both the commercial and recreational catch combined. For the economic valuation discussed in this chapter, total yield was partitioned between commercial and recreational fisheries based on the landings in each fishery (presented in Table I4-1). Because the economic evaluation of recreational yield is based on numbers of fish rather than pounds, foregone recreational yield was converted to numbers of fish, based on the average weight of harvestable fish of each species. Table

I4-2 shows these conversions for impingement and Table I4-3 displays these data for entrainment using the data presented in Section I3-4 of Chapter I3. Note that the numbers of foregone recreational fish harvested are typically lower than the numbers of age 1 equivalent losses, since the age of harvest of most fish is greater than age 1.

Table I4-1: Percentages of Total I&E Impacts at Monroe Occurring to Recreational and Commercial Fisheries[a]

Fish Species	Percent Impacts to Recreational Fishery	Percent Impacts to Commercial Fishery
Bluegill	100	0
Bullhead spp.	0	100
Burbot	50	50
Carp	0	100
Channel catfish	50	50
Crappie	100	0
Freshwater drum	0	100
Gizzard shad	0	100
Muskellunge	100	0
Smallmouth bass	100	0
Smelt	50	50
Suckers	0	100
Sunfish	100	0
Walleye	100	0
White bass	50	50
Whitefish	50	50
Yellow perch	100	0

[a] Accurate recreational landings data for Lake Erie have not yet been located, and thus EPA applied a 50/50 split for species that are both commercially and recreationally harvested.
Fri Feb 15 13:45:13 MST 2002 ; TableA:Percentages of total impacts occurring to the commercial and recreational fisheries of selected species; Plant: monroe ; Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/TableA.Perc.of total.impacts.monroe.csv

Table I4-2: Summary of Mean Annual Impingement of Fishery Species at Monroe

Species	Impingement Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lb)	Commercial Catch (#)	Commercial Yield (lb)	Recreational Catch (#)	Recreational Yield (lb)
Bluegill	375	447	1	0	0	0	1	0
Bullhead spp.	866	1,007	50	22	50	22	0	0
Carp	3,550	3,891	288	1,880	288	1,880	0	0
Channel catfish	666	859	32	27	16	13	16	13
Crappie	655	793	12	7	0	0	12	7
Freshwater drum	128,424	148,171	8,614	7,871	8,614	7,871	0	0
Gizzard shad	19,655,012	34,323,242	4,375,502	1,354,816	4,375,502	1,354,816	0	0
Muskellunge	4	4	0	0	0	0	0	0
Smallmouth bass	97	141	10	6	0	0	10	6
Smelt	4,260	5,132	117	44	58	22	58	22
Suckers	4,139	4,958	122	62	122	62	0	0
Sunfish	3,706	6,177	36	2	0	0	36	2
Walleye	16,687	22,658	178	334	0	0	178	334
White bass	548,775	662,353	54,381	50,469	27,190	25,235	27,190	25,235
Yellow perch	224,123	264,144	2,237	282	0	0	2,237	282
Commercial and Recreational Species Total	20,591,339	35,443,976	4,441,580	1,415,820	4,411,841	1,389,920	29,739	25,900

Table I4-3: Summary of Mean Annual Entrainment Results of Fishery Species at Monroe

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lb)	Commercial Catch (#)	Commercial Yield (lb)	Recreational Catch (#)	Recreational Yield (lb)
Burbot	2,770,000	1,765	132	206	66	103	66	52
Carp	79,700,000	394,554	29,161	190,659	29,161	190,659	0	0
Channel catfish	4,160,000	20,594	775	643	387	322	387	161
Crappie	580,000	23,517	347	195	0	0	347	98
Freshwater drum	158,000,000	143,558	8,346	7,626	8,346	7,626	0	0
Gizzard shad	4,080,000,000	8,747,005	1,115,062	345,264	1,115,062	345,264	0	0
Smallmouth bass	599,000	48,283	3,399	1,972	0	0	3,399	986
Smelt	11,000,000	89,543	2,038	766	1,019	383	1,019	192
Suckers	6,204,000	89,117	2,198	1,108	2,198	1,108	0	0
Sunfish	923,000	311,090	1,821	113	0	0	1,821	57
Walleye	2,080,000	16,749	132	247	0	0	132	124
White bass	156,000,000	772,277	63,406	58,845	31,703	29,423	31,703	14,712
Whitefish	190,000	81	50	73	25	36	25	18
Yellow perch	128,000,000	567,330	4,805	605	0	0	4,805	303
Commercial and Recreational Species Total	4,630,206,000	11,225,463	1,231,670	608,321	1,187,966	574,923	43,704	16,704

I4-2 Value of Baseline Recreational Fishery Losses at the Monroe Facility

I4-2.1 Economic Values for Recreational Losses Based on Literature

There is a large literature that provides willingness-to-pay values for increases in recreational catch rates. These increases in value are benefits to the anglers, and are often referred to by economists as a "consumer surplus" per additional fish caught.

When using values from the existing literature as proxies for the value of a trip or fish at a site not studied, it is important to select values for similar areas and species. Table I4-4 gives a summary of several studies that are closest to the Great Lakes fishery in geographic area and relevant species.

McConnell and Strand (1994) estimated fishery values using data from the National Marine Fisheries Statistical Survey. They created a random utility model of fishing behavior for nine Atlantic states, the northernmost being New York. In this model they specified four categories of fish: small gamefish (e.g., striped bass), flatfish (e.g., flounder), bottomfish (e.g., weakfish, spot, Atlantic croaker, perch), and big gamefish (e.g., shark). For each fish category, they estimated per angler values for access to marine waters and for an increase in catch rates.

Boyle et al. (1998) used the 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation to estimate the marginal economic value of an additional bass, trout, and walleye per trip.

Sorg et al. (1985) used travel cost and contingent valuation methods to estimated the value of recreational fishing at 51 sites in Idaho. Several of the species valued in Sorg et al. are also found in the Great Lakes fishery.

Milliman et al. (1992) used a logit model, creel data, and the responses to a contingent valuation dichotomous choice survey question the study estimated the value of recreational fishing for yellow perch in Green Bay, Michigan.

Table I4-4: Selected Valuation Studies for Estimating Changes in Catch Rates

Authors	Study Location and Year	Item Valued	Value Estimate ($2000)	
McConnell and Strand (1994)	Mid- and south Atlantic coast, anglers targeting specific species, 1988	Catch rate increase of 1 fish per trip[a]	Small gamefish	$10.06
Hicks et al. (1999)	Mid-Atlantic coast, 1994	Catch rate increase of 1 fish per trip	Small gamefish Bottomfish	$2.95 $2.38
Boyle et al. (1998)	National, by state, 1996	Catch rate increase of 1 fish per trip	Bass (low/high)	$1.58 - $5.32
Sorg et al. (1985)	Idaho, 1982	Catch rate increase of 1 fish per trip	Warmwater fish	$5.02
Milliman et al. (1992)	Green Bay	Catch rate increase of 1 fish per trip	Yellow perch	$0.31
Charbonneau and Hay (1978)	National, 1975	Catch rate increase of 1 fish per trip	Walleye Catfish Panfish	$7.92 $2.64 $1.00

[a] Value was reported as "two month value per angler for a half fish catch increase per trip." From 1996 National Survey of Fishing, Hunting and Wildlife-Associated Recreation (U.S. DOI, 1997), the average saltwater angler takes 1.5 trips in a 2 month period. Therefore, to convert to a "1 fish per trip" value, EPA divided the 2 month value by 1.5 trips and then multiplied it by 2, assuming the value of a fish was linear.

Charbonneau and Hay (1978) used travel cost and contingent valuation methods to estimate the consumer surplus for a season of the respondent's favorite wildlife-related activity. These consumer surplus values were then converted to a one fish increase per trip.

I4-2.2 Baseline Losses in Recreational Yield at Monroe and Value of Losses

Since most of these studies discussed in the previous section do not consider the Great Lakes fishery directly, EPA used these estimates to create a range of possible consumer surplus values for the recreational fish landings gained by reducing impingement and entrainment at the Monroe facility. To estimate a unit value for recreational landings, EPA established a lower and upper value for the recreational species, based on values reported in studies in Table I4-4. EPA estimated the economic value of I&E impacts to recreational fisheries using the I&E estimates presented in Tables I4-2 and I4-3 and the economic values in Table I4-5.

EPA used the percentages listed in Table I4-1 to obtain losses to recreational fisheries. Results are displayed in Tables I4-5 and I4-6, for impingement and entrainment, respectively, and are expressed as average annual I&E and corresponding values. The estimated total loss to recreational fisheries ranges from $44,800 to $149,100 for impingement per year, and from $62,800 to $209,100 annually for entrainment.

Table I4-5: Baseline Mean Annual Recreational Impingement Losses at the Monroe Facility and Associated Economic Values

Species	Loss to Recreational Catch from Impingement (number of fish)	Recreational Value/Fish		Loss in Recreational Value from Impingement	
		Low	High	Low	High
Bluegill	1	$0.31	$1.00	$0	$1
Channel catfish	16	$2.64	$5.02	$43	$81
Crappie	12	$1.00	$5.02	$12	$59
Smallmouth bass	10	$1.58	$5.32	$16	$53
Smelt	58	$2.95	$10.06	$172	$588
Sunfish	36	$0.31	$1.00	$11	$36
Walleye	178	$5.02	$7.92	$896	$1,413
White bass	27,190	$1.58	$5.32	$42,961	$144,653
Yellow perch	2,237	$0.31	$1.00	$694	$2,237
Total	29,739			$44,804	$149,121

Fri Feb 15 13:45:23 MST 2002 ; TableB: recreational losses and value for selected species; Plant: monroe ; type: I Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/TableB.rec.losses.monroe.I.csv

Table I4-6: Baseline Mean Annual Recreational Entrainment Losses at the Monroe Facility and Associated Economic Values

Species	Loss to Recreational Catch from Entrainment (number of fish)	Recreational Value/Fish ($2000)		Annual Loss in Recreational Value from Entrainment ($2000)	
		Low	High	Low	High
Burbot	66	$2.95	$10.06	$194	$662
Channel catfish	387	$2.64	$5.02	$1,023	$1,945
Crappie	347	$1.00	$5.02	$347	$1,740
Smallmouth bass	3,399	$1.58	$5.32	$5,370	$18,082
Smelt	1,019	$2.95	$10.06	$3,006	$10,251
Sunfish	1,821	$0.31	$1.00	$564	$1,821
Walleye	132	$5.02	$7.92	$662	$1,045
White bass	31,703	$1.58	$5.32	$50,091	$168,660
Whitefish	25	$1.50	$2.38	$37	$59
Yellow perch	4,805	$0.31	$1.00	$1,490	$4,805
Total	43,704			$62,784	$209,070

Fri Feb 15 13:45:28 MST 2002 ; TableB: recreational losses and value for selected species; Plant: monroe ; type: E Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/TableB.rec.losses.monroe.E.csv

I4-3 Value of Baseline Commercial Fishery Losses at the Monroe Facility

I4-3.1 Baseline Losses in Commercial Yield at Monroe and Value of Losses

I&E losses to commercial catch (pounds) are presented in Tables I4-2 (for impingement) and I4-3 (for entrainment) based on the commercial and recreational splits listed in Table I4-1. Values for commercial fishing are relatively straightforward because commercially caught fish are a commodity with a market price. EPA estimates of the economic value of these losses are displayed in Tables I4-7 and I4-8. Market values per pound are listed as well as the total market losses experienced by the commercial fishery. The estimates of market loss to the commercial fisheries are $229,900 for impingement per year, and $113,400 annually for entrainment.

Table I4-7: Baseline Mean Annual Commercial Impingement Losses at the Monroe Facility and Associated Economic Values

Species	Loss to Commercial Catch from Impingement (lb of fish)	Commercial Value ($/lb of fish)	Annual Loss in Commercial Value from Impingement ($2000)
Bullhead spp.	22	$0.33	$7
Burbot	0	$0.35	$0
Carp	1,880	$0.16	$301
Channel catfish	13	$0.76	$10
Freshwater drum	7,871	$0.21	$1,653
Gizzard shad	1,354,816	$0.15	$203,222
Smelt	22	$0.35	$8
Suckers	62	$0.17	$10
White bass	25,235	$0.98	$24,730
Whitefish	0	$0.82	$0
Total	1,389,920		$229,942

Fri Feb 15 13:45:23 MST 2002 ; TableC: commercial losses and value for selected species; Plant: monroe ; type: I Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/TableC.comm.losses.monroe.I.csv

Table I4-8: Baseline Mean Annual Commercial Entrainment Losses at the Monroe Facility and Associated Economic Values

Species	Loss to Commercial Catch from Entrainment (lb of fish)	Commercial Value ($/lb of fish)	Annual Loss in Commercial Value from Entrainment ($2000)
Burbot	103	$0.35	$36
Carp	190,659	$0.16	$30,505
Channel catfish	322	$0.76	$245
Freshwater drum	7,626	$0.21	$1,601
Gizzard shad	345,264	$0.15	$51,790
Smelt	383	$0.35	$134
Suckers	1,108	$0.17	$188
White bass	29,423	$0.98	$28,834
Whitefish	36	$0.82	$30
Total	574,923		$113,363

Fri Feb 15 13:45:29 MST 2002 ; TableC: commercial losses and value for selected species; Plant: monroe ; type: E Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/TableC.comm.losses.monroe.E.csv

Tables I4-7 and I4-8 express commercial impacts based on changes from dockside market landings only. However, to determine the total economic impact from changes to the commercial fishery, EPA also determined the losses experienced by producers wholesalers, retailers, and consumers.

The total social benefits (economic surplus) are greater than the increase in dockside landings, because the increased landings by commercial fishermen contribute to economic surplus in each of a multi-tiered set of markets for commercial fish. The total economic surplus impact thus is valued by examining the multi-tiered markets through which the landed fish are sold, according to the methods and data detailed in Chapter A9.

The first step of the analysis involves a fishery-based assessment of I&E-related changes in commercial landings (pounds of commercial species as sold dockside by commercial harvesters). The results of this dockside landings value step are described above. The next steps then entail tracking the anticipated additional economic surplus generated as the landed fish pass from dockside transactions to other wholesalers, retailers and, ultimately, consumers. The resulting total economic surplus measures include producer surplus to the watermen who harvest the fish, as well as the rents and consumer surplus that accrue to buyers and sellers in the sequence of market transactions that apply in the commercial fishery context.

To estimate producer surplus from the landings values, EPA relied on empirical results from various researchers that can be used to infer producer surplus for watermen based on gross revenues (landings times wholesale price). The economic literature (Huppert, 1990; Rettig and McCarl, 1985) suggests that producer surplus values for commercial fishing ranges from 50 to 90 percent of the market value. In assessments of Great Lakes fisheries, an estimate of approximately 40% has been derived as the relationship between gross revenues and the surplus of commercial fishermen (Cleland and Bishop, 1984, Bishop, personal communication, 2002). For the purposes of this study, EPA believes producer surplus to watermen is probably in the range of 40% to 70% of dockside landings values.

Producer surplus is one portion of the total economic surplus impacted by increased commercial stocks — the total benefits are comprised of the economic surplus to producers, wholesalers, processors, retailers, and consumers. Primary empirical research deriving "multi-market" welfare measures for commercial fisheries have estimated that surplus accruing to commercial anglers amount to approximately 22% of the total surplus accruing to watermen, retailers and consumers combined (Norton et al., 1983; Holt and Bishop, 2002). Thus, total economic surplus across the relevant commercial fisheries multi-tiered markets can be estimated as approximately 4.5 times greater than producer surplus alone (given that producer surplus is roughly 22% of the total surplus generated). This relationship is applied in the case studies to estimate total surplus from the projected changes in commercial landings.

Applying this method, EPA estimates that baseline economic loss to commercial fisheries ranges from $418,000 to $732,000 per year for impingement, and from $206,000 to $361,000 per year for entrainment at the Monroe facility.

I4-4 Value of Forage Fish Losses at the Monroe Facility

Many species affected by I&E are not commercially or recreationally fished. For the purposes of this study, EPA refers to these species as forage fish. Forage fish are species that are prey for other species, and are important components of aquatic food webs. Table I4-9 summarizes impingement losses of forage species at Monroe and Table I4-10 summarizes entrainment losses. The following sections discuss the economic valuation of these losses using two alternative valuation methods.

Table I4-9: Summary of Mean Annual Impingement of Forage Fish at Monroe

Species	Impingement Count (#)	Age 1 Equivalents (#)	Production Foregone (lb)
Alewife	125	156	2
Logperch	117,327	156,793	781
Shiner spp	180,252	213,319	2,621
Forage species total	297,704	370,267	3,405

Table I4-10: Summary of Mean Annual Entrainment of Forage Fish at Monroe

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Production Foregone (lb)
Alewife	0	0	0
Logperch	2,983,000	115,373	8,873
Shiner spp.	30,420,000	276,928	83,324
Forage species total	33,403,000	392,301	92,197

Replacement cost of fish

The replacement value of fish can be used in several instances. First, if a fish kill of a fishing species is mitigated by stocking of hatchery fish, then losses to the commercial and recreational fisheries would be reduced, but fish replacement costs would still be incurred and should be accounted for. Second, if the fish are not caught in the commercial or recreational fishery, but are important as forage or bait, the replacement value can be used as a lower bound estimate of their value (it is a lower bound because it would not consider how reduction in their stock may affect other species' stocks). Third, where there are not enough data to value losses to the recreational and commercial fisheries, replacement cost can be used as a proxy for lost fishery values. Typically the consumer or producer surplus is greater than fish replacement costs, and replacement costs typically omit problems associated with restocking programs (e.g., limiting genetic diversity).

The cost of replacing forage fish lost to I&E has two main components. The first component is the cost of raising the replacement fish. Table I4-11 displays the replacement costs of two of the forage fish species known to be impinged or entrained at Monroe. The costs are average costs to fish hatcheries (in dollars per pound) across North America to produce different species of fish for stocking. The second component of replacement cost is the transportation cost, which includes costs associated with vehicles, personnel, fuel, water, chemicals, containers, and nets. The AFS (1993) estimates these costs at approximately $1.13 per mile, but does not indicate how many fish (or how many pounds of fish) are transported for this price. Lacking relevant data, EPA does not include the transportation costs in this valuation approach.

Table I4-11 presents the computed values of the annual average forage replacement costs. The value of the losses of forage species using the replacement cost method is $7,000 per year for impingement and $8,000 per year for entrainment.

Table I4-11: Replacement Cost of Various Forage Fish Species at the Monroe Facility[a]

Species	Hatchery Costs ($/lb)	Annual Cost of Replacing Forage Losses ($2000)	
		Impingement	Entrainment
Alewife	$0.52	$1	$0
Logperch	$1.05	$2,104	$1,548
Shiner spp.	$0.91	$5,053	$6,559
Total		$7,158	$8,108

[a] Values are from AFS (1993).
Fri Feb 15 13:45:24 MST 2002 ; TableD: loss in selected forage species; Plant: monroe ; type: I Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/TableD.forage.eco.ter.repl.monroe.I.csv

Production foregone value of forage fish

This approach considers the foregone biomass production of commercial and recreational fishery species fish resulting from I&E losses of forage species based on estimates of trophic transfer efficiency as discussed in Chapter A5 of Part A of this document. The economic valuation of forage losses is based on the dollar value of the foregone fishery yield resulting from the loss of forage.

Table I4-12 displays the results of this method of valuing forage species lost from entrainment. Impingement results were insignificant (as estimated by this method) and thus are not discussed. The values listed are obtained by converting the forage species into species that may be commercially or recreationally valued. The values of entrainment losses range from $822,000 to $1.6 million per year.

Table I4-12: Mean Annual Economic Value of Production Foregone of Selected Fishery Species Resulting from Entrainment of Forage Species at Monroe

Species	Annual Loss in Production Foregone Value from Entrainment of Forage Species ($2000)	
	Low	High
Burbot	$148,564	$444,405
Carp	$13	$23
Channel catfish	$30	$55
Crappie	$2	$12
Freshwater drum	$4	$7
Gizzard shad	$13	$23
Smallmouth bass	$98	$331
Smelt	$83	$273
Suckers	$0	$1
Sunfish	$47	$151
Walleye	$3	$5
White bass	$12	$30
Whitefish	$673,405	$1,133,734
Yellow perch	$1	$2
Total	$822,275	$1,579,051

Fri Feb 15 13:45:29 MST 2002 ; TableD: loss in selected forage species; Plant: monroe ; type: E Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/TableD.forage.eco.ter.repl.monroe.E.csv

I4-5 Nonuse Values for Baseline Losses at the Monroe Facility

Recreational consumer surplus and commercial impacts are only part of the total losses that the public realizes from I&E impacts on fisheries. Nonuse or passive use impacts arise when individuals value environmental changes apart from any past, present, or anticipated future use of the resource in question. Such passive use values have been categorized in several ways in the economic literature, typically embracing the concepts of existence (stewardship) and bequest (intergenerational equity) motives. Using a "rule of thumb" that nonuse impacts are at least equivalent to 50 percent of the recreational use impact (see Chapter A9 of Part A of this document for further discussion), EPA estimated nonuse values for baseline losses at Monroe to range from $22,000 to $75,000 per year for impingement and from $31,000 to $105,000 per year for entrainment.

I4-6 Summary of Mean Annual Values of Baseline Economic Losses at the Monroe Facility

Table I4-13 summarizes the estimated annual baseline losses from I&E at the Monroe facility. Total impacts range from $492,400 to $962,500 per year for impingement and from $308,400 to $2,253,400 per year for entrainment.

Table I4-13: Summary of Valuation of Baseline Mean Annual I&E at Monroe Facility ($2000)

		Impingement	Entrainment	Total
Commercial: Total Surplus (Direct Use, Market)	Low	$418,076	$206,115	$624,191
	High	$731,632	$360,702	$1,092,334
Recreational (Direct Use, Nonmarket)	Low	$44,804	$62,784	$107,588
	High	$149,121	$209,070	$358,191
Nonuse (Passive Use, Nonmarket)	Low	$22,402	$31,392	$53,794
	High	$74,560	$104,535	$179,095
Forage (Indirect Use, Nonmarket)				
Production Foregone	Low	NA	$822,275	$822,275
	High	NA	$1,579,051	$1,579,051
Replacement		$7,158	$8,108	$15,266
Total (Com + Rec + Nonuse + Forage)[a]	Low	$492,440	$308,399	$800,839
	High	$962,471	$2,253,358	$3,215,829

NA = Results were not significant and thus are not reported.

[a] In calculating the total low values for entrainment, the lower of the two forage valuation methods (production foregone and replacement) was used and to calculate the total high values, the higher of the two forage valuation methods was used. For impingement, only the replacement value results are used.

Fri Feb 15 13:45:31 MST 2002 ; TableE.summary; Plant: monroe ; Pathname: P:/Intake/Great_Lakes/GL_Science/scodes/monroe/tables.output/TableE.summary.monroe.csv

Chapter I5: Streamlined HRC Valuation of I&E Losses at the Monroe Facility

This chapter presents the results of EPA's streamlined habitat-based replacement cost (HRC) valuation of I&E losses at the Monroe facility in Monroe, Michigan, for a baseline scenario based on I&E data for the years 1982 and 1985.

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A description of the HRC method and the process for undertaking a complete HRC valuation of I&E losses is provided in Chapter A11 of Part A of this document. To summarize, a complete HRC valuation of I&E losses reflects the combined costs for implementing habitat restoration actions, administering the programs, and monitoring the increased production after the restoration actions. In a complete HRC valuation, these costs are developed by first identifying the preferred habitat restoration alternative for each species with I&E losses and then scaling the level of habitat restoration until the losses across all the species for that restoration alternative have been exactly offset by the expected increases in production of each species. The total value of the I&E losses at the facility is then calculated as the sum of the costs across the set of preferred habitat restoration alternatives that were identified.

The HRC method is thus a supply-side approach for valuing I&E losses in contrast to the more typically used demand-side valuation approaches (e.g., commercial and recreational fishing impacts valuations). An advantage of the HRC method is that the HRC values address losses for species lacking a recreational or commercial fishery (e.g., forage species). Further, the HRC explicitly recognizes and captures the fundamental ecological relationships between species with I&E losses at a facility and their surrounding environment by determining the value of I&E losses through the cost of the actions required to provide an offsetting increase in the existing populations of those species in their natural environment.

Streamlining was necessary to meet the schedule of the 316(b) existing sources rule and entailed combining Step 2 (identification of species habitat requirements), Step 3 (identification of habitat restoration alternatives), and Step 4 (consolidation and prioritization of habitat restoration alternatives), restricting the analysis to readily available information, and eliminating site visits, in-depth discussions with local experts, and development of primary data (see Chapter A11 of Part A of this document), which would be required before doing an actual restoration. Despite these restrictions, the streamlined HRC provided a more comprehensive, ecological-based valuation of the I&E losses than valuation by traditional commercial and recreational impacts methods. In addition, the streamlined HRC valued direct, indirect, and passive uses not included in more traditional economic valuation techniques used in Chapters I4 and I6.

The calculated range in annualized costs, expressed in 2000 dollars, of restoring sufficient fish production habitat to offset the I&E losses in perpetuity at the Monroe facility for the baseline scenario is $1.1 - $14.4 million.

The following subsections describe the streamlined HRC valuation applied to the Monroe facility and the advantages and disadvantages of streamlining the HRC method.

I5-1 Quantify I&E Losses by Species (Step 1)

The streamlined HRC method relies on the same estimates of annual age 1 equivalent species losses that are developed in Chapter I3 from data reported directly by the facility and incorporated in the commercial and recreational fishing impacts valuation presented in Chapter I4. Total I&E losses at the facility may be underestimated, particularly if certain species were not targeted by monitoring efforts or if short duration population spikes occurred outside of monitoring events. The HRC method inherently reduces the former problem by targeting restoration activities that might benefit species lost but not monitored, but like all other measures of I&E losses, it relies on representative monitoring.

Various life stages of organisms were lost to I&E at the Monroe facility. As with other facilities, primarily early stages such as eggs and larvae are entrained, and primarily juveniles and adults are impinged. However, EPA estimated total losses for each species by converting all losses to a common equivalent life stage by applying average mortality rates between life stages for each species. These mortality rates were derived from the literature and best professional judgment. Conversion between life stages did not change the overall scale of required restoration in the streamlined HRC method because many eggs are equivalent to few adults on both the I&E loss and increased production sides of the HRC equation. For example, if on average one adult survives from 10 eggs via a 90% cumulative mortality rate and 1 acre of habitat produces 10 eggs, then restoration of 1 acre is needed to produce either one adult or 10 eggs.

Age 1 equivalent I&E losses of 20 species of fish were calculated using the available I&E monitoring data available from the Monroe facility. A summary of average annual age 1 equivalent losses from the available data is presented in Table I5-1.

Table I5-1: Average Annual I&E Losses of Age 1 Equivalent Fish at the Monroe Facility

Species	Baseline Scenario: (1982 and 1985)		
	Impinged	Entrained	Total
Gizzard shad	34,323,242	8,747,005	43,070,247
White bass	662,353	772,277	1,434,630
Yellow perch	264,144	567,330	831,474
Shiner spp.	213,319	276,928	490,247
Carp	3,891	394,554	398,445
Sunfish spp.	6,177	311,090	317,267
Freshwater drum	148,171	143,558	291,729
Logperch	156,793	115,373	272,166
Smelt	5,132	89,543	94,675
Suckers	4,958	89,117	94,075
Smallmouth bass	141	48,283	48,424
Walleye	22,658	16,749	39,407
Crappie spp.	793	23,517	24,310
Channel catfish	859	20,594	21,453
Burbot	0	1,765	1,765
Bullhead spp.	1,007	0	1,007
Bluegill	447	0	447
Alewife	156	0	156
Whitefish	0	81	81
Muskellunge	4	0	4
Total	**35,814,245**	**11,617,764**	**47,432,009**

Several species impinged or entrained at the Monroe facility are important to commercial or recreational fishing, including walleye, yellow perch, catfish, and crappie. Many others, including alewife, smelt, and shiners, indirectly affect commerce and recreation because they are prey for commercially or recreationally important aquatic and terrestrial wildlife species such as salmon and northern pike, bald eagles, and mink. Furthermore, all of the species provide numerous, complex, ecological services as sources of carbon and energy transfer through the food web, as well as continuous interactive exploitation of niches available in the Great Lakes ecosystem (a system already under tremendous stress from exotic species introductions, hazardous substance contamination, nonpoint source runoff, heat contamination, habitat loss, overfishing, and I&E) from multiple sources.

For example, freshwater drum feed on a variety of small fish. When food supplies are short, freshwater drum often out-compete other species and thereby may increase mortality rates or decrease growth rates for those species (Edsall, 1967). In addition, several species of Centrarchids, including the crappie, are sensitive to the size of their predators' population. When predators such as walleye are absent, species such as crappie can overcrowd their habitats and exhaust their own food supplies, resulting in stunted growth (Wang, 1986a; Steiner, 2000). Finally, some species are already subject to wide fluctuations in population size from year to year, and may not be able to tolerate I&E losses, particularly at certain times of the year. For example, the gizzard shad is often subject to high mortality in the winter (Miller, 1960).

I5-2 Identify Species Habitat Requirements (Step 2), Identify Habitat Restoration Alternatives (Step 3), and Prioritize Restoration Alternatives (Step 4)

EPA combined steps 2, 3, and 4 of the HRC method by seeking a single habitat restoration program capable of increasing production for most of the species with quantified I&E losses at the Monroe facility. Addressing each of these steps separately for each of the I&E species would improve the analysis but would require more time than was available for the analysis for the proposed rule.

The selection of coastal wetland restoration as the preferred restoration alternative for offsetting the I&E losses at the Monroe facility builds of the work conducted in the streamlined HRC valuation of the I&E losses at the nearby J.R. Whiting facility. This decision is viewed as appropriate recognizing the relative proximity of the Monroe and J.R. Whiting facilities, the existence of coastal wetland preservation and restoration programs in many Great Lakes states, and the prior knowledge that many of the fish species with quantified age 1 equivalent I&E losses at the Monroe facility have readily available information describing their abundance in Great Lakes' coastal wetlands which can be used as a proxy for increased production benefit estimates.

I5-3 Quantify the Benefits for the Prioritized Habitat Restoration Alternatives (Step 5)

A literature search revealed a study (Brazner, 1997) that provides fish capture data by species from sampling efforts conducted at a series of Green Bay (Lake Michigan) coastal wetland and sand beach sites. No other studies provide more direct measures of increased fish species production following Great Lakes coastal wetland restoration, or fish capture data in wetlands closer to the Monroe facility. However, the Brazner study sampled wetlands in the warmer, shallower, more eutrophic waters of southern Green Bay, which are similar to the waters of western Lake Erie. After examining the data from the Brazner study and discussing them with the author, EPA dropped less similar sites from northern Green Bay. For almost all of the species with quantified I&E losses at the Monroe facility, a match was found with a species, or combination of species, among those captured at the southern sites in the Brazner study. Table I5-2 shows the species caught in the Brazner study that were paired with the species being lost at the Monroe facility (this represents only a fraction of the species caught in these southern locations in the Brazner study).

Because of the similarity between the physical habitats of southern Green Bay and western Lake Erie and the confirmed presence of similar species in both locations, EPA estimated densities for each southern Green Bay species and used them as a proxy for direct measurements of potential increased production following wetland restoration. This approach assumed that additional wetland habitat restored near the Monroe facility would provide similar densities of each species as the wetland habitats sampled in Green Bay. Direct measurements of densities of each species before and after actual wetland habitat restorations in western lake Erie could test this assumption and improve the reliability of the HRC valuation for the Monroe facility.

Table I5-2: Species with I&E Loss Estimates at the Monroe Facility and the Corresponding Species Captured in Green Bay Wetland Sampling

Species with I&E Loss Estimates at the Monroe Facility	Corresponding Species Caught in Sampling of Green Bay Coastal Wetlands (Brazner, 1997)
Alewife	Yes
Bluegill	Yes
Bullhead spp.	Yes (as sum of black, brown, and yellow bullhead)
Burbot	No
Carp	Yes
Channel catfish	Yes
Crappie spp.	Yes (as black crappie)
Freshwater drum	Yes
Gizzard shad	Yes
Logperch	Yes
Muskellunge	Yes
Shiner spp.	Yes (as sum of common, emerald, golden, spotfin, and spottail shiner)
Smallmouth bass	Yes
Smelt	Yes (as rainbow smelt)
Suckers spp.	Yes (as white sucker)
Sunfish	Yes (as green sunfish)
Walleye	Yes
White bass	Yes
Whitefish	No
Yellow perch	Yes

EPA developed the density estimates for each species for each site using aggregate sampling results provided by the author (J. Brazner, U.S. EPA, Duluth Lab, personal communication, 2001). Table I5-3 provides a summary of the Green Bay capture data (J. Brazner, U.S. EPA, Duluth Lab, personal communication, 2001) for each species that has quantified I&E losses at the Monroe facility for which a matching species or groups of species was available. Data for each of four Green Bay sites are presented, as are the average and maximum of all four sites.

The raw capture data were converted to density estimates for each species by assuming that each sampling event of 100 m of linear coastal wetland frontage corresponded to an average of 100 m of perpendicular width of connected coastal wetlands (i.e., each sampling event included fish from an assumed 100 m x 100 m area of wetlands). This assumption is based on discussions with the author about the likely perpendicular width of the sampled wetlands that was being used as habitat by the sampled species (J. Brazner, U.S. EPA, personal communication, 2001). A further adjustment was then made to the raw capture data to recognize the fact that shoreline sampling would capture only a portion of the fish actually using the 100 m x 100 m wetland habitat. After discussions with the author, the capture data were increased by a factor of 100 (1/0.01), based on the assumption that only 1% of the fish present or relying on the wetland habitat were captured in the sampling event.

The resulting per acre average density estimates for each species was used in the HRC equation as the measure of increased production that would most likely be provided by wetland habitat restoration near the Monroe facility. The maximum per acre density estimate for each species was used as an upper bound estimate of fish density that would result from wetland restoration near the Monroe facility.

Brazner (1997) captured young-of-year (younger than age 1), age 1 fish, and adult fish (older than age 1) in the Green Bay wetlands. In this evaluation, the capture data were treated as if it represented age 1 fish, which eliminated the need to apply mortality rates to adjust for survival between life stages for each species, as was done for I&E losses. Since Brazner (1997) reports a high percentage of young-of-year fish captured at all Green Bay sites, this assumption most likely results in a slight overestimation of age 1 fish densities, and therefore potentially underestimates the scale of restoration required to offset the average annual I&E loss for each species (i.e., it underestimates baseline losses from I&E).

Table I5-3: Green Bay Wetland Abundance Data

Species Name for HRC Analysis	Number Captured: Lower Green Bay Wetland Locations[a]				Summary Statistics	
	Long Tail Point Wetland	Little Tail Point Wetland	Atkinson Marsh	Sensiba Wildlife Refuge	Average	Maximum
Yellow perch	3,525	942	333	1,108	1,477	3,525
Shiner spp.[b]	1,202	499	526	769	749	1,202
Gizzard shad	384	264	160	137	236	384
Alewife	265	142	92	124	156	265
White bass	52	226	106	9	98	226
Sucker spp.[c]	14	10	1	103	32	103
Carp	19	10	3	1	8	19
Sunfish [d]	3	5	22	2	8	22
Bluegill	18	3	0	6	7	18
Freshwater drum	4	4	7	1	4	7
Bullhead spp.[e]	9	4	0	2	4	9
Crappie spp.[f]	1	2	1	1	1	2
Channel catfish	0	0	3	0	1	3
Muskellunge	2	0	0	0	1	2
Smallmouth bass	0	0	0	2	1	2
Logperch	0	0	0	1	0	1
Smelt.[g]	0	1	0	0	0	1
Walleye	1	0	0	0	0	1
Burbot	not captured in Green Bay wetlands				n/a	n/a
Whitefish	not captured in Green Bay wetlands				n/a	n/a

[a] Number captured in samples of 100 meters linear coastal wetland frontage. Reflects age 1 fish (not eggs and larvae).
[b] Shiner spp. values are the sum of the common, emerald, golden, spotfin, and spottail shiner values at each location.
[c] Sucker spp. values are those reported for white sucker.
[d] Sunfish values are those reported for green sunfish.
[e] Bullhead spp. values are the sum of the black, brown, and yellow bullhead values at each location.
[f] Crappie spp. values are those reported for black crappie.
[g] Smelt values are those reported for rainbow smelt.

I5-4 Scale the Habitat Restoration Alternatives to Offset I&E Losses (Step 6)

EPA calculated the amount of Great Lakes coastal wetland restoration required to offset I&E losses for each species at the Monroe facility by dividing the combined average annual I&E loss for each species in the baseline scenario by its per-acre estimate of increased production of age 1 equivalents. The results of this scaling are presented in Table I5-4.

Whether using average or maximum production values, over half of the species listed in Table I5-4 would require that hundreds or thousands of acres of wetland habitat be restored to fully offset the I&E losses caused by the Monroe facility's CWIS. If Great Lakes coastal wetland restoration is the best natural restoration alternative for offsetting losses for each of these species, then approximately 26,900 acres of coastal wetland restoration is required to fully offset all I&E losses under the baseline scenario using the average adjusted per acre density estimates (because restoring logperch would require that much wetland restoration, and all other species would be fully restored as well). However, without further discussions with local experts, and perhaps additional investigation of the relationship between feasible restoration activities and per-acre production benefits (particularly for the species driving the highest acreage needs), these assumptions may not be valid. On the other hand, the benefit of any given restoration program should always vary among species, and species with relatively high productivity or low I&E losses cannot drive the HRC results without sacrificing necessary offsets for other species with lower productivity or higher I&E losses. As seen in the results in Table I5-4, a large restoration requirement can reflect either low productivity of the restored habitat for the species (e.g., logperch and smelt) or very large I&E losses (e.g., gizzard shad).

Table I5-4: Wetland Restoration Required to Offset Combined I&E Losses at the Monroe CWIS

Species	Average Annual Age 1 Equivalents Lost to I&E	Per-Unit Production Benefit (age 1 fish per restored coastal wetland acre)		Required Acres of Wetland Restoration to Offset I&E Loss (rounded to nearest acre)	
		Average Value	Maximum Value Across Sites	Based on Average Production Value	Based on Maximum Production Value
Logperch	272,166	10	40	26,901	6,725
Smelt	94,675	10	40	9,358	2,339
Gizzard shad	43,070,247	9,561	15,540	4,505	2,771
Walleye	39,407	10	40	3,895	974
Smallmouth bass	48,424	20	81	2,393	598
Freshwater drum	291,729	162	283	1,802	1,030
Carp	398,445	334	769	1,193	518
Sunfish	317,267	324	890	980	356
Channel catfish	21,453	30	121	707	177
Crappie spp.	24,310	51	81	481	300
White bass	1,434,630	3,976	9,146	361	157
Suckers spp.	94,075	1,295	4,168	73	23
Shiner spp.	490,247	30,312	48,645	16	10
Yellow perch	831,474	59,774	142,657	14	6
Bullhead spp.	1,007	152	364	7	3
Bluegill	447	273	728	2	1
Muskellunge[a]	4	20	81	0	0
Alewife[b]	156	6,303	10,725	0	0
Burbot	1,765	n/a			
Whitefish	81	n/a			

[a] The exact requirement for restored wetland acreage for muskellunge is 0.20 acres under the average production value estimate and 0.05 acres under the maximum production value estimate. Both values are rounded to 0 acres for presentation.
[a] The exact requirement for restored wetland acreage for alewife is 0.02 acres under the average production value estimate and 0.01 acres under the maximum production value estimate. Both values are rounded to 0 acres for presentation.

Table I5-4 also shows that both the scale and distribution of the estimates of required wetland restoration change when maximum species density estimates are substituted for the averages. EPA used average species density estimates as the primary source of information because they are more representative of wetland productivity in the Brazner study, and more accurately reflect the difficulties of achieving full function in restored versus native habitats.[1]

Since a rigorous investigation of the relationship between feasible restoration alternatives and per-unit production estimates was not completed under the streamlined approach, using the highest restoration requirement (for logperch) may not be justified. Therefore, the restoration requirements were ordered for all of the species so that percentiles could be calculated. Using the 100th percentile (logperch) would offset losses for all of the species, as appropriate under a complete HRC analysis. However, the 90th and 50th percentiles (corresponding to smelt and channel catfish, respectively) were used to bound the estimate of the required scale of restoration. Using a lower percentile than the 100th recognizes that further analyses (or monitoring) might identify restoration programs more efficient and less costly than wetland restoration for species with the highest wetland restoration needs, or might produce better and higher wetland restoration productivity estimates (lower cost) for those same species. Nevertheless, using lower percentiles risks underestimating the costs of needed restoration because most species benefit from wetland restoration, and wetland restoration could easily prove to be the best alternative for those species with the greatest wetland restoration needs. Further, improved analysis and monitoring are as

[1] The maximum species-density-based estimates are included only as a sensitivity analysis and reflect a minimal scale of restoration that would be required if Lake Erie wetland restorations were much more highly successful then EPA anticipates. Detailed, repeated monitoring of I&E species in areas where restoration has occurred will increase the accuracy of future analyses.

likely to lower productivity estimates as they are to raise them. Therefore, percentiles less than the 50th were rejected as unreasonable.[2]

Table I5-5 presents the 90th and 50th percentile results from the distribution of required Great Lakes coastal wetland restoration calculated using the average species density estimates as a proxy for increased species production for the baseline scenario and combined average annual I&E losses of age 1 equivalent fish. Table I5-5 also presents the results using the maximum species density estimates as a sensitivity analysis.

Table I5-5: Acres of Coastal Wetland Restoration Required under Different I&E Scenarios with Alternative Increased Production Benefits Assumptions

I&E Scenario	Acres of Required Wetland Restoration with Average Species-Specific Density Estimates (preferred alternative)		Acres of Required Wetland Restoration with Maximum Species-Specific Density Estimates (sensitivity test)	
	90th Percentile Result	50th Percentile Result	90th Percentile Result	50th Percentile Result
Baseline	9,358	707	2,771	300

I5-5 Estimate "Unit Costs" for the Habitat Restoration Alternatives (Step 7)

EPA calculated annualized per-acre costs for restoring coastal wetlands in a Great Lakes ecosystem from the information in the Restoration and Compensation Determination Plan (RCDP) produced for the Lower Fox River/Green Bay Natural Resource Damage Assessment (U.S. Fish and Wildlife Service and Stratus Consulting, 2000), which incorporated a similar program of Great Lakes wetland restoration as a restoration alternative. The RCDP's per-acre cost included expenses for the restoration implementation (fieldwork), project administration, maintenance, and monitoring.

The RCDP's wetland restoration program focused on acquiring lands around Green Bay that are currently in agricultural use and that are located on hydric soils (an indicator of a wetland area). These former wetlands were generally brought into agricultural production through the draining or tiling of the land. Therefore, most of the expense (63%) in the RCDP's per-acre cost estimates was for land acquisition and restoration actions necessary to re-establish functioning wetlands. Maintenance costs (9%) consisted of expenses for periodic mowing and burning to maintain the dominance of wetland vegetation. The remaining expenditures (28%) covered anticipated administrative expenses for the program. The per-acre cost estimates for the various components of the wetland restoration program as presented in the Lower Fox River/Green Bay RCDP are provided in Table I5-6 along with the equivalent annualized per-acre cost that is used to value the required scale of wetland restoration in this streamlined HRC (the development of this annualized value is discussed in the following paragraph).

In annualizing the RCDP's unit costs for this streamlined HRC, EPA made a distinction between expected initial one-time program outlays (expenditures for land, transaction costs, restoration actions, contingency, and agency overhead) and anticipated recurring annual expenses (project maintenance and monitoring). Those costs that were viewed as initial program outlays were treated as a capital cost and annualized over a 20-year period at a 7% interest rate providing an annualized value of $882 from their initial combined value of $9,360. EPA then estimated the present value (PV), using a 7% interest rate, of the recurring annual expenses for 10 years as this is the length of time incorporated for monitoring in the complete HRC valuations conducted for the Brayton Point and Pilgrim facility case studies. This PV for the recurring annual expenses was then annualized over a 20 year period, again using a 7% interest rate resulting in an annualized expense of $658. This process effectively treats the monitoring expenses associated with the wetland restoration consistently with the annual operating and maintenance costs presented in the costing, economic impact, and cost-benefit analysis chapters. The annualized recurring expenses were then added to the annualized initial program outlays resulting in a total annualized cost for the wetlands restoration alternative of $1,540 per acre.

[2] For instance, using the 25th percentile restoration requirement from Table I5-4 (14 acres for yellow perch) would be valid only if further analysis produced superior (cheaper or more productive) restoration alternatives, or superior wetland productivity estimates that were higher for most of the species, including logperch, smelt, gizzard shad, walleye, smallmouth bass, freshwater drum, carp, sunfish, channel catfish, crappie, white bass, suckers, and shiner spp. Even the 50th percentile value that we use as a lower bound estimate assumes that eight of these species could each be produced more effectively with different restoration alternatives, or that wetland productivity is actually higher for all eight species.

Table I5-6: Wetland Restoration Costs (2000 dollars)

Restoration Program Component	$/Acre	Cost Method
Land acquisition	3,000	Survey of land prices
Land transaction costs	600	20% of land price, reflects agency (U.S. FWS) experience
Restoration action	2,600	Project experience (See Table Source)
Contingency on restoration action	260	10% of restoration actions, consistent with standard practice
Project maintenance	590	Project experience (See Table Source)
Monitoring	340	5% of total of land acquisition, land transaction, restoration action, and maintenance
Agency (landowner) overhead (project administration)	2,900	38.84% of sum of all other cost, reflects agency (U.S. FWS) experience
Total Cost	10,300	
Total Annualized Cost	**1,540**	

Source: U.S. Fish and Wildlife Service and Stratus Consulting, 2000.

However, these unit costs probably understate the cost of monitoring that would be sufficient to measure per-unit production benefits in restored wetlands, which could then improve future HRC calculations. In the RCDP's wetland restoration monitoring program, the emphasis was on evaluating whether the hydrology of the former wetlands and the associated vegetation were returning over time, activities that could be achieved with relatively minimal effort. In contrast, a monitoring program capable of addressing whether anticipated increases in the production of certain species were being achieved in the restored wetland areas would require a far more significant commitment of time and resources, resulting in commensurately larger expenditures.

I5-6 Develop Total Cost Estimates for I&E Losses (Step 8)

EPA estimated the total annualized cost to offset the average annual I&E losses at the Monroe facility by multiplying the 50th percentile and 90th percentile results of the required acreage of wetland restoration (see Table I5-5) by the annualized per-acre wetlands restoration costs from the RCDP (see Table I5-6). These results are presented in Table I5-7.

Table I5-7: Total Annualized Costs for a Wetland Restoration Program to Offset I&E Losses (millions of 2000 dollars)

I&E Scenario	Cost of Required Wetland Restoration with Average Species-Specific Density Estimates (preferred results)		Cost of Required Wetland Restoration with Maximum Species-Specific Density Estimates (sensitivity test)	
	90th Percentile Result	50th Percentile Result	90th Percentile Result	50th Percentile Result
Baseline	$14.4	$1.1	$4.3	$0.5

The results of the streamlined HRC provide an annualized present value estimate of roughly $14.4 million for a program of Great Lakes coastal wetland restoration that would offset the average annual age 1 equivalent losses from the baseline period in perpetuity using the 90th percentile results and average species density estimates. Incorporating the maximum observed species density from any of the sampled wetlands in Green Bay reduces the value of the 90th percentile scenario results to between one-third and one-fourth the average species density results.

Table I5-8 shows the results of the streamlined HRC analysis for impingement losses, entrainment losses, and total I&E losses separately.

Table I5-8: Annualized Results for the Monetization of I&E Losses at the Monroe Facility Incorporating Average Species-Specific Density Estimates (millions of 2000 dollars)

I&E Scenario	Component of I&E Loss	Annualized Value	
		90th Percentile	50th Percentile
Baseline	Impingement	$5.5	$0.0[a]
	Entrainment	$13.6	$1.4
	I&E total[b]	$14.4	$1.1

[a] The exact value of $24,141 is rounded to $0.0 when rounded to millions of dollars for presentation.
[b] The total is not equal to the sum of the results from the I&E components because of different numbers of species in these components as well as different rankings of the species based on the extent of required restoration in these components.

I5-7 Strengths and Weaknesses of the Streamlined HRC Analysis

The fundamental appeal of the HRC is its ability to incorporate and value environmental losses that are either undervalued or ignored by traditional valuation approaches, such as recreational and commercial fishing valuation (see Chapter A11 in Part A of this document for additional discussion). The primary advantage of the streamlined HRC is the limited effort and time required to provide regulators with an initial assessment of whether a complete HRC is justified. For facilities like Monroe with relatively large I&E impacts and I&E impacts to many species not targeted by anglers, a complete HRC is likely to be worthwhile, even given budgetary and time constraints associated with permit re-issuance cycles. In addition, the streamlined HRC provides regulators with a framework to evaluate mitigation proposals put forth by industry to address residual I&E losses associated with the permitted BTA.

The primary weakness of the streamlined HRC is the uncertainty resulting from limited opportunities to access local resource experts and unpublished primary data in the selection of a preferred restoration alternative, the development of per-unit production benefits for each species, and the estimation of restoration unit costs.

For these reasons, streamlining an HRC may be most appropriate when:

- a limited number of species experience I&E losses or the majority of I&E losses are realized by a small number of species
- the regulator is familiar with, or can quickly determine, the preferred restoration alternative for these critical species
- benefits information from evaluations of local habitats is available, and extrapolations do not lead to extreme variability
- published sources of information allow estimation of all important aspects of the restoration costs.

If these conditions are absent, a complete HRC analysis will provide a more comprehensive estimate of the losses associated with I&E than provided by traditional valuations.

In conclusion, the streamlined HRC method provides regulators, industry, and the public with an important method to quickly estimate the likely value of I&E losses at § 316(b)-regulated facilities. Further, because regulators and local experts can often quickly assess whether appropriate and necessary information exists for the valuation of I&E resources, streamlining may offer many opportunities to broaden the evaluation of I&E to include ecological and related public services, even when facing significant time and budgetary constraints.

Chapter I6: Benefits Analysis for the Monroe Facility

This chapter presents the results of EPA's evaluation of the economic benefits associated with reductions in estimated current I&E at the Monroe facility. The economic benefits reported here are based on the values presented in Chapters I4 and I5, and EPA's estimates of I&E at the facility (see Chapter I3). Section I6-1 presents a summary of I&E losses and associated monetized losses. Section I6-2 presents estimated economic benefits of reduced I&E, and Section I6-3 discusses the uncertainties in the analysis.

Chapter Contents

I6-1 Overview of I&E and Associated Economic Values

The flowchart in Figure I6-1 summarizes how the economic values of I&E losses at Monroe were derived from the I&E estimates in Chapter I3. Figures I6-2 and I6-3 indicate the distribution of I&E losses by species category and associated economic values. These diagrams reflect baseline losses based on current technology. All dollar values and percentages of losses reflect midpoints of the ranges for the categories of commercial, recreational, nonuse, and forage values.

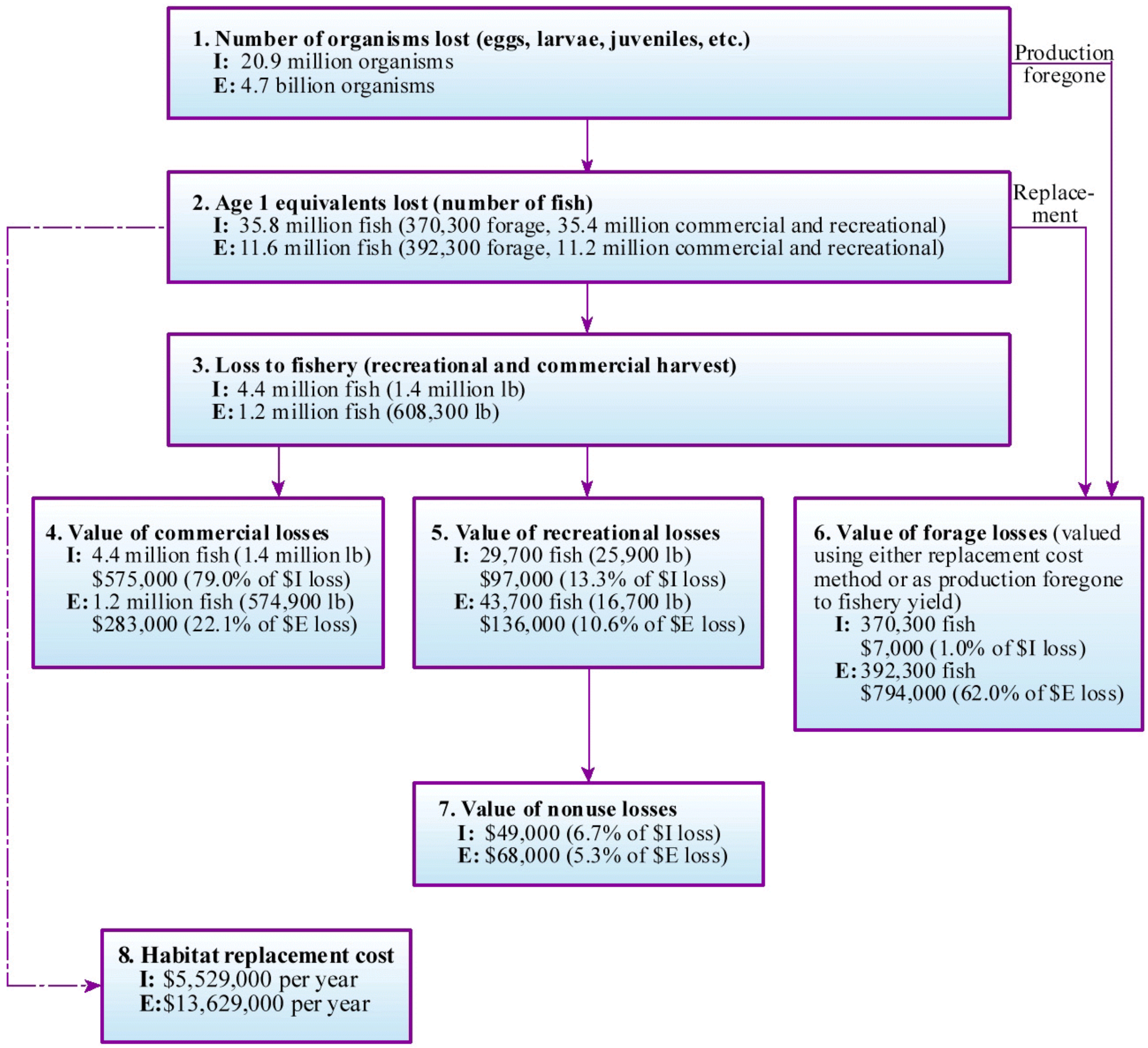
Baseline economic losses due to I&E at Monroe were calculated in Chapters I4 and I5. In Chapter I4, total economic loss was estimated using a benefits transfer approach to estimate the commercial, recreational, forage, and nonuse values of fish lost to I&E. This is a demand-driven approach, i.e., it focuses on the values that people place on fish. In Chapter I5, total economic loss was estimated by calculating the cost to increase fish populations using habitat restoration techniques (HRC approach). This is a supply-driven approach, i.e., it focuses on the costs associated with producing fish in natural habitats.

The total annual economic losses associated with each method are summarized in Table I6-1. These values range from $727,000 to $5,529,000 for impingement, and from $1,281,000 to $13,629,000 for entrainment. The range of economic loss is developed by taking the midpoint of the benefits transfer results and the 90th percentile species results from the HRC approach.

I6-2 Potential Economic Benefits due to Regulations

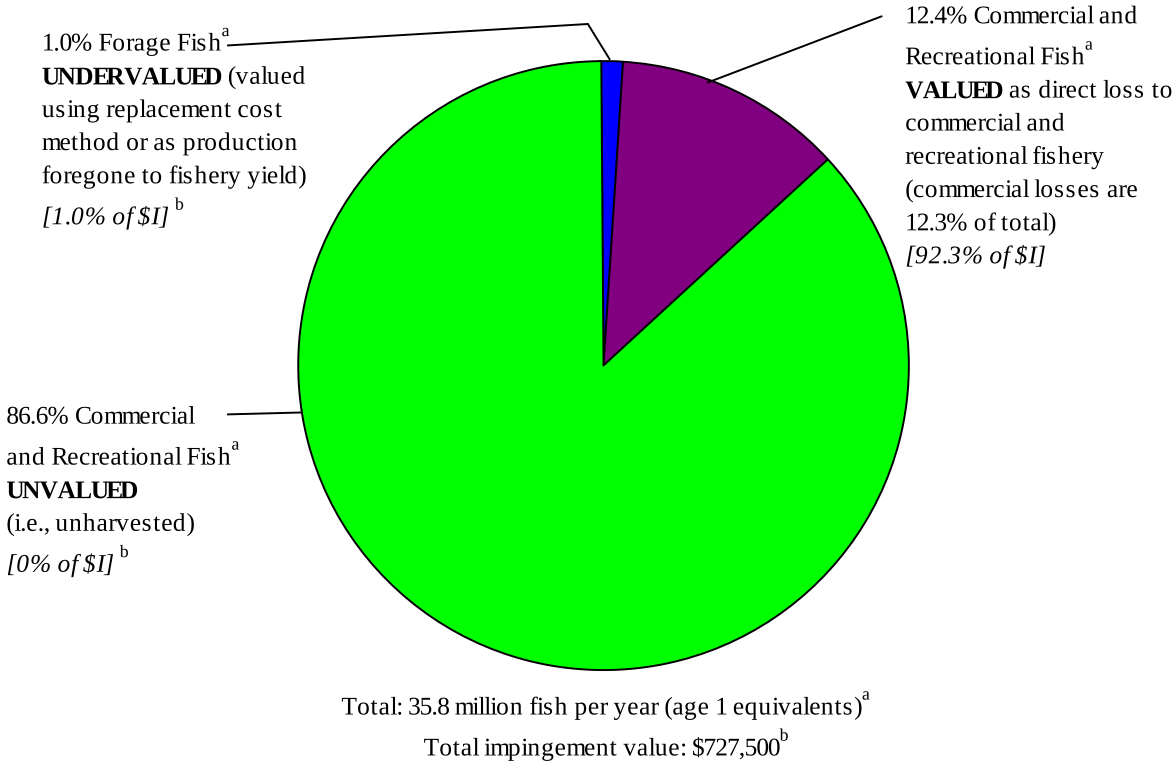
Table I6-2 summarizes the total annual benefits from I&E reductions under scenarios ranging from 10 percent to 90 percent reductions in I&E. Table I6-3 indicates that the benefits are expected to range from $582,000 to $4.4 million for a 80 percent reduction in impingement and from $640,000 to $6.8 million for a 50 percent reduction in entrainment.

Figure I6-1: Overview and Summary of Average Annual I&E and Associated Economic Values for the Monroe Facility (all results are annualized)[a,b]



[a] All dollar values are the midpoint of the range of estimates.
[b] I&E loss estimates are from Tables I4-2, I4-3, I4-9, and I4-10 in Chapter I4.
Note: Species with I&E < 1% of the total I&E were not valued.

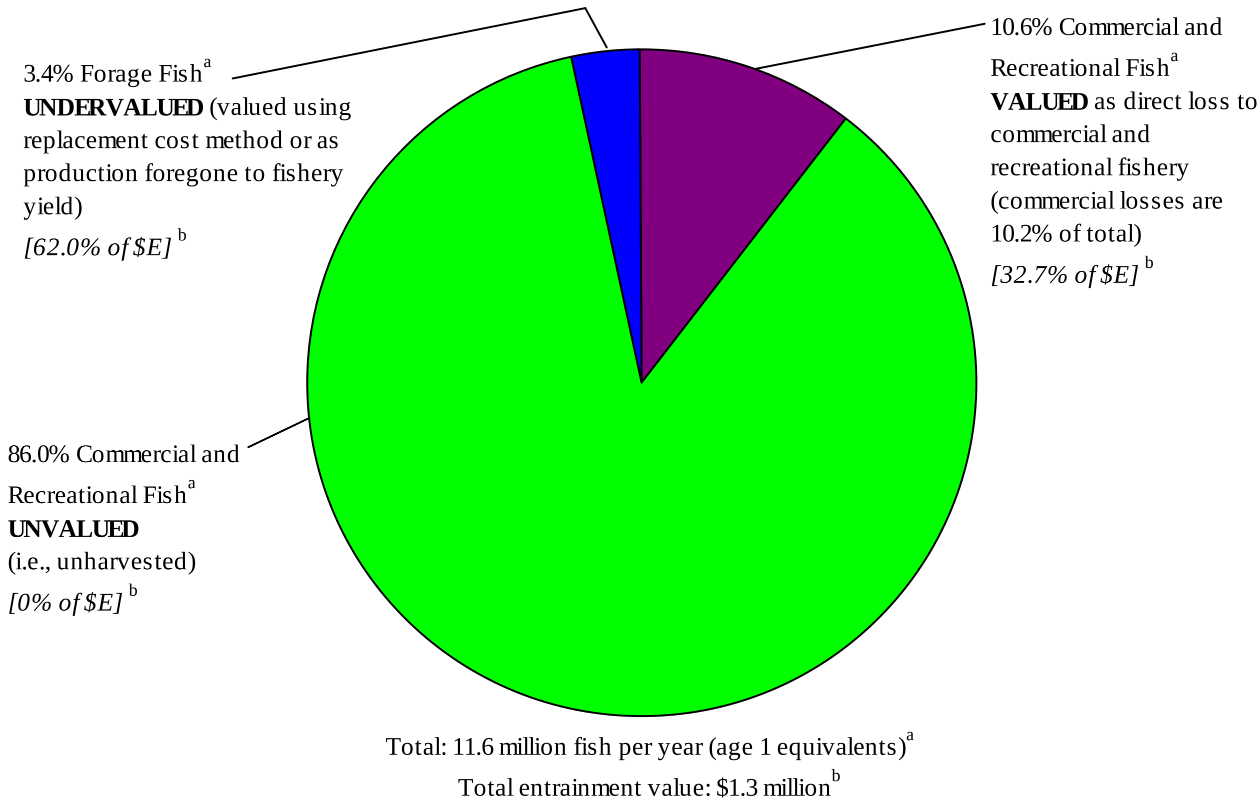
Figure I6-2: Monroe: Distribution of Impingement Losses by Species Category and Associated Economic Values



[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.

[b] Midpoint of estimated range. Nonuse values are 6.7% of total estimated $I loss.

Figure I6-3: Monroe: Distribution of Entrainment Losses by Species Category and Associated Economic Values



[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 5.3% of total estimated $E loss.

Table I6-1: Total Baseline Economic Loss from I&E (2000$, annually)

	Impingement	Entrainment
Benefits transfer approach (demand driven approach from Chapter I4)[a]	$727,000	$1,281,000
Habitat replacement cost approach (supply driven approach from Chapter I5)[b]	$5,529,000	$13,629,000
Range	$0.7 million to $5.5 million	$1.3 million to $13.6 million

[a] Midpoint of Range from Chapter I4.
[b] Based on cost to restore 90th percentile species impacted. Note that the lower bound estimates from the HRC approach reflect restoration of only half the impacted fish species (i.e., the 50th percentile). As such, the low end values for HRC were not considered in establishing the range of losses.

Table I6-2: Summary of Current Economic Losses and Benefits of a Range of Potential I&E Reductions at Monroe Facility ($2000)

		Impingement	Entrainment	Total
Baseline losses	low	$727,000	$1,281,000	$2,008,000
	high	$5,529,000	$13,629,000	$19,158,000
Benefits of 10% reductions	low	$73,000	$128,000	$201,000
	high	$553,000	$1,363,000	$1,916,000
Benefits of 20% reductions	low	$145,000	$256,000	$402,000
	high	$1,106,000	$2,726,000	$3,832,000
Benefits of 30% reductions	low	$218,000	$384,000	$602,000
	high	$1,659,000	$4,089,000	$5,747,000
Benefits of 40% reductions	low	$291,000	$512,000	$803,000
	high	$2,211,000	$5,452,000	$7,663,000
Benefits of 50% reductions	low	$364,000	$640,000	$1,004,000
	high	$2,764,000	$6,815,000	$9,579,000
Benefits of 60% reductions	low	$436,000	$769,000	$1,205,000
	high	$3,317,000	$8,177,000	$11,495,000
Benefits of 70% reductions	low	$509,000	$897,000	$1,406,000
	high	$3,870,000	$9,540,000	$13,410,000
Benefits of 80% reductions	low	$582,000	$1,025,000	$1,607,000
	high	$4,423,000	$10,903,000	$15,326,000
Benefits of 90% reductions	low	$655,000	$1,153,000	$1,807,000
	high	$4,976,000	$12,266,000	$17,242,000

Table I6-3: Summary of Benefits of Potential I&E Reductions at Monroe Facility ($2000)

		Impingement	Entrainment	Total
80% impingement reductions and 50% entrainment reductions	low	$582,000	$640,000	$1,222,000
	high	$4,423,000	$6,815,000	$11,238,000

I6-3 Summary of Omissions, Biases, and Uncertainties in the Benefits Analysis

Table I6-4 presents an overview of omissions, biases, and uncertainties in the benefits estimates. Factors with a negative impact on the benefits estimate bias the analysis downward, and therefore would raise the final estimate if they were properly accounted.

Table I6-4: Omissions, Biases, and Uncertainties in the Benefits Estimates

Issue	Impact on Benefits Estimate	Comments
Long-term fish stock effects not considered	Understates benefits[a]	EPA assumed that the effects on stocks are the same each year, and that the higher fish kills would not have cumulatively greater impact.
Effect of interaction with other environmental stressors	Understates benefits[a]	EPA did not analyze how the yearly reductions in fish may make the stock more vulnerable to other environmental stressors. In addition, as water quality improves over time because of other watershed activities, the number of fish impacted by I&E may increase.
Recreation participation is held constant[a]	Understates benefits[a]	Recreational benefits estimated via benefits transfer reflect only anticipated increase in value per activity outing; increased levels of participation are omitted.
Boating, bird-watching, and other in-stream or near-water activities are omitted[a]	Understates benefits[a]	The only impact to recreation considered is fishing.
Effect of change in stocks on number of landings	Uncertain	EPA assumed a linear stock to harvest relationship, that a 13 percent change in stock would have a 13 percent change in landings; this may be low or high, depending on the condition of the stocks.
Nonuse benefits	Uncertain	EPA assumed that nonuse benefits are 50 percent of recreational angling benefits.
Use of unit values from outside the Great Lakes	Uncertain	The recreational and commercial values used are not all studies from the Great Lakes specifically.
HRC based on capture data assumed to represent age 1 fish	Understates benefits[a]	High percent of less than age 1 fish observed in capture data, thereby leading to potential underestimate of scale of restoration required
HRC monitoring program costs for wetland restoration not consistent with evaluating fish production/abundance	Understates benefits[a]	A monitoring program to determine wetland production (abundance of fish) would be more labor intensive than current monitoring program.

[a] Benefits would be greater than estimated if this factor were considered.

Chapter I7: Conclusions

As summarized in Chapter I3, EPA estimates that impingement at the Monroe facility is 35.8 million age 1 equivalents or 1.4 million pounds of lost fishery yield per year. Entrainment impact amounts to 11.6 million age 1 equivalents or 608,300 pounds of lost fishery yield each year.

The results of EPA's evaluation of the dollar value of I&E at Monroe (as calculated using benefits transfer, in Chapter I4) indicate that baseline economic losses range from $492,400 to $962,500 per year for impingement and from $308,400 to $2,253,400 per year for entrainment (all in $2000).

EPA also developed an HRC analysis to examine the costs of restoring I&E losses at Monroe. The HRC results for impingement ($5.5 million) and entrainment ($13.6 million) were used for upper bounds, and the midpoints from the benefits transfer method were used for lower bounds. Combining these approaches, the value of I&E losses at Monroe range from approximately $0.7 million to $5.5 million per year for impingement and from $1.3 million to $13.6 million per year for entrainment (all in $2000).

EPA also estimated the economic benefit of the proposed rule for the Monroe facility (Chapter I6). The resulting estimates of the economic value of benefits for the proposed rule range from $582,000 to $4.4 million per year for 80 percent impingement reductions, and from $769,000 to $8.2 million per year for 60 percent entrainment reductions (all in $2000).

For a variety of reasons, EPA believes that the estimates developed here underestimate the total economic benefits of reducing I&E at the Monroe facility. EPA assumed that the effects of I&E on fish populations are constant over time (i.e., that fish kills do not have cumulatively greater impacts on diminished fish populations). EPA also did not analyze whether the number of fish affected by I&E would increase as populations increase in response to improved water quality or other improvements in environmental conditions. In the economic analyses, EPA also assumed that fishing is the only recreational activity affected.

Appendix I1: Monroe Life History Parameter Values

The tables in this appendix present the life history parameter values used by EPA to calculate age 1 equivalents, fishery yields, and production foregone from I&E data for the Monroe facility.

Table I1-1: Alewife Parameters

Stage Name	Natural Mortality (per stage)[a]	Fishing Mortality (per stage)[b]	Fraction Vulnerable to Fishery[b]	Weight (lb)
Eggs	11.5	0	0	0.000022[c]
Larvae	5.5	0	0	0.011[c]
Age 1+	0.5	0	0	0.016[a]
Age 2+	0.5	0	0	0.0505[a]
Age 3+	0.5	0	0	0.0764[a]
Age 4+	0.5	0	0	0.0941[a]
Age 5+	0.5	0	0	0.108[a]
Age 6+	0.5	0	0	0.13[a]
Age 7+	0.5	0	0	0.149[a]

[a] Spigarelli et al., 1981.
[b] Not a commercial or recreational species, thus no fishing mortality.
[c] Assumed based on Spigarelli et al. (1981).

Table I1-2: Bluegill Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	1.73[a]	0	0	0.0000000108[g]
Larvae	0.576[a]	0	0	0.00000156[g]
Age 0+	4.62[a]	0	0	0.00795[h]
Age 1+	0.39[b]	0	0	0.00992[h]
Age 2+	0.151[c]	0	0	0.032[h]
Age 3+	0.735[d]	0.735	0.5	0.0594[h]
Age 4+	0.735[d]	0.735	1	0.104[h]
Age 5+	0.735[d]	0.735	1	0.189[h]
Age 6+	0.735[d]	0.735	1	0.193[h]
Age 7+	0.735[d]	0.735	1	0.209[h]
Age 8+	0.735[d]	0.735	1	0.352[h]
Age9+	0.735[d]	0.735	1	0.393[h]

[a] Bartell and Campbell, 2000.
[b] Froese and Pauly, 2001.
[c] Calculated from survival (Carlander, 1977) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[d] Carlander, 1977. Assumed half of total mortality was natural and half was fishing.
[e] Recreational species. Fraction vulnerable assumed.
[f] Weight calculated from length using the formula: (4.33×10^{-6})*Length(mm)$^{3.209}$ = weight(g) (Froese and Pauly, 2001).
[g] Length from Wang (1986a).
[h] Length from Carlander (1977).

Table I1-3: Bullhead Species Parameters				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)[c]**	**Fraction Vulnerable to Fishery[d]**	**Weight (lb)[e]**
Eggs	2.3[a]	0	0	0.000000559[f]
Larvae	4.61[b]	0	0	0.00018[g]
Age 0+	1.39[b]	0	0	0.00132[h]
Age 1+	0.223[c]	0.223	0.5	0.0362[h]
Age 2+	0.223[c]	0.223	1	0.0797[h]
Age 3+	0.223[c]	0.223	1	0.137[h]
Age 4+	0.223[c]	0.223	1	0.233[h]
Age 5+	0.223[c]	0.223	1	0.402[h]
Age 6+	0.223[c]	0.223	1	0.679[h]
Age 7+	0.223[c]	0.223	1	0.753[h]
Age 8+	0.223[c]	0.223	1	0.815[h]
Age9+	0.223[c]	0.223	1	0.823[i]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from survival for channel catfish (Geo-Marine Inc., 1978) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Calculated from survival for brown bullhead (Carlander, 1969) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality). Assumed half of total mortality was natural and half was fishing.
[d] Commercial species. Fraction vulnerable assumed.
[e] Weight calculated from length using the formula for black bullhead: $(8.797\text{x}10^{-6})$*Length(mm)$^{3.06}$ = weight(g) (Froese and Pauly, 2001).
[f] Length for black bullhead from Wang (1986a).
[g] Length assumed based on Wang (1986a) and Carlander (1969).
[h] Length for black bullhead from Carlander (1969).
[i] Length assumed based on Carlander (1969).

Table I1-4: Burbot Parameters				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)[c]**	**Fraction Vulnerable to Fishery[d]**	**Weight (lb)[e]**
Eggs	2.3[a]	0	0	0.0000000120[f]
Larvae	8.05[b]	0	0	0.00000144[f]
Age 1+	0.462[c]	0.1	0.5	0.129[g]
Age 2+	0.462[c]	0.1	1	0.513[g]
Age 3+	0.462[c]	0.1	1	0.842[g]
Age 4+	0.462[c]	0.1	1	1.23[g]
Age 5+	0.462[c]	0.1	1	1.99[g]
Age 6+	0.462[c]	0.1	1	2.68[g]
Age 7+	0.462[c]	0.1	1	2.97[g]
Age 8+	0.462[c]	0.1	1	3.35[g]
Age9+	0.462[c]	0.1	1	3.57[g]
Age 10+	0.462[c]	0.1	1	4.09[g]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Calculated from survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality). Fishing mortality rate assumed based on minimal mortality (Schram et al., 1998).
[d] Commercial and recreational species. Fraction vulnerable assumed.
[e] Weight calculated from length using the formula: $(2.084\text{x}10^{-6})$*Length(mm)$^{3.208}$ = weight(g) (Schram et al., 1998).
[f] Length from Snyder (1998).
[g] Length from Scott and Crossman (1998).

Table I1-5: Carp Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.000000143[f]
Larvae	4.61[b]	0	0	0.0000118[f]
Age 0+	1.39[b]	0	0	0.0225[g]
Age 1+	0.13[c]	0.13	0.5	0.79[g]
Age 2+	0.13[c]	0.13	1	1.21[g]
Age 3+	0.13[c]	0.13	1	1.81[g]
Age 4+	0.13[c]	0.13	1	5.13[g]
Age 5+	0.13[c]	0.13	1	5.52[h]
Age 6+	0.13[c]	0.13	1	5.82[h]
Age 7+	0.13[c]	0.13	1	6.76[g]
Age 8+	0.13[c]	0.13	1	8.17[g]
Age9+	0.13[c]	0.13	1	8.55[h]
Age 10+	0.13[c]	0.13	1	8.94[h]
Age 11+	0.13[c]	0.13	1	9.76[h]
Age 12+	0.13[c]	0.13	1	10.2[h]
Age 13+	0.13[c]	0.13	1	10.6[h]
Age 14+	0.13[c]	0.13	1	11.1[h]
Age 15+	0.13[c]	0.13	1	11.5[h]
Age 16+	0.13[c]	0.13	1	12[h]
Age 17+	0.13[c]	0.13	1	12.5[h]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from survival (Geo-Marine Inc., 1978) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001. Assumed half of total mortality was natural and half was fishing.
[d] Commercial species. Fraction vulnerable assumed.
[e] Weight calculated from length using the formula: $(1.095 \times 10^{-5})*\text{Length(mm)}^{3.025} = \text{weight(g)}$ (Froese and Pauly, 2001).
[f] Length from Wang (1986a).
[g] Length from Carlander (1969).
[h] Length assumed based on Carlander (1969).

Table I1-6: Channel Catfish Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.000000408[f]
Larvae	4.61[b]	0	0	0.0000191[f]
Age 0+	1.39[b]	0	0	0.00987[g]
Age 1+	0.41[c]	0.41	0.5	0.0554[g]
Age 2+	0.41[c]	0.41	1	0.189[g]
Age 3+	0.41[c]	0.41	1	0.436[g]
Age 4+	0.41[c]	0.41	1	0.71[g]
Age 5+	0.41[c]	0.41	1	1.22[g]
Age 6+	0.41[c]	0.41	1	1.55[g]
Age 7+	0.41[c]	0.41	1	2.27[g]
Age 8+	0.41[c]	0.41	1	2.66[g]
Age 9+	0.41[c]	0.41	1	3.41[g]
Age 10+	0.41[c]	0.41	1	5.59[g]
Age 11+	0.41[c]	0.41	1	5.81[h]
Age 12+	0.41[c]	0.41	1	5.92[g]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from survival (Geo-Marine Inc., 1978) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Calculated from survival (Geo-Marine Inc., 1978) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality). Assumed half of total mortality was natural and half was fishing.
[d] Commercial and recreational species. Fraction vulnerable assumed.
[e] Weight calculated from length using the formula: (2.945×10^{-6})*Length(mm)$^{3.133}$ = weight(g) (Froese and Pauly, 2001).
[f] Length from Wang (1986a).
[g] Length from Carlander (1969).
[h] Length assumed based on Carlander (1969).

Table I1-7: Crappie Parameters

Stage Name	Natural Mortality (per stage)[a]	Fishing Mortality (per stage)[b]	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	1.8[a]	0	0	0.0000000179[e]
Larvae	0.498[a]	0	0	0.00000857[e]
Age 0+	2.93[a]	0	0	0.012[f]
Age 1+	0.292[b]	0.292	0.5	0.128[f]
Age 2+	0.292[b]	0.292	1	0.193[f]
Age 3+	0.292[b]	0.292	1	0.427[f]
Age 4+	0.292[b]	0.292	1	0.651[f]
Age 5+	0.292[b]	0.292	1	0.888[f]
Age 6+	0.292[b]	0.292	1	0.925[f]
Age 7+	0.292[b]	0.292	1	0.972[f]
Age 8+	0.292[b]	0.292	1	1.08[f]
Age9+	0.292[b]	0.292	1	1.26[f]

[a] Bartell and Campbell, 2000. Black crappie.
[b] Bartell and Campbell, 2000. Black crappie. Assumed half of total mortality was natural and half was fishing.
[c] Recreational species. Fraction vulnerable assumed.
[d] Weight calculated from length using the formula for black crappie: (1.014×10^{-5})*Length(mm)$^{3.066}$ = weight(g) (Froese and Pauly, 2001).
[e] Length for black crappie from Wang (1986a).
[f] Length for black crappie from Carlander (1977).

Table I1-8: Freshwater Drum Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[b]	Fraction Vulnerable to Fishery[c]	Weight (lb)
Eggs	2.27[a]	0	0	0.0000011[d]
Larvae	6.13[a]	0	0	0.00000295[a]
Age 0+	1.15[a]	1.15	0.5	0.0166[a]
Age 1+	0.155[b]	0.155	1	0.05[e]
Age 2+	0.155[b]	0.155	1	0.206[e]
Age 3+	0.155[b]	0.155	1	0.438[e]
Age 4+	0.155[b]	0.155	1	0.638[e]
Age 5+	0.155[b]	0.155	1	0.794[e]
Age 6+	0.155[b]	0.155	1	0.95[e]
Age 7+	0.155[b]	0.155	1	1.09[e]
Age 8+	0.155[b]	0.155	1	1.26[e]
Age9+	0.155[b]	0.155	1	1.44[e]
Age 10+	0.155[b]	0.155	1	1.6[e]
Age 11+	0.155[b]	0.155	1	1.78[e]
Age 12+	0.155[b]	0.155	1	2[e]

[a] Bartell and Campbell, 2000.
[b] Froese and Pauly, 2001. Assumed half of total mortality was natural and half was fishing.
[c] Commercial species. Fraction vulnerable assumed.
[d] Assumed based on Bartell and Campbell (2000).
[e] Scott and Crossman, 1973.

Table I1-9: Gizzard Shad Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)
Eggs	2.3[a]	0	0	0.0000022[e]
Larvae	6.33[b]	0	0	0.00000663[b]
Age 0+	0.511[b]	0	0	0.0107[b]
Age 1+	1.45[c]	1.45	0.5	0.141[b]
Age 2+	1.27[c]	1.27	1	0.477[b]
Age 3+	0.966[c]	0.966	1	0.64[b]
Age 4+	0.873[c]	0.873	1	0.885[b]
Age 5+	0.303[c]	0.303	1	1.17[b]
Age 6+	0.303[c]	0.303	1	1.54[b]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Wapora, 1979.
[c] Wapora, 1979. Assumed half of total mortality was natural and half was fishing.
[d] Commercial species. Fraction vulnerable assumed.
[e] Assumed based on Wapora (1979).

Table I1-10: Logperch Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	3.09E-09[f]
Larvae	1.9[b]	0	0	0.000276[g]
Age 0+	1.9[b]	0	0	0.00345[f]
Age 1+	0.7[c]	0	0	0.0128[f]
Age 2+	0.7[c]	0	0	0.0274[f]
Age 3+	0.7[c]	0	0	0.0443[f]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] Not a commercial or recreational species, thus no fishing mortality.
[e] Weight calculated from length using the formula: $(5.240x10^{-7})$*Length(mm)$^{6.641}$ = weight(g) (Carlander, 1997).
[f] Length from Carlander (1997).
[g] Length assumed based on Carlander (1997).

Table I1-11: Muskellunge Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)[f]
Eggs	1.08[a]	0	0	0.000000205[g]
Larvae	5.49[b]	0	0	0.0133[h]
Age 0+	5.49[b]	0	0	0.0451[g]
Age 1+	0.15[c]	0	0	0.365[g]
Age 2+	0.15[c]	0	0	1.1[g]
Age 3+	0.15[c]	0	0	1.53[g]
Age 4+	0.15[c]	0	0	2.72[g]
Age 5+	0.15[c]	0	0	6.19[g]
Age 6+	0.15[c]	0	0	7.02[g]
Age 7+	0.15[c]	0	0	8.92[g]
Age 8+	0.15[c]	0	0	12.3[g]
Age9+	0.15[c]	0	0	13.9[g]
Age 10+	0.075[d]	0.075	0.5	16.6[g]
Age 11+	0.075[d]	0.075	1	19[g]
Age 12+	0.075[d]	0.075	1	24.2[g]
Age 13+	0.075[d]	0.075	1	25.3[g]
Age 14+	0.075[d]	0.075	1	30[g]
Age 15+	0.075[d]	0.075	1	32.4[g]
Age 16+	0.075[d]	0.075	1	34.3[g]
Age 17+	0.075[d]	0.075	1	45.6[g]
Age 18+	0.075[d]	0.075	1	45.8[h]
Age 19+	0.075[d]	0.075	1	47.7[g]
Age 20+	0.075[d]	0.075	1	48.8[h]
Age 21+	0.075[d]	0.075	1	48.9[h]
Age 22+	0.075[d]	0.075	1	49[h]
Age 23+	0.075[d]	0.075	1	49.1[h]
Age 24+	0.075[d]	0.075	1	49.2[h]
Age 25+	0.075[d]	0.075	1	49.3[h]
Age 26+	0.075[d]	0.075	1	49.4[h]
Age 27+	0.075[d]	0.075	1	49.4[h]

[a] Calculated from survival (Carlander, 1997) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] Froese and Pauly, 2001. Assumed half of total mortality was natural and half was fishing.
[e] Recreational species. Fraction vulnerable assumed based on Pennsylvania (1999).
[f] Weight calculated from length using the formula: $(5.590 \times 10^{-6}) * \text{Length(mm)}^{3.016} = \text{weight(g)}$ (Froese and Pauly, 2001).
[g] Length from Carlander (1969).
[h] Length assumed based on Carlander (1969).

Table I1-12: Shiner Species Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[c]	Weight (lb)[d]
Eggs	2.3[a]	0	0	0.000000252[e]
Larvae	4.61[b]	0	0	0.0016[e]
Age 0+	0.776[b]	0	0	0.0135[f]
Age 1+	0.371[b]	0	0	0.026[f]
Age 2+	4.61[b]	0	0	0.0478[f]
Age 3+	4.61[b]	0	0	0.106[f]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] (Wapora, 1979). Emerald shiner.
[c] Not a commercial or recreational species, thus no fishing mortality.
[d] Weight calculated from length using the formula for emerald shiner: (1.144×10^{-4})*Length(mm)$^{2.922}$ = weight(g) (Fuchs, 1967).
[e] Length assumed based on (Trautman, 1981).
[f] Length from (Trautman, 1981).

Table I1-13: Smallmouth Bass Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	1.9[a]	0	0	0.000000331[f]
Larvae	2.7[b]	0	0	0.0000198[f]
Age 0+	0.446[a]	0	0	0.0169[g]
Age 1+	0.86[c]	0.23	0.5	0.202[g]
Age 2+	1.17[c]	0.322	1	0.518[g]
Age 3+	0.755[c]	0.208	1	0.733[g]
Age 4+	1.05[c]	0.288	1	1.04[g]
Age 5+	0.867[c]	0.238	1	1.44[g]
Age 6+	0.867[c]	0.238	1	2.24[g]
Age 7+	0.867[c]	0.238	1	2.56[h]
Age 8+	0.867[c]	0.238	1	2.92[h]
Age9+	0.867[c]	0.238	1	3.3[g]

[a] Calculated from survival (Carlander, 1977) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Bartell and Campbell, 2000.
[c] Carlander, 1977.
[d] Recreational species. Fraction vulnerable assumed.
[e] Weight calculated from length using the formula: (2.494×10^{-5})*Length(mm)$^{2.917}$ = weight(g) (Froese and Pauly, 2001).
[f] Length from Wang (1986a).
[g] Length from Carlander (1977).
[h] Length assumed based on Carlander (1977).

Table I1-14: Smelt Parameters				
Stage Name	**Natural Mortality (per stage)[a]**	**Fishing Mortality (per stage)[a]**	**Fraction Vulnerable to Fishery[b]**	**Weight (lb)[c]**
Eggs	11.5	0	0	0.0000000115[d]
Larvae	5.5	0	0	0.00000233[d]
Age 1+	0.4	0.03	0.5	0.0195[e]
Age 2+	0.4	0.03	1	0.041[f]
Age 3+	0.4	0.03	1	0.177[f]
Age 4+	0.4	0.03	1	0.338[g]
Age 5+	0.4	0.03	1	0.537[g]
Age 6+	0.4	0.03	1	0.597[g]

[a] Spigarelli et al., 1981.
[b] Commercial and recreational species. Fraction vulnerable assumed.
[c] Weight calculated from length using the formula for rainbow smelt: $(5.23 \times 10^{-6})*\text{Length(mm)}^{3.114} = \text{weight(g)}$ (Froese and Pauly, 2001).
[d] Length for rainbow smelt from Able and Fahay (1998).
[e] Length assumed based on Able and Fahay (1998) and Scott and Scott (1988).
[f] Length for rainbow smelt from Scott and Scott (1988).
[g] Length assumed based on Scott and Scott (1988).

Table I1-15: Sucker Parameters				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)[b]**	**Fraction Vulnerable to Fishery[c]**	**Weight (lb)[d]**
Eggs	2.05[a]	0	0	0.0000000135[e]
Larvae	2.56[a]	0	0	0.00000198[e]
Age 0+	2.3[a]	0	0	0.000145[f]
Age 1+	0.274[b]	0.274	0.5	0.0447[f]
Age 2+	0.274[b]	0.274	1	0.249[f]
Age 3+	0.274[b]	0.274	1	0.305[f]
Age 4+	0.274[b]	0.274	1	0.609[f]
Age 5+	0.274[b]	0.274	1	0.823[f]
Age 6+	0.274[b]	0.274	1	0.929[f]

[a] Bartell and Campbell, 2000.
[b] Bartell and Campbell, 2000. Assumed half of total mortality was natural and half was fishing.
[c] Commercial species. Fraction vulnerable assumed.
[d] Weight calculated from length using the formula for river carpsucker: $(6.130 \times 10^{-6})*\text{Length(mm)}^{3.099} = \text{weight(g)}$ (Froese and Pauly, 2001).
[e] Length assumed based on Carlander (1969).
[f] Length from Carlander (1969).

Table I1-16: Sunfish Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	1.71[a]	0	0	0.00000000736[f]
Larvae	0.687[b]	0	0	0.000000994[f]
Age 0+	0.687[b]	0	0	0.000878[g]
Age 1+	1.61[a]	0	0	0.00666[g]
Age 2+	1.61[a]	0	0	0.0271[g]
Age 3+	1.5[c]	1.5	0.5	0.0593[g]
Age 4+	1.5[c]	1.5	1	0.0754[g]
Age 5+	1.5[c]	1.5	1	0.142[g]
Age 6+	1.5[c]	1.5	1	0.18[g]
Age 7+	1.5[c]	1.5	1	0.214[g]
Age 8+	1.5[c]	1.5	1	0.232[g]

[a] Calculated from survival for pumpkinseed (Carlander, 1977) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from extrapolated survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Calculated from survival for pumpkinseed (Carlander, 1977) using the using the equation: (natural mor0tality) = -LN(survival) - (fishing mortality). Assumed half of total mortality was natural and half was fishing.
[d] Recreational species. Fraction vulnerable assumed.
[e] Weight calculated from length using the formula for pumpkinseed: $(3.337\text{x}10^{-6})*\text{Length(mm)}^{3.262}$ = weight(g) (Froese and Pauly, 2001).
[f] Length for pumpkinseed from Bartell and Campbell (2000).
[g] Length for pumpkinseed from Carlander (1977).

Table I1-17: Walleye Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	1.05[a]	0	0	0.00000000506[f]
Larvae	3.55[b]	0	0	0.0000768[g]
Age 0+	1.93[b]	0	0	0.03[g]
Age 1+	0.7[c]	0.1	0.5	0.328[g]
Age 2+	0.7[c]	0.1	1	0.907[g]
Age 3+	0.7[c]	0.1	1	1.77[g]
Age 4+	0.7[c]	0.1	1	2.35[g]
Age 5+	0.7[c]	0.1	1	3.37[g]
Age 6+	0.7[c]	0.1	1	3.97[g]
Age 7+	0.7[c]	0.1	1	4.66[g]
Age 8+	0.7[c]	0.1	1	5.58[f]
Age 9+	0.7[c]	0.1	1	5.75[g]

[a] Calculated from survival (Carlander, 1997) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Bartell and Campbell, 2000.
[c] Thomas and Haas, 2000.
[d] Recreational species. Fraction vulnerable assumed.
[e] Weight calculated from length using the formula: $(2.297\text{x}10^{-6})*\text{Length(mm)}^{3.23}$ = weight(g) (Froese and Pauly, 2001).
[f] Length assumed based on Carlander (1997).
[g] Length from Carlander (1997).

Table I1-18: White Bass Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[d]	Fraction Vulnerable to Fishery[e]	Weight (lb)
Eggs	2.3[a]	0	0	0.0000000266[f]
Larvae	4.61[b]	0	0	0.00000174[f]
Age 0+	1.39[b]	0	0	0.174[g]
Age 1+	0.42[c]	0.7	0	0.467[g]
Age 2+	0.42[c]	0.7	0.5	0.644[g]
Age 3+	0.42[c]	0.7	1	1.02[g]
Age 4+	0.42[c]	0.7	1	1.16[g]
Age 5+	0.42[c]	0.7	1	1.26[g]
Age 6+	0.42[c]	0.7	1	1.66[g]
Age 7+	0.42[c]	0.7	1	1.68[h]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Calculated from survival (Geo-Marine Inc., 1978) using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[c] Froese and Pauly, 2001.
[d] McDermot and Rose, 2000.
[e] Commercial and recreational species. Fraction vulnerable assumed.
[f] Weight calculated from assumed length based on (Carlander, 1997) using the formula: $(1.206 \times 10^{-5})*$ Length(mm)$^{3.132}$ = weight(g) (Van Oosten, 1942).
[g] Carlander, 1997.
[h] Assumed based on Carlander (1997).

Table I1-19: Whitefish Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)[e]
Eggs	2.3[a]	0	0	0.000000252[f]
Larvae	8.2[b]	0	0	0.000171[g]
Juvenile	0.25[c]	0	0	0.0117[g]
Age 1+	0.25[c]	0.997	0.5	0.705[f]
Age 2+	0.25[c]	0.997	1	1.27[f]
Age 3+	0.25[c]	0.997	1	2.32[f]
Age 4+	0.25[c]	0.997	1	2.85[f]
Age 5+	0.25[c]	0.997	1	3.52[f]
Age 6+	0.25[c]	0.997	1	4.09[f]
Age 7+	0.25[c]	0.997	1	4.76[f]
Age 8+	0.25[c]	0.997	1	5.7[f]
Age 9+	0.25[c]	0.997	1	5.73[h]
Age 10+	0.25[c]	0.997	1	5.85[f]
Age 11+	0.25[c]	0.997	1	6.1[f]
Age 12+	0.25[c]	0.997	1	6.83[f]
Age 13+	0.25[c]	0.997	1	7.11[f]
Age 14+	0.25[c]	0.997	1	7.29[f]
Age 15+	0.25[c]	0.997	1	7.32[h]
Age 16+	0.25[c]	0.997	1	8.66[f]

[a] Calculated from assumed survival using the using the equation: (natural mortality) = -LN(survival) - (fishing mortality).
[b] Froese and Pauly, 2001.
[c] Schorfhaar and Schneeberger, 1997.
[d] Commercial and recreational species. Fraction vulnerable assumed.
[e] Weight calculated from length using the formula for lake whitefish: $(4.721\times10^{-6})*\text{Length(mm)}^{3.152} = \text{weight(g)}$ (Froese and Pauly, 2001).
[f] Length from Scott and Crossman (1998).
[g] Length from Fish (1932).
[h] Length assumed based on Scott and Crossman (1998).

Table I1-20: Yellow Perch Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)[c]	Fraction Vulnerable to Fishery[d]	Weight (lb)
Eggs	2.75[a]	0	0	0.0000022[e]
Larvae	3.56[b]	0	0	0.00000384[b]
Age 0+	2.53[b]	0	0	0.0232[b]
Age 1+	0.361[b]	0	0	0.0245[b]
Age 2+	0.248[b]	0	0	0.0435[b]
Age 3+	0.844[b]	0.36	0.5	0.0987[b]
Age 4+	0.844[b]	0.36	1	0.132[b]
Age 5+	0.844[b]	0.36	1	0.166[b]
Age 6+	0.844[b]	0.36	1	0.214[b]

[a] PSEG, 1999c.
[b] Wapora, 1979.
[c] Thomas and Haas, 2000.
[d] Recreational species. Fraction vulnerable assumed.
[e] Assumed based on Wapora (1979).