Ohio Sea Grant

FISHERIES AND THE DESIGN OF ELECTRIC POWER PLANTS: THE LAKE ERIE EXPERIENCE

Jeffrey M. Reutter, Ph.D.
Charles E. Herdendorf, Ph.D.
Center for Lake Erie Area Research
The Ohio State University

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FISHERIES AND THE DESIGN OF ELECTRIC POWER PLANTS:

THE LAKE ERIE EXPERIENCE

ABSTRACT

Estimates of annual fish impingement and entrainment at three power plants on the south shore of the Western Basin of Lake Erie have been performed by Ohio State University's Center for Lake Erie Area Research. The Davis-Besse Nuclear Power Plant produces almost 50% more power than the Acme and Bay Shore Power Plants combined, but it impinges less than 0.1% of the fish and entrains less than 1% of the ichthyoplankton the older fossil-fuel plants do. All three plants are in unfavorable locations, as they are situated in areas of high fish densities. However, Davis-Besse has a closed cycle cooling system, off-shore intake, bottom intake, and closed intake canal. All these components appear to contribute to low levels of entrainment and impingement at this facility.

1. INTRODUCTION

Lake Erie is the smallest of the Laurentian Great Lakes, but with the major urban centers of Detroit, Toledo, Cleveland, Erie and Buffalo dotting its shoreline, more people live around it and utilize its water than any of the others. To service this large population, Lake Erie is surrounded by 18 power plants, 14 of which operate with once-through cooling systems without cooling towers, and many municipal water intakes. These power plants utilize large quantities of water for cooling purposes. The Monroe, Michigan Power Plant, the largest, uses over 1,300,000 gpm, and the eight plants servicing the Cleveland area require over 6,000,000 gpm (1). The Lake Erie Basin is also a center of industry with over 450 industrial intakes and discharges in the fifteen counties of northeastern Ohio (1).

Lake Erie is also the most biologically productive of the Great Lakes, producing more fish for human consumption each year than are produced from the other four Great Lakes combined. The resurgence of the walleye (Stizostedion v. vitreum) population since 1975 has prompted a 6-fold increase in the charter fishing fleet with approximately 800,000 Ohio anglers fishing Lake Erie and creating a multimillion dollar recreational industry.

This multiplicity of demands upon the resources of the lake is expected to increase by the year 2000 when water shortages are projected for many regions of the country. It is imperative that adverse environmental impacts from the many intakes and discharges be minimized. At the same time, the continued growth of the area is largely dependent upon a good supply of low-cost power. Therefore, regulations pertaining to the design and siting of water intakes and discharges must be supported with information showing their value and effectiveness. This paper will show the value of cooling water intake and discharge design and siting criteria on Lake Erie, by evaluating entrainment and impingement at three power plants with different intake and cooling system designs located in the Western Basin of the lake. The plants are operated by the Toledo Edison Company. Acme and Bay Shore are coal-fired with once-through cooling systems and intakes on the estuarine portion of the Maumee River (Fig. 1). Davis-Besse is a new nuclear plant with a closed cooling system located on the southwest shore of the lake at Locust Point (Table 1). All data from these plants were collected by The Ohio State University's Center for Lake Erie Area Research.

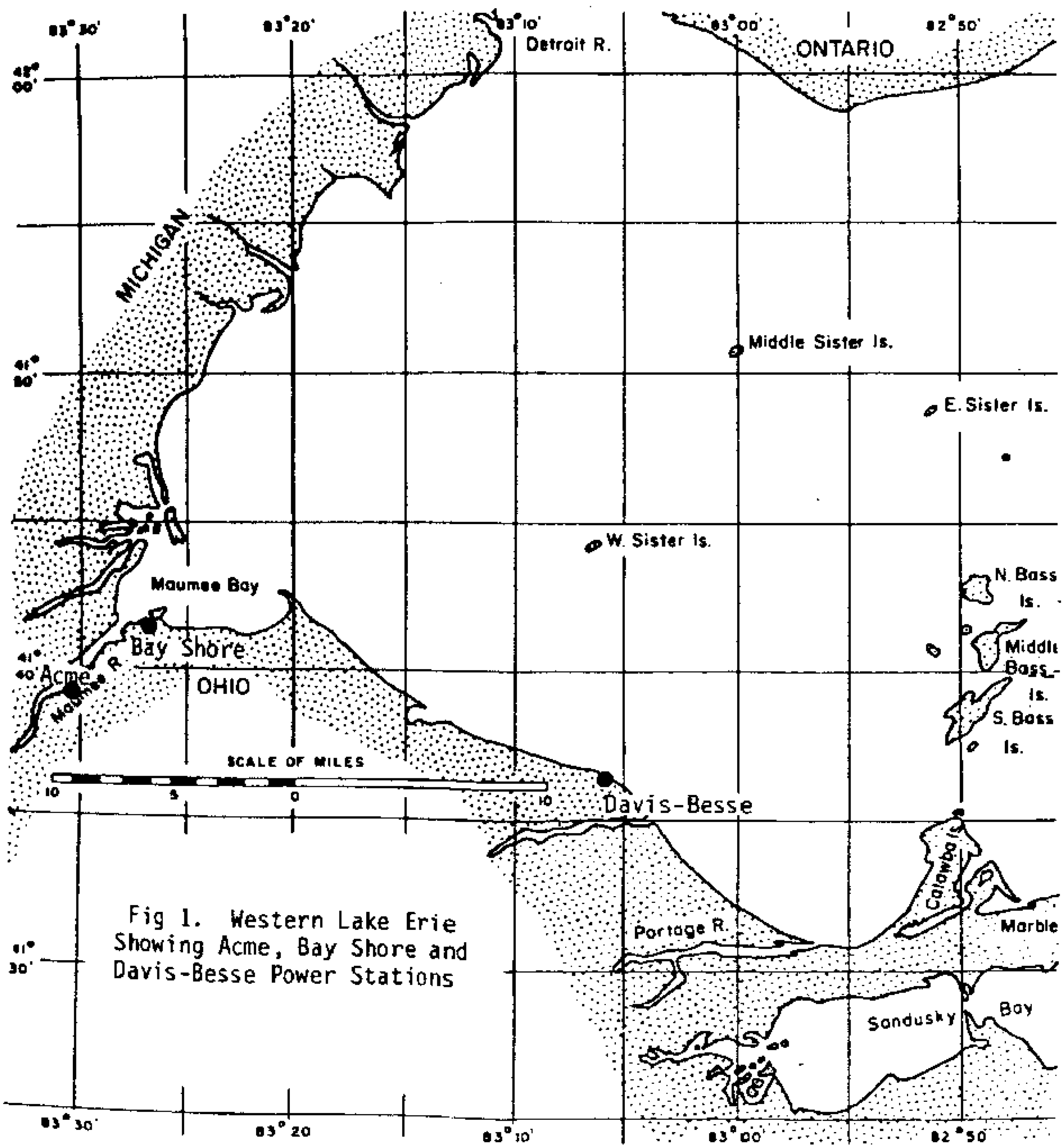

Fig 1. Western Lake Erie Showing Acme, Bay Shore and Davis-Besse Power Stations

TABLE 1. Operating Characteristics of the Power Stations.

PLANT	TYPE	COOLING SYSTEM	PUMPING RATE (GPM)		POWER PRODUCTION (MWe/hr)	
			MAX	MEAN	MAX RATING	MEAN
Acme	Fossil-fuel	Once-through	272,000	172,000	322	104*
Bay Shore	Fossil-fuel	Once-through	518,000	453,000	660	511*
Davis-Besse (Unit I)	Nuclear	Recycled, cooling tower	42,000	21,000	906	872**

*Mean for period 1971-1975

**Projected mean after plant is fully operational

2. PLANT DESCRIPTIONS

2.1. Acme Power Plant

The Acme Power Plant is located in the city of Toledo, Ohio at approximately 41°39'00" N latitude and 83°31'00" W longitude, 3.7 miles upstream from the mouth of the Maumee River (Fig. 1). This plant has five steam electric units with a total rated capacity of 322 megawatts (MW_e). At maximum capacity, 322 MW_e, the plant utilizes cooling water at a rate of 272,000 gpm with an associated heat rise of 15.3°F above ambient. However, this is a peaking plant where the normal load is less than 50 MW_e 40% of the time, less than 100 MW_e 61% of the time, and more than 250 MW_e only 1% of the time. From 1971-1975, the average output was 104.3 MW_e, with a mean temperature rise across the condensers of 9.4°F.

Cooling water for this plant is obtained from the Maumee River. Cooling water enters through a 270-foot inlet canal, traverses the condensers, and is discharged back to the Maumee River through a 760-foot discharge canal to a point approximately 657 feet downriver of the intake. Cooling water traverses a trash rack and one of 6 banks of traveling screens (¼-inch bar mesh) before entering the condensers. Material collected on the traveling screens is washed into a sluiceway and transported to the discharge canal.

2.2. Bay Shore Power Plant

The Bay Shore Power Plant is located on the southern shore of Maumee Bay at approximately 41°41'00" N latitude and 83°26'00" W longitude, near the mouth of the Maumee River (Fig. 1). This is a base load plant with a net summer capacity of 623 megawatts (MW_e) and net winter capacity of 636 MW_e provided by four coal-fired, steam electric units. At a net capacity of 623 MW_e, this plant utilizes 518,000 gpm of water for once-through cooling at a calculated temperature rise of 9.6°F above ambient. Cooling water for the Bay Shore Power Plant is obtained from the Maumee River and after traversing the condensers, is discharged to Maumee Bay. Cooling water enters through a 3,000-foot inlet canal and discharges through a short canal.

The 3,000-foot long intake canal is 250 feet wide and varies in depth from 15 to 20 feet, depending on silt accumulation and dredging frequency. The cooling water traverses a trash rack and one of nine 1/4 or 3/8-inch mesh traveling screens before entering the condenser. Material collected on the traveling screens is washed into a sluiceway and transported to the discharge canal.

2.3. Davis-Besse Nuclear Power Plant

The Davis-Besse Nuclear Power Station is located in Ottawa County, Ohio, at Locust Point on the southwest shore of Lake Erie, about 21 miles east of Toledo. Unit 1 has a net electrical capacity of 906 MW_e and a closed cycle cooling system which dissipates heat to the atmosphere by means of a natural-draft cooling tower, 493 feet high and 415 feet in diameter at its base. Make-up water for cooling purposes is drawn from Lake Erie from a submerged intake crib 3,000 feet offshore through a buried eight-foot diameter conduit to a closed, but uncovered, intake canal (Fig. 2). The canal is approximately 2,950 feet long and terminates at the trash racks of the intake structure. Water is drawn through the intake crib and conduit by gravity. Design capacity for Unit 1 is 42,000 gpm with a resultant approach velocity through the crib ports of 0.25 ft/sec. Cooling tower blowdown is discharged at a point approximately 1,200 feet offshore through a six-foot diameter buried conduit which terminates in a high velocity nozzle to promote rapid mixing. The maximum allowable ΔT is 20^oF.

3. METHODS

3.1. Impingement

Acme and Bay Shore. Impinged fish were collected during a 24-hour period once every seven days from September 15, 1976 (September 1, 1976 for Acme) to March 16, 1977 and from June 16 to September 15, 1977, and once every four days from March 16 to June 16, 1977. Each 24-hour collection was divided into a 12-hour "night" and a 12-hour "day" collection. Fish were collected by placing a basket (1/4 inch bar mesh) in the sluiceway leading from the traveling screens. This basket was monitored and emptied when full. The percentage of time that the basket was out (being emptied) while the screens were running was recorded. Estimates of the total number of fish impinged were adjusted accordingly. The fish so collected during each 12-hour sampling period were sorted by species and then into size classes or "strata" within each species. This was done to reduce the coefficient of variation of the weights of each species or size class of fish. Based on the coefficient of variation within each size class, the number of fish which had to be weighed and measured (standard length) individually to estimate the mean weight of the fish within that size class to within 10% of the true mean (95% confidence) was determined. The total weight of all fish impinged was determined by actual field measurement. The total weight of each species or size class divided by the mean weight provided the estimate of the number of fish within that species.

This method provided a good estimate of fish impingement on sampling days. These results were converted to a concentration (number of fish/100 cubic meters of cooling water) to estimate impingement on non-sampling days. The mean of the daily concentrations before and after a non-sampling day was multiplied by the flow through the plant on the non-sampling day to estimate impingement on that day.

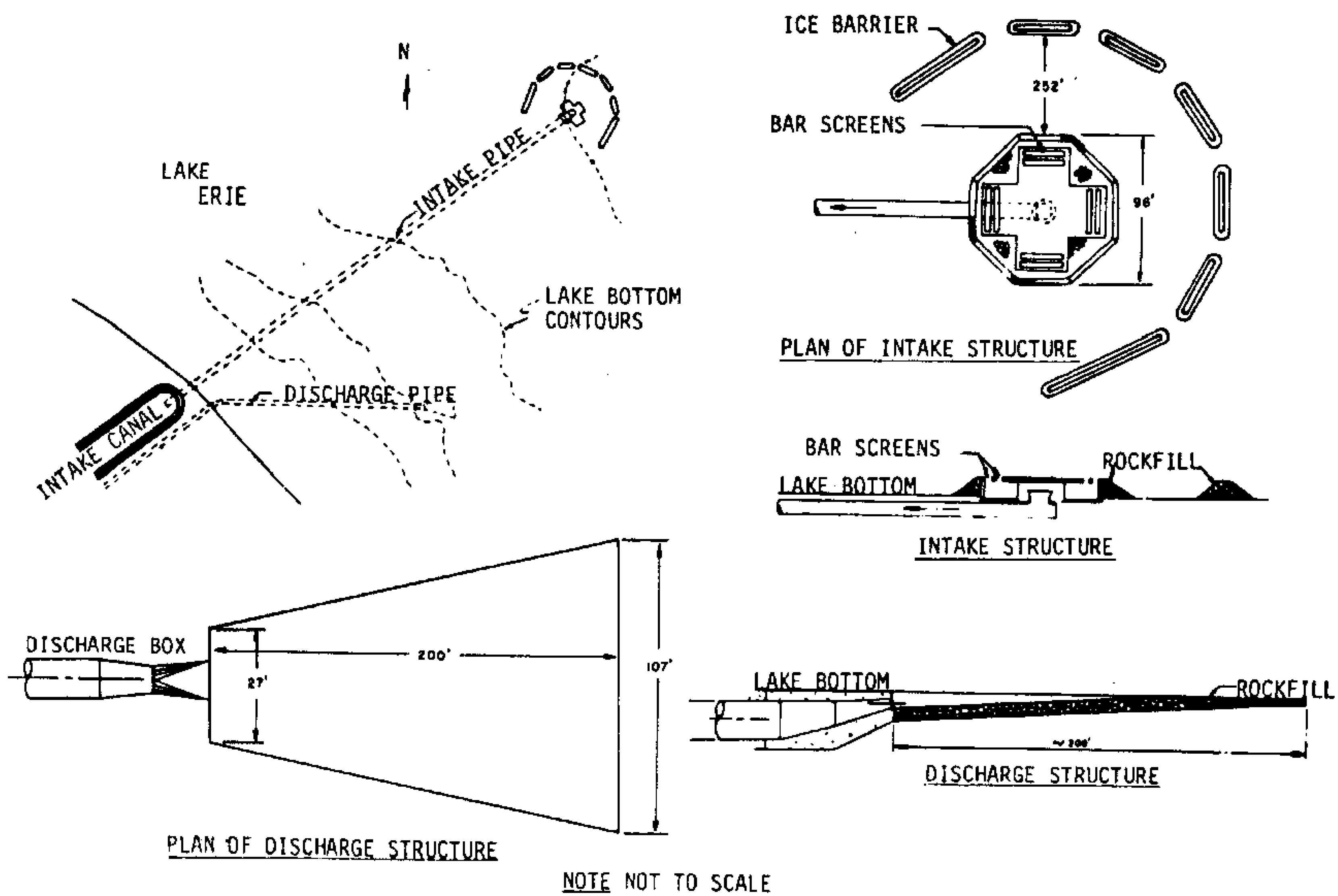

Fig. 2. Intake and Discharge Configuration at the Davis-Besse Nuclear Power Plant.

Davis-Besse. Between January 1 and December 31, 1978 the traveling screens at the Davis-Besse Nuclear Power Station were operated 221 times, while between January 1 and December 31, 1979 the screens were operated 272 times. The date, time, and duration of each screen operation were recorded, even when the impinged fish were not collected. Collections of impinged fish were made on 144 of the 221 screen operations during 1978 and on 134 of the 272 screen operations in 1979 by placing a screen having the same mesh size as the traveling screens (¼-inch bar mesh) in the sluiceway through which the backwashed material passed. In addition to the information pertinent to traveling screen operation, the total number and total weight of each species and the length and weight of each individual fish were also recorded.

Since the time and duration of every screen operation was known, it was possible to determine the number of hours represented by each collection. From this a rate, fish impinged/hour, was developed and used to estimate impingement on days when samples were not collected.

3.2. Entrainment

Acme and Bay Shore. Two submersible pumps (Kenco model no. 139) were placed in the intake canal in front of the trash racks (one meter below the surface and one meter above the bottom) and operated continuously for a 24-hour period once every seven days from September 1 to September 15, 1976 and June 16 to September 1, 1977 and once every four days from March 16 to June 16, 1977. Each 24-hour period was divided into a 12-hour "night" and a 12-hour "day" collection. The effluent from each pump emptied into a plankton net (50 cm diameter, 0.571 mm mesh) to capture ichthyoplankton. Larvae were identified and categorized by developmental stage (pro-larva, early post-larva, and late post-larva). The ichthyoplankton concentration per unit volume of water was determined by dividing the number of each species and each developmental stage in each collection by the volume of water pumped through the net during that 12-hour collection. The flow rate of each pump was recalculated on each sampling day. The mean of surface and bottom ichthyoplankton concentrations from each period was multiplied by the total flow through the plant during that 12-hour period to obtain the number of larvae and eggs entrained with the cooling water.

The above method provided an estimate of entrainment on sampling days. Mean ichthyoplankton concentrations from several sampling days were averaged and used to estimate entrainment losses on non-sampling days based on the flow through the plant on that day. Variability in these estimates, as evidenced by the confidence intervals, is due to variability in the ichthyoplankton concentrations between sampling periods.

Davis-Besse. Ichthyoplankton entrainment at the Davis-Besse Nuclear Power Plant was computed by multiplying the ichthyoplankton concentration observed at the intake by the intake volume. Ichthyoplankton densities were determined at approximately 10-day intervals from April - August of 1978 and 1979 from four 3-minute, oblique (bottom to surface) tows at 3-4 knots made at night on each date with a 0.75 meter diameter heavy-duty oceanographic plankton net (No. 00, 0.75 mm mesh) equipped with a calibrated General Oceanics flowmeter.

From the above estimates it was possible to determine an approximate period of occurrence for each species and a mean density during that period. For example, during 1978 walleye were not found on April 30 or on June 7 or later. They were present in samples from May 11 and May 21. Therefore, the period of occurrence was estimated to have been from May 6 (the midpoint between April 30 and May 11) to May 30 (the midpoint between May 21 and June 7). The mean density of walleye during this period was estimated to have been $41.6/100\ m^3$, computed from the concentration of $79.2/100\ m^3$ observed on May 11 and the concentration of $4.0/100\ m^3$ observed on May 21. It was this concentration, $41.6/100\ m^3$, which was multiplied by the volume of water drawn through the plant from May 6 to May 30.

4. RESULTS

4.1. Impingement

It is estimated that between September 15, 1976 (September 1, 1976 for Acme) and September 15, 1977, 5,729,064 fish of 43 species were impinged at the Acme Power Plant and 17,810,633 fish of 52 species were impinged at Bay Shore (Tables 2 and 3). These estimates do not include fish runs which occurred on seven occasions at Acme and one occasion at Bay Shore. The seven runs at Acme lasted a total of 44.5 hours and impingement an estimated 6,024,060 fish. The run at Bay Shore was less than 12 hours in duration and yielded 506,112 fish. At both plants gizzard shad, emerald shiners and alewives constituted over 99.8% of the fish impinged during runs and over 90% of the fish impinged at all times. At Acme, only three species, gizzard shad, emerald shiner and freshwater drum, represented more than 0.5% of the total number impinged. All fish runs and over 75% of the impingement at Bay Shore and 90% of the impingement at Acme occurred between mid-October and mid-February (Fig. 3).

A total of 6,607 fish of 20 species were impinged at Davis-Besse during 1978, while 4,385 fish of 19 species were impinged during 1979 (Tables 2 and 3). Davis-Besse began commercial operation in August 1977. The plant has not

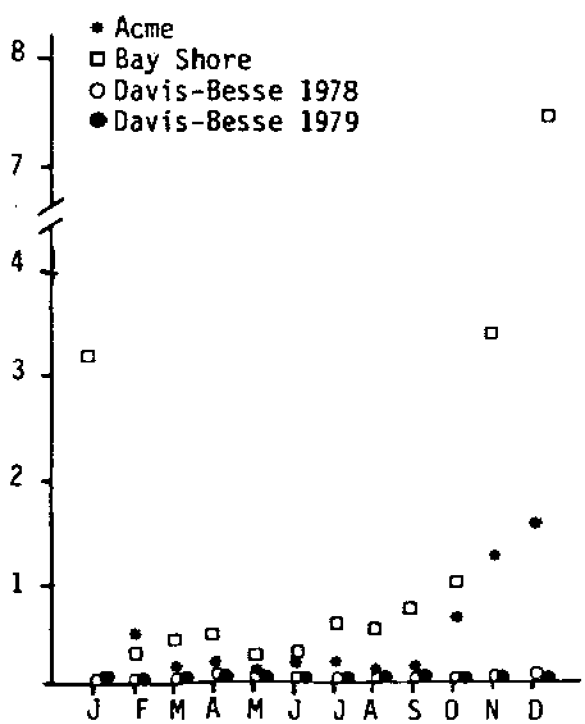

Fig. 3. Millions of Fish Impinged Monthly

TABLE 2. Common and Scientific Names of Fish Impinged and Entrained at the Acme, Bay Shore and Davis-Besse Power Plants.

COMMON NAME	SCIENTIFIC NAME	Acme Ent.	Acme Imp.	Bay Shore Ent.	Bay Shore Imp.	Davis-Besse Ent.	Davis-Besse Imp.
Alewife	*Alosa pseudoharengus*		*		*		*
Bigmouth Buffalo	*Ictiobus cyprinellus*				*		
Black Bullhead	*Ictalurus melas*		*		*		*
Black Crappie	*Pomoxis nigromaculatus*		*		*		*
Blackside Darter	*Percina maculata*						*
Bluegill	*Lepomis macrochirus*		*	*	*		*
Bluntnose Minnow	*Pimephales notatus*		*		*		*
Bowfin	*Amia calva*				*		
Brindled Madtom	*Noturus miurus*		*		*		
Brook Silversides	*Labidesthes sicculus*				*		
Brown Bullhead	*Ictalurus nebulosus*		*		*		*
Carp	*Cyprinus carpio*	*	*	*	*	*	*
Channel Catfish	*Ictalurus punctatus*	*	*	*	*		*
Channel Darter[a]	*Percina copelandi*				*		
Chinook Salmon	*Oncorhynchus tschawytscha*				*		
Coho Salmon	*O. kisutch*		*		*		
Creek Chub	*Semotilus atromaculatus*		*				
Emerald Shiner	*Notropis atherinoides*		*	*	*	*	*
Fathead Minnow	*Pimephales promelas*		*		*		
Freshwater Drum	*Aplodinotus grunniens*	*	*	*	*	*	*
Gizzard Shad	*Dorosoma cepedianum*	*	*	*	*	*	*
Golden Shiner	*Notemigonus crysoleucas*		*		*		
Goldfish	*Carassius auratus*		*		*		*
Green Sunfish	*Lepomis cyanellus*		*		*		*
Johnny Darter	*Etheostoma nigrum*				*		
Logperch	*Percina caprodes*	*	*	*	*	*	*
Long-nosed Gar	*Lepisosteus osseus*		*		*		
Mooneye[a]	*Hiodon tergisus*		*		*		
Mottled Sculpin	*Cottus bairdi*				*		
Northern Hog Sucker	*Hypentelium nigricans*				*		
Northern Pike	*Esox lucius*		*		*		
Orangespotted Sunfish	*Lepomis humilis*		*		*		
Pumpkinseed	*L. gibbosus*		*		*		*
Quillback	*Carpiodes cyprinus*		*		*		
Rainbow Smelt	*Osmerus mordax*		*	*	*	*	*
Rock Bass	*Ambloplites rupestris*				*		
Sauger	*Stizostedion canadense*		*		*		
Sea Lamprey	*Petromyzon marinus*		*		*		
Shorthead Redhorse	*Moxostoma macrolepidotum*		*		*		
Silver Chub[a]	*Hybopsis storeriana*		*		*		
Silver Lamprey[a]	*Ichthyomyzon unicuspis*		*		*		
Smallmouth Bass	*Micropterus dolomieui*				*		
Spotfin Shiner	*Notropis spilopterus*		*		*		
Spottail Shiner	*N. hudsonius*	*	*	*	*	*	*

TABLE 2 (continued).

COMMON NAME	SCIENTIFIC NAME	Acme Ent.	Acme Imp.	Bay Shore Ent.	Bay Shore Imp.	Davis-Besse Ent.	Davis-Besse Imp.
Stonecat	*Noturus flavus*		*		*		*
Tadpole Madtom	*N. gyrinus*		*		*		
Threespine Stickleback	*Gasterosteus aculeatus*		*		*		
Troutperch	*Percopsis omiscomaycus*		*	*	*		*
Walleye	*Stizostedion v. vitreum*	*	*	*	*	*	
White Bass	*Morone chrysops*	*	*	*	*	*	*
White Crappie	*Pomoxis annularis*		*		*		*
White Perch	*Morone americana*						*
White Sucker	*Catostomus commersoni*	*	*	*	*	*	
Yellow Bullhead	*Ictalurus natalis*		*		*		
Yellow Perch	*Perca flavescens*	*	*	*	*	*	*

[a]On Ohio's list of endangered wild animals.

operated continuously since that time, but circulating pumps have been operated over 90% of the time, and, as of April 30, 1981, no fish runs were observed. Goldfish was the dominant species impinged, and although numbers were very low, yellow perch constituted a significant portion of the number impinged. As with Acme and Bay Shore, impingement was primarily a cold water phenomenon and young-of-the-year was the dominant age class.

4.2 Entrainment

It is estimated that during the study, 79,492,563 larval fish representing 15 taxa and 178,048,309 fish eggs were entrained at Acme, while 284,717,618 larval fish representing 19 taxa and 426,150,109 fish eggs were entrained at Bay Shore (Tables 2 and 4). At Davis-Besse over a similar period of time, it is estimated that 6,311,371 larvae and 44,278 eggs were entrained during 1978 and 20,620,799 larvae and 101,405 eggs were entrained during 1979. Gizzard shad was the dominant species entrained at all three plants.

5. DISCUSSION

Although the Davis-Besse Nuclear Power Plant produces more power than the Acme and Bay Shore power plants combined. Davis-Besse impinges only 0.05% of the number impinged at Acme and 0.03% of the number impinged at Bay Shore; it entrains only 16.9% of the number of larval fishes entrained at Acme and only 4.7% of the number entrained at Bay Shore; and it entrains only 0.04% of the number of eggs entrained at Acme and only 0.02% of the number entrained at Bay Shore (Fig. 4). Obviously the fact that Davis-Besse has a cooling tower and is not a once-through plant as Acme and Bay Shore are accounts for some of this reduction in impingement and a great majority of the reduction in the entrainment, but the cooling tower reduces the cooling water requirements to 4.6% of Bay Shore's and 12.2% of Acme's, and the impingement losses and total ichthyoplankton (larvae and eggs) losses at Davis-Besse are much less than

TABLE 3. Annual Fish Impingement at the Acme, Bay Shore and Davis-Besse Power Plants in Western Lake Erie.

SPECIES	POWER PLANT	NUMBER IMPINGED	% OF TOTAL	95% CONFIDENCE LOWER	95% CONFIDENCE UPPER
Alewife	Acme	21,412	0.37	15,013	30,539
	Bay Shore	1,375,911	7.73	786,515	2,406,986
	D-B 1978	4	0.06	1	9
	D-B 1979	1	0.02	0	5
Channel Catfish	Acme	3,225	0.06	1,951	5,333
	Bay Shore	20,995	0.12	16,214	27,186
	D-B 1978	3	0.05	1	7
	D-B 1979	0	0.00	0	0.00
Emerald Shiner	Acme	823,791	14.38	554,701	1,223,418
	Bay Shore	3,282,597	18.43	2,147,664	5,017,285
	D-B 1978	991	15.00	636	1,545
	D-B 1979	214	4.88	90	511
Freshwater Drum	Acme	114,152	1.99	90,495	143,994
	Bay Shore	365,779	2.05	271,584	492,697
	D-B 1978	80	1.21	55	114
	D-B 1979	115	2.62	61	218
Gizzard Shad	Acme	4,709,444	82.19	3,306,856	6,706,934
	Bay Shore	11,347,255	63.70	8,698,622	14,802,368
	D-B 1978	391	5.92	201	758
	D-B 1979	162	3.69	95	275
Goldfish	Acme	746	0.01	524	1,061
	Bay Shore	4,471	0.03	3,292	6,073
	D-B 1978	3,299	49.93	2,435	4,468
	D-B 1979	3,449	78.66	2,266	5,248
Rainbow Smelt	Acme	2,644	0.05	1,930	3,624
	Bay Shore	87,374	0.49	62,615	121,923
	D-B 1978	69	1.04	45	107
	D-B 1979	32	0.73	18	55
Spottail Shiner	Acme	15,789	0.28	12,968	19,224
	Bay Shore	212,515	1.19	164,608	274,365
	D-B 1978	15	0.23	9	25
	D-B 1979	9	0.21	5	16
Walleye	Acme	454	0.01	331	623
	Bay Shore	12,187	0.07	9,466	15,690
	D-B 1978	0	0.00	0	0
	D-B 1979	0	0.00	0	0

TABLE 3 (continued).

SPECIES	POWER PLANT	NUMBER IMPINGED	% OF TOTAL	95% CONFIDENCE LOWER	95% CONFIDENCE UPPER
White Bass	Acme	21,549	0.38	17,089	27,174
	Bay Shore	624,078	3.50	467,610	832,902
	D-B 1978	0	0.00	0	0
	D-B 1979	3	0.07	1	12
Yellow Perch	Acme	6,063	0.11	5,153	7,134
	Bay Shore	437,260	2.46	347,626	550,007
	D-B 1978	1,582	23.94	1,082	2,312
	D-B 1979	285	6.50	129	631
Others	Acme	9,795	0.17		
	Bay Shore	40,211	0.23		
	D-B 1978	173	2.62		
	D-B 1979	115	2.62		
TOTAL	Acme	5,729,064	100.00		
	Bay Shore	17,810,633	100.00		
	D-B 1978	6,607	100.00	5,447	8,015
	D-B 1979	4,385	100.00	3,128	6,149

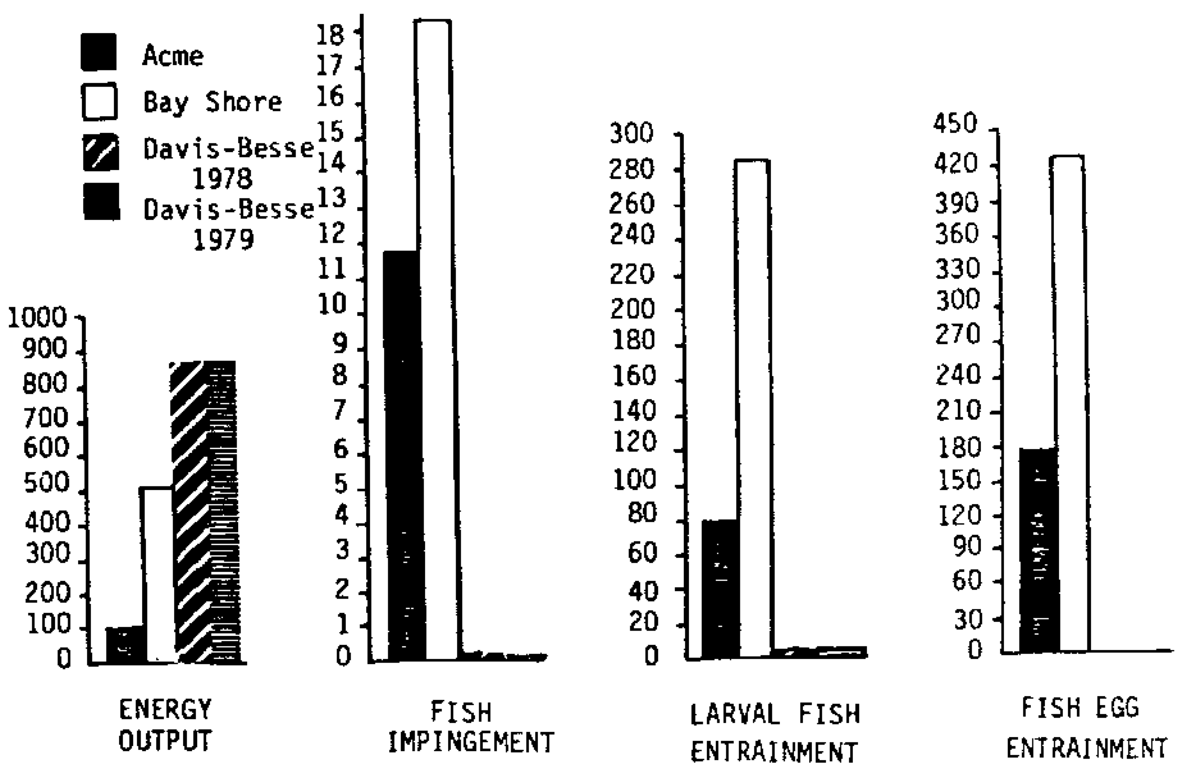

Fig. 4. Megawatts of Power Produced Compared to Millions of Fish Entrained and Impinged.

TABLE 4. Annual Fish Entrainment in Thousands at the Acme, Bay Shore And Davis-Besse Power Plants in Western Lake Erie.

SPECIES	POWER PLANT	NUMBER ENTRAINED	% OF TOTAL	95% CONFIDENCE LOWER	95% CONFIDENCE UPPER
Carp	Acme	1,145	1.44	472	2,774
	Bay Shore	8,252	2.90	4,160	16,368
	D-B 1978	7	0.11	0	27
	D-B 1979	47	0.21	8	86
Channel Catfish	Acme	92	0.12	29	295
	Bay Shore	565	0.20	165	1,935
	D-B 1978	0	0.00	0	0
	D-B 1979	0	0.00	0	0
Emerald Shiner	Acme	0	0.00	0	0
	Bay Shore	143	0.05	34	595
	D-B 1978	345	5.47	0	1,257
	D-B 1979	6,815	33.06	2,842	10,788
Freshwater Drum	Acme	26,514	33.35	13,382	52,533
	Bay Shore	13,479	4.73	7,373	24,644
	D-B 1978	100	1.58	0	457
	D-B 1979	1,014	4.92	575	1,454
Gizzard Shad	Acme	44,930	56.52	19,516	103,438
	Bay Shore	223,290	78.42	134,750	370,008
	D-B 1978	4,796	76.00	0	13,099
	D-B 1979	10,187	49.41	6,910	13,463
Logperch	Acme	130	0.16	23	738
	Bay Shore	28	0.01	4	173
	D-B 1978	0	0.00	0	0
	D-B 1979	57	0.28	16	98
Rainbow Smelt	Acme	0	0.00	0	0
	Bay Shore	897	0.32	388	2,075
	D-B 1978	95	1.51	0	272
	D-B 1979	763	3.70	471	1,055
Spottail Shiner	Acme	41	0.05	7	247
	Bay Shore	238	0.08	44	1,283
	D-B 1978	16	0.25	0	37
	D-B 1979	38	0.18	0	110
Walleye	Acme	195	0.25	82	462
	Bay Shore	442	0.16	207	943
	D-B 1978	917	14.53	0	11,445
	D-B 1979	42	0.20	22	61
White Bass	Acme	5,778	7.27	2,369	14,365
	Bay Shore	33,108	11.63	13,497	81,216
	D-B 1978	0	0.00	0	0
	D-B 1979	52	0.25	24	79

TABLE 4 (continued).

SPECIES	POWER PLANT	NUMBER ENTRAINED	% OF TOTAL	95% CONFIDENCE LOWER	95% CONFIDENCE UPPER
White Sucker	Acme	33	0.04	12	89
	Bay Shore	674	0.24	249	1,820
	D-B 1978	0	0.00	0	0
	D-B 1979	2	0.01	0	6
Yellow Perch	Acme	14	0.02	3	61
	Bay Shore	2,426	0.85	875	6,728
	D-B 1978	35	0.55	0	91
	D-B 1979	1,595	7.73	1,293	1,897
Others	Acme	621	0.78		
	Bay Shore	1,176	0.41		
	D-B 1978	0	0.00	0	0
	D-B 1979	10	0.05		
TOTAL	Acme	79,493	100.00		
	Bay Shore	284,718	100.00		
	D-B 1978	6,311	100.00		
	D-B 1979	20,622	100.00		
Eggs	Acme	178,048	100.00	53,425	593,375
	Bay Shore	426,150	100.00	239,225	759,133
	D-B 1978	44	100.00	0	185
	D-B 1979	101	100.00	36	167

these figures. Furthermore, adult fish populations near Davis-Besse can be twice that observed at Bay Shore and eight times that observed at Acme [2]. Consequently, the real key to the success of Davis-Besse is in the location and design of the intake.

At Davis-Besse, adult fish densities increased in a shoreward direction, and were only half as great 3,000 feet from shore (where the intake is) as they were 1,500 feet from shore [2]. Consequently, Davis-Besse's off-shore intake is a major advantage over the open shoreline intake canals at Acme and Bay Shore. Furthermore, the fact that these are "open" shoreline canals whereas Davis-Besse's is closed, is also significant, for the open canal causes the many schooling species in Lake Erie (yellow perch, gizzard shad, alewife, emerald shiner) which are following the shoreline to turn and swim into the intakes of the power plants.

The last new design feature of real significance at Davis-Besse is the bottom intake, for bottom ichthyoplankton densities are only approximately half as large as surface densities [2].

In summary, the design features utilized at Davis-Besse, closed cycle cooling system, off-shore intake, closed intake canal, and bottom intake, are effective measures to reduce entrainment and impingement at cooling water intakes in Lake Erie. Siting is also a significant factor in minimizing entrainment and impingement. The authors recommend the Central Basin of the lake for future plant construction because adult fish densities are lower and ichthyoplankton densities along the south shore of Lake Erie decrease very significantly in an eastward direction [3]. In fact, this reduction is so dramatic that it is the opinion of the authors that in the area east of Cleveland, cooling towers may not be warranted if the plant has an off-shore, bottom intake and a closed intake canal. Furthermore, new plants constructed in this area can anticipate entrainment and impingement levels significantly lower than those of Davis-Besse.

6. CONCLUSIONS

The following power plant design features are very effective at reducing fish entrainment and impingement in Lake Erie: closed cycle cooling system, off-shore intake, bottom intake, and closed intake canal. Due to a significant reduction in fish densities as one leaves the Western Basin and moves eastward, future power plant construction on the south shore of Lake Erie should take place in the area east of Cleveland and no new plants should be constructed anywhere in the Western Basin of the lake. If these suggestions are followed, new plants can be constructed on Lake Erie without harming the valuable and growing fishery.

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