Supplement to
316(a) and 316(b) Demonstration

for

THE QUAD CITIES NUCLEAR
GENERATING STATION

Commonwealth Edison Company
Chicago, Illinois

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Acknowledgements

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Introduction

This summary reviews operational monitoring and special studies conducted at Quad Cities Station. Based on the results of these programs, Commonwealth Edison Company believes that it has been adequately demonstrated that no adverse impact on the fish and shellfish populations results from operation of the present intake or discharge during open-cycle cooling, and that there now exist sufficient data to justify relief from the closed-cycle cooling requirements for both units.

This summary is a supplement to the document previously submitted to Region V, U.S. Environmental Protection Agency (USEPA) by Commonwealth Edison Company (Commonwealth Edison Company, 1975) in support of its application for an alternate effluent limitation at Quad Cities Station under Section 316(a) of the Federal Water Pollution Control Act (FWPCA). This report also serves to update Commonwealth Edison's demonstration under Section 316(b) of the FWPCA that no significant adverse environmental impact will result from operation of the Station's intake structure during open-cycle cooling.

The original Demonstrations were submitted to USEPA in two parts. The first part of the 316(a) Demonstration was submitted on February 28, 1975. The second submittal, which included the 316(b) Demonstration and a supplement to the 316(a) Demonstration followed on April 11, 1975. The 316(a) Demonstration requested an alternate effluent limitation which would allow discharge to the Mississippi River equivalent to that of one of the two Quad Cities Station units. The 316(b) Demonstration concluded that no significant adverse environmental impact results from the Station's intake during open-cycle cooling water operation. These updated Demonstrations, however, are for the case where both units are operating open-cycle.

A preliminary determination was issued by the USEPA on April 4, 1977, which indicated that data and analyses presented were insufficient to justify relief from the thermal discharge restrictions specified in the NPDES permit. Subsequent information was submitted to USEPA at its request on May 30, June 20 and July 22, 1977.

Since its start-up in April, 1972, Quad Cities Station has utilized several means of discharging cooling water to the Mississippi River. The original design proposed that the Station operate open-cycle discharging cooling water by means of a channel which would convey the water along a straight wing dam into the deeper, higher velocity region of the river. However, a thermal-hydraulic study (Jain, et al., 1971) predicted that this method of open-cycle discharge would result in a heated plume that exceeded the State of Illinois thermal criteria.

Model studies conducted by the Iowa Institute of Hydraulic Research to determine the best method for obtaining rapid mixing of heated and ambient river waters narrowed the alternatives to some type of multiport diffuser system (Jain, et al., 1971). Since sufficient time was not available to adequately design, test and install the multiport diffuser system prior to Station start-up, an interim side-jet system was developed. This system operated from the time of Station start-up (January, 1972) until August, 1972, when the diffuser system was placed into operation.

Commonwealth Edison Company entered into an agreement with the Attorney General of the State of Illinois, Izaak Walton League of America and Illinois State Community Action Program of the United Automobile, Aerospace and

Agricultural Implement Workers on March 27, 1972, requiring that, except in certain circumstances, both units at Quad Cities Station be operated with closed-cycle cooling beginning May 1, 1975. Design and construction of a spray canal approximately 16,000 feet in length was, therefore, initiated in 1972 and completed in 1975. The diffuser system was operated as an open-cycle discharge for both units until May 1, 1974, and subsequently for one unit until May 1, 1975.

Tests of the closed cycle cooling system, or spray canal, have shown that it operates at substantially less than anticipated efficiency (Freeman, et al., 1980). Since the Station was designed to operate most efficiently at a certain maximum inlet temperature (60°F), when actual inlet temperatures increase above this level not as much power can be generated. As a result, the Station's generating capability is reduced on days when outside temperatures are high and the spray canal is unable to achieve the required minimum level of cooling.

The auxiliary power required to operate the spray canal is 24 MWe. This assumes that all spray modules and the maximum number of lift pumps are operating. Based on Station operating data for an 87 day period during the months of July, August and September, 1978, it was estimated that an average thermal derating of 128 MWe was experienced during partial open-cycle operation.

On July 9, 1979, Commonwealth Edison Company received a revised NPDES permit for the Station. The permit, effective August 2, 1979, and to expire on September 30, 1980, was jointly issued by the Illinois Environmental Protection Agency and the Iowa Department of Environmental Quality. It allows partial

open-cycle operation of the condenser cooling system at times when the temperature of the water returning from the spray canal exceeds 93°F or during certain infrequent maintenance periods when the Station water exceeds 85°F. This was followed in August, 1979, by an interim modification by the parties to the closed-cycle operation agreements of March 1972, which allows partial open-cycle operation of the Station when required to avoid substantial capacity losses. This interim agreement will continue until parties to the original agreement make a final determination with respect to the cooling water system to be used at the Station.

Numerous hydrological and biological studies and data reviews have been conducted since submittal of the original 316(a) and 316(b) Demonstrations. The studies have included special investigations to document effects of open-cycle operation during the low flow year of 1976. The reviews include consideration of the hydrological data base and the results of monitoring studies conducted from 1968 through the present. Also included is a review of the physiological effects that elevated temperatures might have on the fishes of Pool 14. This subject, which has never been addressed before the Quad Cities Station discharge is discussed in a separate section of this report as part of the supplement to the 316(a) Demonstration. On the basis of this new information and on the expanded consideration of the results of the monitoring program, Commonwealth Edison Company requests that Quad Cities Station be permitted to operate open-cycle using the diffuser system as a means of discharge.

Literature Cited

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Jain, S.C., W.W. Sayre, Y.A. Akyeampong, D. McDougall and J.F. Kennedy, 1971. Model Studies and Design of Thermal Outfall Structures Quad Cities Nuclear Plant. Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa. IIHR Report No. 135. 101 pp.

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Executive Summary

Quad Cities Station is a nuclear-fueled steam electric generating facility located on the Illinois shore of Pool 14 of the Mississippi River at River Mile 506.5. The Station utilizes two boiling water nuclear reactors, each unit producing 809 megawatts electric (MWe) power for a total Station output of 1618 MWe. Make-up cooling water for Quad Cities Station is withdrawn from the Mississippi River, circulated through the Station and directed through a spray canal system from which it is recirculated to the Station. This method of operation is called closed-cycle. The Station may also be operated open-cycle where cooling water after circulation through the plant's condensers is discharged to the Mississippi River through a two pipe multiport diffuser system in the river. Finally, the Station may be operated in a partial open-cycle mode. In this operating mode approximately 50% of the cooling water discharge is circulated through the spray canal system while the remainder is discharged through one or both of the diffuser pipes.

From January, 1972 until May, 1974, when the spray canal system began operation, Quad Cities Station operated in the open-cycle mode discharging condenser cooling water to the river via a side jet canal from January through July, 1972 and via the diffuser system from August, 1972 through April, 1974.

In accordance with an agreement between Commonwealth Edison Company and the Attorney General of the State of Illinois, the Izaak Walton League of America and the United Automobile Workers of America, which requires closed-cycle cooling, operation of the spray canal commenced on May 1, 1974, with the Station operating with the equivalent of one unit discharging cooling water to the canal and one unit discharging directly into the river. This mode of operation continued until May 1, 1975, when cooling water from both units was routed to the canal (closed-cycle).

Closed-cycle operation continued until August 2, 1979, upon receipt of the currently applicable NPDES permit for the Station which allows partial open-cycle operation of the condenser cooling system at times when the temperature of the water returning from the spray canal exceeds 93°F. Operation of the Station is also subject to an interim modification effective August 27, 1979, by the parties to the closed-cycle agreement which allows partial open-cycle operation of the Station when required to avoid substantial capacity losses.

This document is a supplement which updates the document previously submitted to Region V, U.S. Environmental Protection Agency by Commonwealth Edison Company in 1975, and subsequent updates in 1977, in support of its application for an alternate effluent limitation at Quad Cities Station under Section 316(a) of the Federal Water Pollution Control Act (FWPCA). This summary also serves to update Commonwealth Edison Company's Demonstration, submitted in 1975, under Section 316(b) of the FWPCA that no significant adverse environmental impact will result from operation of the Station's intake during open-cycle cooling water operation. The 316(a) Demonstration requested an alternate effluent limitation which would allow discharge to the Mississippi River equivalent to that of one of the two Quad Cities Station units.

This document reviews numerous hydrological and biological studies and data reviews that have been conducted since submittal of the original 316(a) and 316(b) Demonstrations. These reviews include consideration of the hydrological data base, results of biological monitoring studies conducted from 1968 through the present, as well as a review of the physiological effects that elevated temperatures might have on the fishes of Pool 14. On the basis

of this information, Commonwealth Edison Company requests that Quad Cities Station be permitted to operate open-cycle using the diffuser system as a means of discharge.

The diffuser pipe system for Quad Cities Station has been investigated through analysis of laboratory test data and field data collected for a wide range of river discharges with the plant operating at full load and at various partial loads. With the plant operating at full load in the open-cycle mode, tests indicate that temperatures at the edge of the mixing zone meet applicable state standards for all river flows greater than approximately 16,000 cfs. Mississippi River flows at the location of Quad Cities Station exceed 16,000 cfs about 98% of the time.

Environmental studies including many intensive monitoring and special programs began in 1968 with several of these programs still continuing. Water quality as well as the nature and abundance of the biota in Pool 14 has been evaluated during those programs.

Water quality in the river was measured from 1968 through 1977. Results showed water quality in Pool 14 to generally be good. Although there have been periods of degraded water quality which resulted in occasionally high levels of total iron, mercury, manganese, copper, hexane soluble materials and phenols, increased concentration of these materials were in no way attributable to Station operation.

Studies of the lower trophic level biota (phytoplankton, zooplankton, periphyton and benthos) were conducted from 1968 through 1977. Results of these

studies have shown that Station operation has not adversely affected population levels in these various groups. No consistent changes in species composition or distribution of those organisms were observed between control and potentially impacted sampling locations in the river associated with diffuser operation. These programs were sensitive enough to have detected short or long term effects that Station operation might have had on the water quality or aquatic biota of the Pool. This fact was continually demonstrated in that natural variation between seasons, years and major habitat types could be defined with confidence in addition to the detection of numerous localized effects associated with Station operation. These effects were expected and their detection demonstrates that the monitoring programs were sufficiently sensitive to have detected any major perturbations had they occurred.

Ichthyoplankton studies have been conducted from 1971 through the present with comparisons for this Demonstration made from 1975 through 1979. Taxa of eggs and larvae collected over this period of time have remained constant with freshwater drum, carp and cyprinids (minnows other than carp) being the most abundant taxa. Ambient river water temperatures appear to directly influence the density of ichthyoplankton. However, in general there has not been any obvious correlation with river flow. An intensive sampling program conducted in 1978, showed there was little difference between average day and night abundances of total larvae. Although there was little difference in the vertical distribution of these organisms, horizontal differences were noted with the main channel and Illinois side of the river exhibiting somewhat higher total larvae abundance. During 1978 and 1979, sampling conducted also showed freshwater drum eggs and larvae were abundant at all locations upstrean of the

Station and demonstrated that all of Pool 14 in this area is a spawning and nursery area for this species.

Adult and juvenile fish monitoring has been conducted in the area of Quad Cities Station since 1971. Methods of sampling have included electroshocking, bottom trawling (1971-1979), haul seining (1978 and 1979) and sampling of selected slough habitats using a cove rotenone technique (1977 and 1979).

Results of these programs conducted each year have shown little significant variation in the number of species collected each year. Total catch-per-effort values (without gizzard shad) from the electroshocking program, remained similar among the one year of preoperational monitoring (1971) and the first two years of operational monitoring (1972 and 1973) when the Station operated open-cycle. There was, however, a fairly steady pattern of decline throughout the study area from 1974 through 1979, when the Station principally operated closed-cycle or partial open-cycle. Since the decrease was observed at both upstream (control) and downstream (potentially impacted) locations, it cannot be attributed to thermal discharge associated with Station operation.

It can be hypothesized that the catch-per-effort was higher during the earlier open-cycle years than during the later closed-cycle years because Station operation affected subsequent population levels due to entrainment and impingement. This hypothesis was discarded, however, because entrainment losses were shown to be about the same for open and partial closed-cycle operation. Impingement losses have also been shown to be very low (less than 1% of the standing stock in Pool 14). Thus, neither of these factors can be reasonably expected to have resulted in the population decreases seen over the study period.

Results of bottom trawling studies have shown very little annual change in species composition of fish in the main channel over the nine year period. These data, in conjunction with temperature to evaluate avoidance or attraction of fish to the vicinity of the diffuser system, have also shown there has been no correlation between temperature and fish catches in the area of the diffuser discharge.

The possible physiological effects of Quad Cities Station open-cycle cooling discharge through the diffuser system on fish in Pool 14 of the Mississippi River were also evaluated. Effects considered were (a) jet entrainment of planktonic eggs and larvae, (b) plume attraction of juvenile and adult forms, (c) occasional long term exposures (weeks) to low-level temperature increments of <3.95°F and (d) the potential for cold-shock and gas bubble disease. Data on fish occurrence and distribution in Pool 14, special studies conducted at the Station relating to thermal effects as well as sources from scientific literature were evaluated. In addition, procedures recommended by the USEPA for evaluating thermal effects were employed. These considerations have revealed no existing or potential impacts on fish that would be associated with the thermal plume. In fact, temperatures downstream of the Station (82°F after full mixing of condenser discharge with river water) to which even the most sensitive species would be exposed will not exceed maximum weekly average temperature for that species for extreme conditions of low flow (7Q10) and 100% operating capacity of the Station. Finally, this average maximum temperature is well below the upper incipient lethal temperature for even the most sensitive species in Pool 14.

Since submission of the original 316(b) Demonstration, several studies have been conducted to document the effects of open-cycle operation on organisms

entrained in condenser cooling water as well as studies to minimize impingement and to quantify impingement losses relative to population levels in Pool 14.

Results of entrainment studies for plankton (phytoplankton and zooplankton) indicated that the portion of the plankton assemblage passing the Station affected by Station operation was very low. The reductions, however, were also sufficiently small that they were not detectable in field programs in spite of the fact that sampling procedures in those programs were sensitive enough to detect natural variations in this community. It is also evident that entrainment effects on the total plankton community is of no consequence since entrainment never results in 100% mortality and very small percentages of the total river flow are used for condenser cooling during open-cycle operation.

Effects of entrainment from open-cycle operation on ichthyoplankton is also minimal. Special studies conducted to measure the survival of fish larvae passing through Quad Cities Station condensers concluded that entrainment losses are primarily a function of Station discharge temperatures. Most larvae survive entrainment when discharge temperatures are below 91.4°F. Further, evaluations of river and Station operating data indicated that most ichthyoplankton pass the Station prior to discharge temperatures reaching these levels. In addition, it was also concluded that there were little meaningful differences between estimates of total ichthyoplankton abundance lost due to open-cycle operation and the present operating mode (partial open-cycle operation) where the volume of river water used for make-up is increased when return water from the spray canal exceeds 93°F.

Impingement exploitation rates were estimated and it was concluded based on these projections that losses due to impingement at Quad Cities Station are minimal. Further it has also been demonstrated that placement of a barrier net in front of the forebay has been effective in minimizing fish losses during closed-cycle operation. From these results it is evident that the net would be effective in reducing impingement during open-cycle operation through the judicious operation of the circulating water pumps and the ice melt line throughout the year.

During the summer months it is expected that impingement can be minimized by diverting condenser cooling water back to the forebay through the ice melt line located on the floor of the forebay. This will increase temperatures in the forebay and it is believed that fish will avoid the intake during this period of the year.

During the winter months, impingement can be minimized during open-cycle operation by installing a barrier net in front of the forebay in conjunction with reducing the number of operating circulating water pumps and by diverting condenser discharge back to the intake forebay by means of the ice melt line. By reducing the number of operating circulating water pumps in addition to diverting condenser discharge back to the forebay, intake velocities at the river's edge during open-cycle operation would correspondingly be reduced, by about 50%, to about 0.5 ft/sec.

A testing period will be needed to define the extent that the barrier net and increased temperatures in the forebay decrease impingement. The extent of the reduction cannot be quantified without operational data. Existing data do demonstrate, however, that these methods will reduce impingement.

Section I

Description and History of Station Operation

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Description and History of Station Operation

Quad Cities Station is a nuclear-fueled steam electric generating facility located on the Illinois shore of Pool 14 of the Mississippi River approximately 21 miles north of Davenport, Iowa, Moline, Rock Island and East Moline, Illinois (Figure 1). Quad Cities Station utilizes two boiling water nuclear reactors. Each unit produces 809 megawatts electric (MWe) power for a total Station output of 1618 MWe. When operating at maximum capacity in the open-cycle mode, cooling water is withdrawn from the Mississippi River at a rate of 2230 cfs. The temperature of the cooling water is raised a maximum of 23°F before it is returned to the river, resulting in a heat rejection rate of 11.48×10^9 Btu/hr.

The Station began operation in January, 1972, when low power testing was initiated. Following the completion of low power testing in early April, 1972, start-up testing began and was continued until August, 1972. From January until August, 1972, cooling water was withdrawn from the Mississippi River, circulated through the condenser cooling system and discharged through a side-jet discharge canal as shown in Figure 2.

A diffuser system was installed in the Mississippi River in 1972. The diffuser system consists of two 16-foot diameter multi-port manifolds buried in the river bed as shown in Figure 3. Open-cycle, two-pipe diffuser operation began in August, 1972, at which time the use of the side-jet discharge was permanently discontinued. The diffuser mode of operation continued until 1 May 1974.

On May 1, 1974, a new cooling system commenced operation consisting of a spray canal approximately 16,000 feet long, 185 feet wide and 9 feet deep (Figure 4). The Station operated with the equivalent of one unit discharging cooling water to the canal and one unit discharging directly into the river

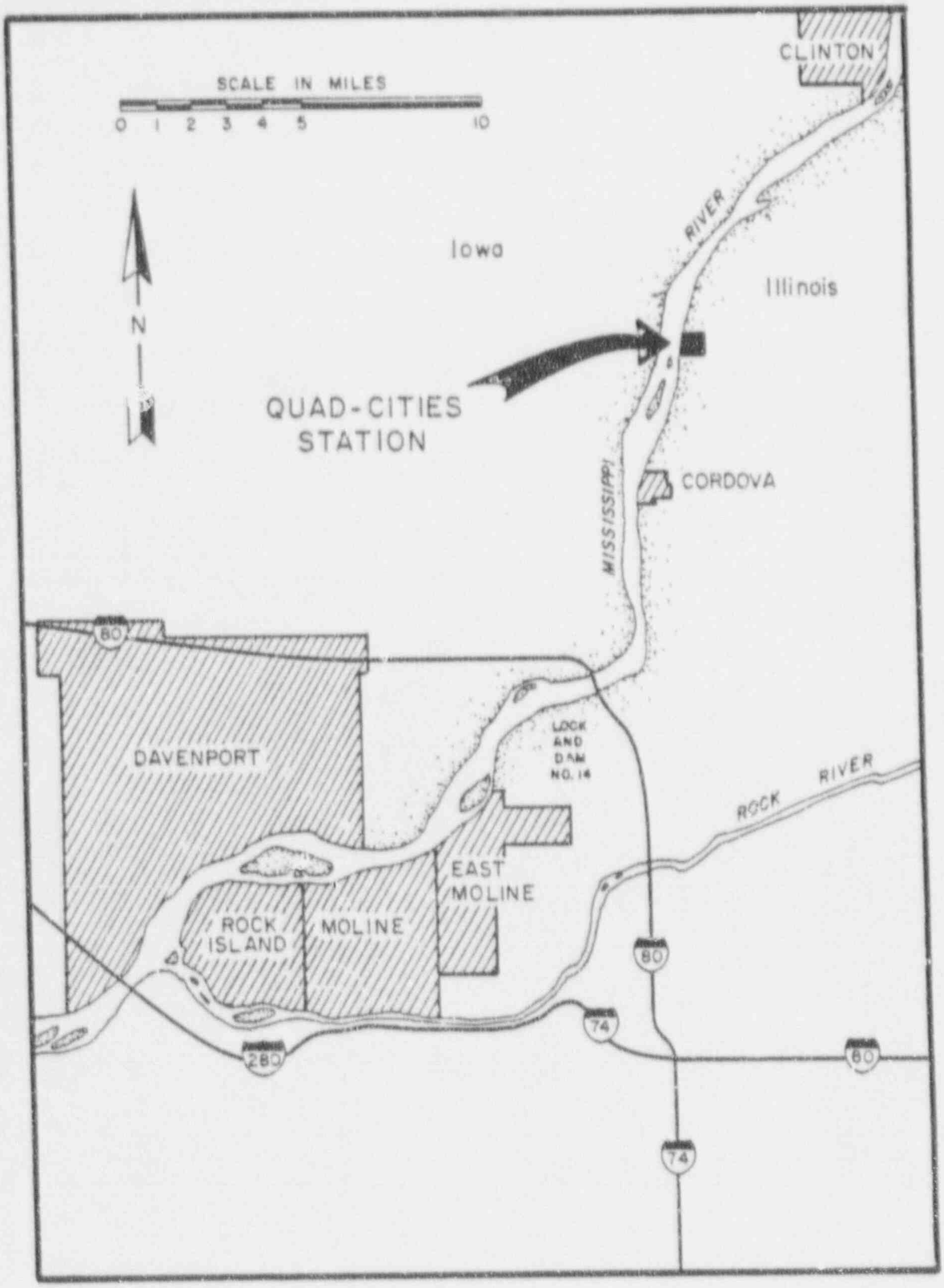

Figure 1. Geographical Location of the Quad-Cities station

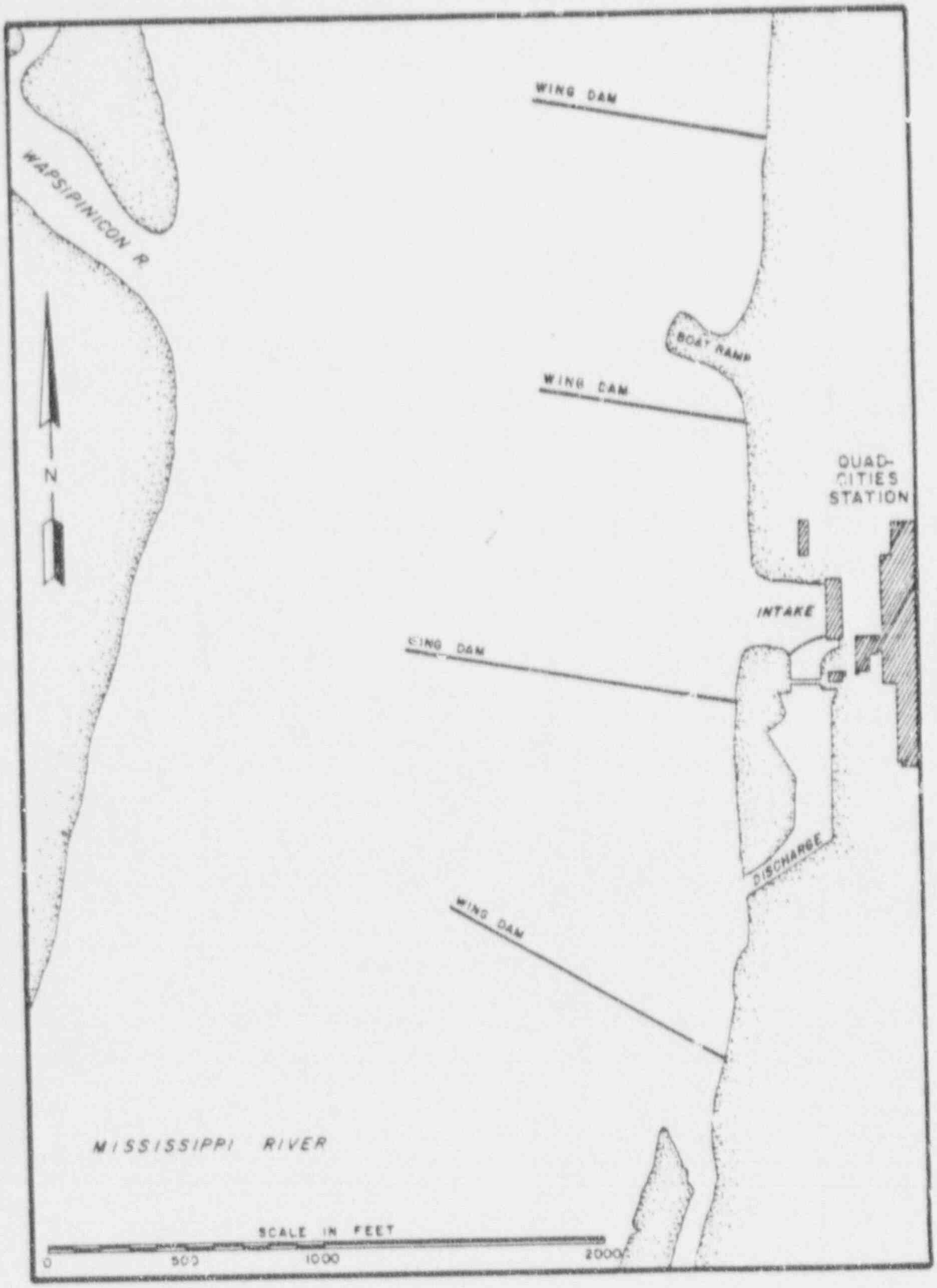

Figure 2 Quad-Cities Station cooling system configuration
April 1972 through July 1972

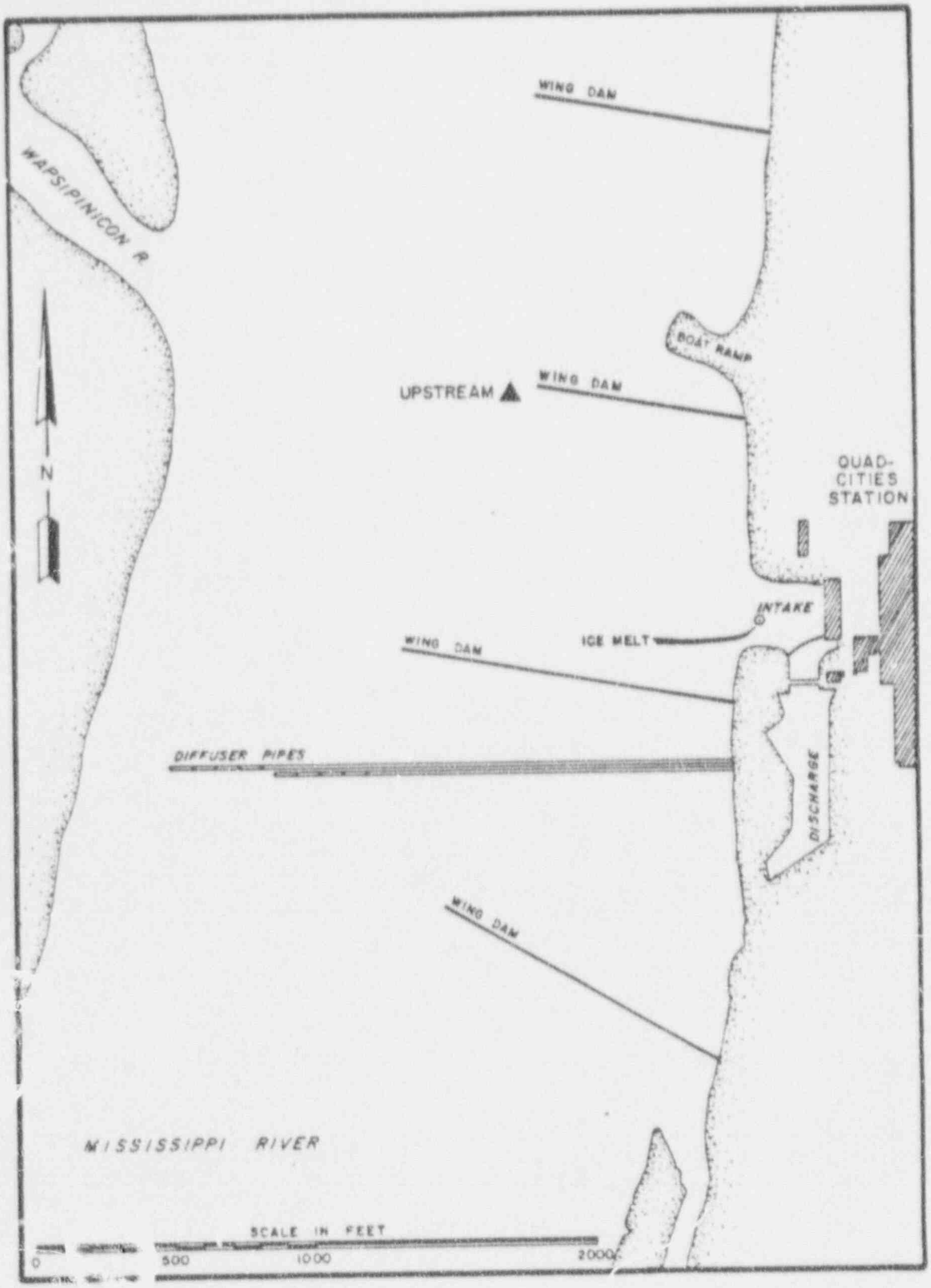

Figure 3 Quad Cities Station cooling system configuration
August 1972 through April 1974

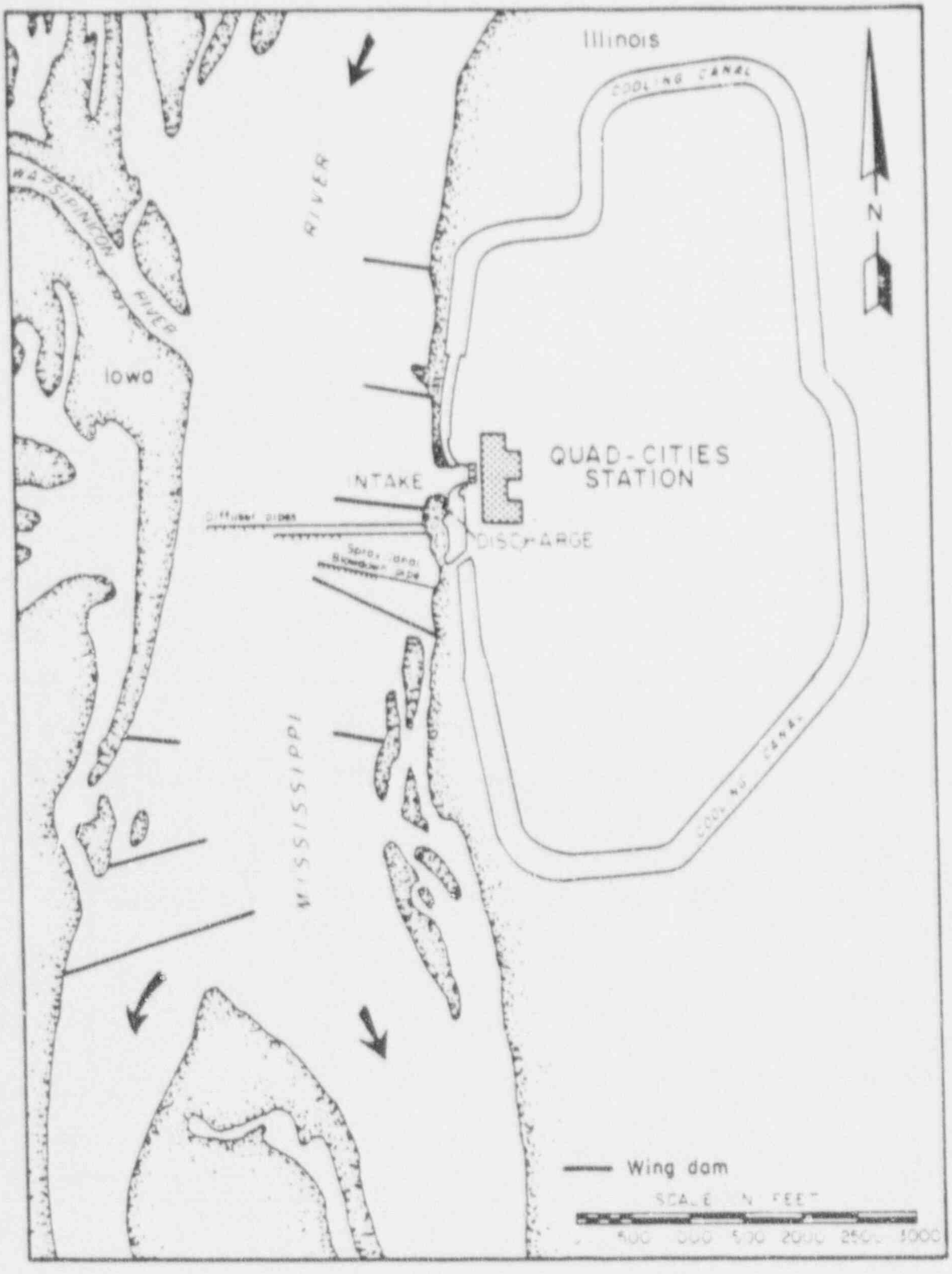

Figure 4 Quad-Cities Station cooling system configuration
May 1974 through December 1978

until May 1, 1975, when cooling water from both units was routed to the canal. During closed cycle cooling, thermal effluent is moved from the discharge bay to the spray canal via five lift pumps, each with a capacity of 372 cfs. In the spray canal, 328 spray modules are used to cool the water by evaporative action. The cooled water is returned to the intake bay by way of a spillway and recirculated through the Station condensers. At maximum operating capacity, approximately 2063 cfs of water is circulated through the spray canal. Discharge (blowdown) (Figure 4) through a four foot diameter multi-port manifold to the Mississippi River consists of approximately 111 cfs (annual average) of cooling water. In addition to the 111 cfs blowdown, approximately 56 cfs of water in the spray canal is lost due to evaporation. To make up for these losses, 167 cfs of cooling water is withdrawn from the Mississippi River.

After the introduction of spray canal operation, thermal effluent from the Station could be cooled by the following methods: open-cycle operation with a single or two-pipe diffuser, closed-cycle operation with spray canal and combination or partial open-cycle operation with spray canal and diffuser. When operating in combination cycle, approximately 1182 cfs (53%) of the cooling water is circulated through the spray canal while 1048 (47%) of the water is discharged through one or both of the diffuser pipes. Make-up water is equal to the amount of water discharged through the diffuser system. The flow of cooling water through the Quad Cities Station during the various modes of operation is presented in Figure 5. Table 1 presents the average monthly Station capacity factor from August, 1972, through December, 1979. The Station capacity factor is defined as the power output over the maximum amount of power the Station is capable of producing and is expressed as a percentage. The monthly total Station capacity factor varied between 6 and 92% over the eight year period of operation.

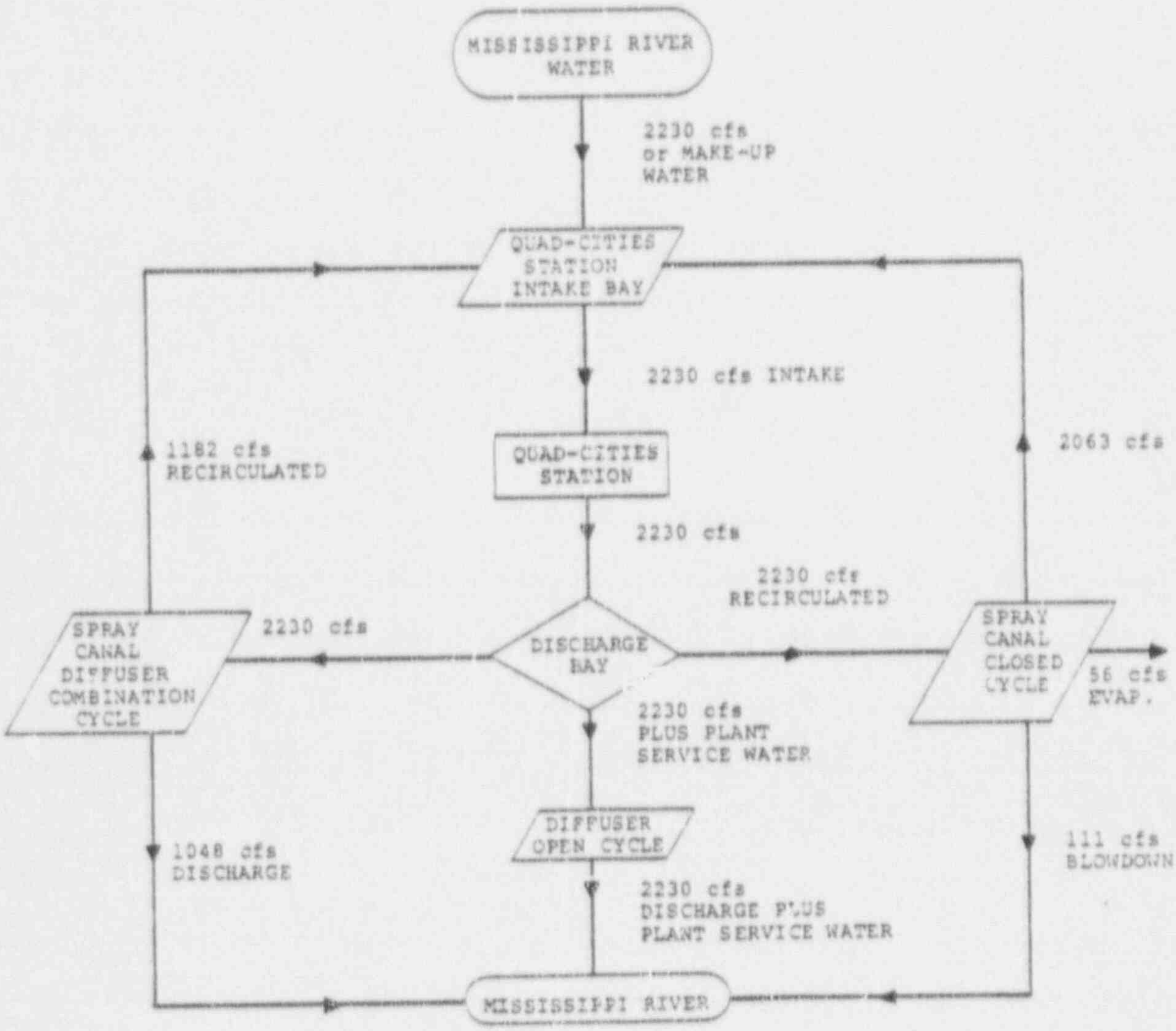

Figure 5 Flow of cooling water through the Quad-Cities Station.

TABLE 1. Monthly Capacity Factors[a,b], Quad Cities Station
August, 1972 through December, 1979.

	Year							
	1972	1973	1974	1975	1976	1977	1978	1979
Month	Capacity Factor							
January								
Unit 1		77	60	25	4	81	94	27
Unit 2		64	77	c	95	94	33	89
Total		71	69	12	50	88	64	58
February								
Unit 1		73	72	11	0	66	72	c
Unit 2		78	76	c	68	63	c	79
Total		76	74	6	34	65	36	40
March								
Unit 1		75	79	99	22	50	92	79
Unit 2		92	66	c	76	28	47	81
Total		84	73	45	49	39	70	80
April								
Unit 1		51	c	93	70	c	59	90
Unit 2		41	77	1	92	92	88	74
Total		46	39	47	81	46	74	82
May								
Unit 1		45	a	62	70	40	64	68
Unit 2		64	83	72	80	79	61	82
Total		55	42	67	75	60	62	75
June								
Unit 1		82	c	81	49	70	72	94
Unit 2		86	39	74	70	77	54	79
Total		84	20	78	59	74	63	86
July								
Unit 1		86	11	74	29	72	83	94
Unit 2		79	78	65	72	62	86	75
Total		82	45	69	50	67	84	84
August								
Unit 1	48	69	82	67	54	38	88	89
Unit 2	39	76	84	38	67	44	95	62
Total	44	73	83	53	61	41	92	75
September								
Unit 1	57	60	88	78	87	30	79	55
Unit 2	c	69	44	66	23	48	87	51
Total	28	65	66	72	55	39	83	53
October								
Unit 1	68	68	49	74	82	51	71	97
Unit 2	32	70	75	8	c	70	83	51
Total	50	69	62	41	41	64	77	74

TABLE 1. (continued)

	Year							
	1972	1973	1974	1975	1976	1977	1978	1979
Month	Capacity Factor							
November								
Unit 1	74	70	77	67	66	79	65	90
Unit 2	73	82	74	60	67	64	83	37
Total	74	76	76	63	67	71	74	63
December								
Unit 1	76	84	84	62	87	81	64	68
Unit 2	69	86	46	91	75	79	90	c
Total	73	85	65	76	81	80	77	34

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[a]Based on daily average power output as determined by Commonwealth Edison Company.

[b]Total Station Capacity = 1618 MWe.

[c]Unit inoperative.

The physical aspects of Station operation have been monitored on a daily basis since August, 1972. These data are presented in the reports entitled, "Operational Environmental Monitoring in the Mississippi River near Quad Cities Station" (Industrial Bio-Test, 1972, 1973a, 1973b, 1974a, 1974b, 1975; NALCO Environmental Sciences, 1975, 1976a, 1976b, 1977a, 1977b, 1978a, 1978b; Hazleton Environmental Sciences, 1979a, 1979b; Environmental Research and Technology, 1980). These data include temperatures taken upstream of the plant (river ambient), at the Station intake, at the return side of the spray canal, at the discharge and downstream of the discharge. These reports also present a chronology of Station operation which includes a record of the number of lift pumps operating to the spray canal, the number of operating circulating water pumps and the mode of Station operation (open, closed or combination cycle cooling). Monthly minimum, maximum and mean water temperatures at the Quad Cities Station are presented in Table 2.

TABLE 2

Monthly Minimum, Maximum and Mean Water Temperatures (°F)
at the Quad Cities Station, August, 1972 Through December, 1979

Year	Month	Upstream			Intake[a]			Discharge			Downstream		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max	Mean
1972	August	67.5	83.0	68.5	68.5	83.0	72.9	70.0	100.0	85.1	68.0	83.5	75.2
	September	58.0	75.5	69.3	58.0	74.0	67.8	61.5	95.5	75.4	58.0	75.8	68.9
	October	44.5	59.5	51.8	42.0	59.5	51.7	50.0	73.5	63.7	45.0	60.0	52.4
	November	33.1	46.9	40.0	33.6	53.2	40.7	45.0	76.5	63.8	33.0	48.0	40.4
	December	32.0	34.0	32.3	32.0	69.5	35.1	32.0	79.5	66.4	32.0	35.5	33.5
1973	January	32.0	32.5	32.1	32.0	46.6	32.4	41.0	76.0	59.4	32.0	34.0	32.4
	February	32.0	34.0	[illegible]	32.0	34.1	32.4	45.5	68.0	58.3	32.0	36.0	33.1
	March	33.6	46.5	[illegible]	33.4	46.5	41.3	51.5	74.0	64.4	33.6	46.8	41.4
	April	38.5	58.0	[illegible]	38.5	65.0	48.0	56.0	74.0	64.2	38.5	58.4	49.3
	May	54.0	63.7	[illegible]	54.0	63.7	58.8	56.8	83.9	74.1	53.8	64.4	58.9
	June	63.6	80.5	[illegible]	63.7	81.0	74.0	74.7	100.0	93.2	63.5	80.5	74.1
	July	73.9	82.8	78.1	73.8	82.8	78.1	86.2	101.4	97.4	74.1	84.4	79.3
	August	71.4	80.2	72.1	71.5	80.5	76.7	72.9	101.5	95.7	71.7	81.4	77.6
	September	61.2	80.7	69.3	61.5	80.7	69.4	71.5	100.0	87.9	62.0	82.1	70.2
	October	50.1	65.6	59.7	50.3	65.9	59.7	64.0	87.0	77.1	50.7	66.9	60.4
	November	39.0	50.1	42.1	37.4	50.1	39.4	50.5	72.4	63.0	37.6	52.0	42.9
	December	32.0	41.1	33.6	32.0	41.1	33.6	51.0	65.1	57.3	32.0	41.4	34.4
1974	January	32.0	32.8	32.1	32.0	32.9	32.1	32.4	62.4	53.5	32.0	35.5	32.7
	February	32.0	33.7	32.3	32.0	33.8	32.3	50.8	58.9	56.3	32.0	45.6	33.5
	March	31.9	39.6	37.2	31.9	40.0	37.2	33.7	63.4	57.3	32.5	40.8	37.6
	April	38.8	60.1	49.2	38.9	60.5	49.3	47.0	78.3	63.2	38.9	61.1	49.4
	May	53.0	67.2	60.0	52.8	68.5	60.3	64.5	99.9	79.2	53.1	68.0	58.5
	June	65.5	73.5	65.1	65.4	73.6	69.9	66.3	109.0	79.5	65.4	74.5	70.1
	July	74.1	83.3	78.5	73.9	83.3	79.6	74.7	108.9	98.9	73.8	85.0	80.2
	August	69.0	78.4	74.6	69.0	78.2	74.5	85.4	112.1	105.9	68.5	80.6	75.4
	September	58.5	73.2	65.9	58.5	72.0	65.5	72.0	109.9	89.0	58.5	74.6	64.1
	October	49.5	57.8	54.4	49.5	61.5	53.0	54.0	111.0	86.1	49.3	59.3	54.9
	November	33.8	72.0	44.4	33.8	73.0	44.5	55.0	104.1	82.7	33.4	59.7	45.0
	December	32.0	69.8	33.1	32.0	64.0	33.2	42.0	105.0	58.0	32.0	36.9	33.9
1975	January	32.0	33.3	32.1	32.0	33.1	32.1	32.0	50.2	36.1	32.0	34.3	32.4
	February	32.0	38.0	32.0	32.0	32.5	32.0	32.0	55.8	34.8	32.0	32.4	32.1
	March	32.2	35.2	33.1	32.0	35.2	32.9	41.5	74.5	58.9	32.0	35.5	33.3
	April	32.9	52.0	43.9	33.0	52.1	[illegible]	47.7	85.0	63.3	33.0	52.5	44.0

TABLE ? (continued)

Year	Month	Upstream Min.	Upstream Max.	Upstream Mean	Intake Min.	Intake Max.	Intake Mean	Discharge Min.	Discharge Max.	Discharge Mean	Downstream Min.	Downstream Max.	Downstream Mean
1975	May	50.4	73.[illegible]	69.9	50.5	75.6	63.7	69.2	115.0	99.0	50.0	74.3	62.6
	June	66.0	82.4	73.2	60.0	82.5	73.6	93.0	1[illegible].0	103.6	66.4	84.1	73.7
	July	73.0	84.5	79.5	73.0	84.5	79.9	85.6	11[illegible]	103.7	72.9	85.5	80.0
	August	72.3	84.0	77.8	72.[illegible]	37.5	78.3	81.5	114.[illegible]	96.2	72.4	85.5	78.4
	September	58.6	76.8	66.1	58.[illegible]	77.1	66.1	76.5	100.0	89.6	58.6	78.1	66.1
	October	51.0	63.1	57.5	53.5	72.4	63.1	76.2	109.0	88.7	50.5	63.5	57.8
	November	34.0	55.0	46.0	37.0	63.0	50.5	60.0	115.4	93.5	34.4	56.5	46.5
	December	32.0	37.9	32.7	26.6[c]	52.0	41.2	81.8	111.5	101.6	32.0	38.0	33.0
1976	January	32.0	32.2	32.0	32.0	52.0	40.1	67.5	107.5	83.7	32.0	32.4	32.0
	February	32.0	38.9	33.3	33.5	45.0	40.6	32.0	99.4	73.3	32.0	37.6	32.8
	March	32.5	49.7	39.5	33.5	59.5	47.1	71.0	108.5	86.7	33.3	49.9	39.6
	April	43.9	60.0	53.0	47.0	77.0	62.3	80.0	120.5	109.2	43.7	59.4	51.2
	May	53.1	69.5	62.0	59.5	79.2	69.1	88.4	120.1	110.3	53.5	69.9	64.4
	June	67.8	79.1	73.6	71.0	86.3	76.6	80.0	113.6	99.5	67.2	80.2	74.3
	July	70.2	82.8	78.6	72.0	87.0	80.1	89.0	111.0	99.0	72.1	84.9	79.3
	August	72.6	79.6	76.3	72.6	83.6	77.1	83.5	108.5	98.2	73.1	81.3	77.0
	September	62.0	74.7	67.0	60.0	75.0	67.1	b	b	b	60.1	76.3	67.4
	October	43.6	63.5	52.2	43.5	63.4	51.1	53.9	96.6	79.2	44.0	65.1	52.8
	November	32.2	44.4	36.5	32.1	44.8	36.6	43.0	84.9	67.9	32.3	46.7	38.2
	December	32.0	38.0	32.5	32.0	59.7	44.0	52.6	115.0	88.5	32.0	37.5	34.1
1977	January	32.0	32.3	32.0	32.0	58.9	37.6	63.5	113.0	83.2	32.0	38.9	33.7
	February	32.0	36.5	32.3	32.0	57.7	34.3	53.5	98.6	70.7	32.0	36.7	33.8
	March	32.0	49.6	37.5	32.0	49.6	41.2	43.0	100.9	77.6	32.2	49.6	37.8
	April	43.8	66.3	56.1	43.8	66.2	56.1	66.5	104.8	89.1	44.3	68.4	56.7
	May	61.1	79.3	70.4	61.0	87.3	70.6	83.3	111.0	95.7	61.3	80.9	72.8
	June	67.5	82.2	73.9	68.3	82.0	74.6	83.9	100.7	100.0	67.4	84.7	74.7
	July	75.9	85.0	80.0	73.1	86.5	81.0	84.4	116.5	104.0	75.9	87.0	81.3
	August	67.0	78.2	74.5	67.1	86.0	77.6	79.5	107.0	96.2	67.3	80.7	75.2
	September	61.9	74.9	67.6	74.3	80.3	72.6	88.0	112.7	102.5	62.1	77.0	68.1
	October	49.2	59.7	52.0	49.3	66.9	60.5	55.7	112.4	97.1	49.4	60.3	52.3
	November	32.0	53.5	43.0	40.5	63.6	52.9	52.6	108.7	95.6	32.0	54.4	43.1
	December	32.0	33.4	32.3	32.0	60.8	43.7	78.8	112.5	98.6	32.0	38.9	32.7

TABLE 2 (continued)

Year	Month	Upstream Min.	Upstream Max.	Upstream Mean	Intake[a] Min.	Intake[a] Max.	Intake[a] Mean	Discharge Min.	Discharge Max.	Discharge Mean	Downstream Min.	Downstream Max.	Downstream Mean
1978	January	32.0	32.0	32.0	32.0	56.3	38.2	60.6	114.0	89.2	32.0	35.7	32.8
	February	32.0	32.0	32.0	32.0	51.7	32.4	32.9	99.5	74.3	32.0	35.3	32.6
	March	32.0	36.2	32.5	32.0	38.6	32.6	34.0	92.0	61.4	32.0	41.1	33.0
	April	32.7	51.7	47.3	32.5	71.5	52.5	58.8	107.1	88.1	32.0	52.2	47.6
	May	50.6	74.4	60.3	53.5	77.1	64.0	80.3	113.2	103.5	50.6	75.5	62.6
	June	70.3	79.8	73.3	70.1	80.2	74.8	85.4	110.0	99.9	68.5	80.0	73.3
	July	73.0	81.5	77.4	70.5	82.5	76.2	94.8	118.9	107.3	73.0	82.7	77.9
	August	73.3	80.2	76.4	71.0	81.6	75.5	101.0	112.0	107.9	73.0	81.6	77.2
	September	62.2	79.8	72.0	59.8	81.0	71.4	91.2	111.8	103.1	53.3	81.9	72.0
	October	48.3	62.2	53.8	48.7	68.7	58.1	86.0	111.2	100.5	47.2	65.0	54.4
	November	32.2	51.9	41.2	32.0	62.3	46.5	74.2	119.8	107.8	32.0	53.8	41.1
	December	32.0	33.8	32.3	32.0	68.3	48.4	80.8	119.9	103.6	32.0	37.5	32.4
1979	January	32.0	33.5	32.0	32.0	70.0	39.4	40.2	120.0	87.5	32.0	35.0	32.3
	February	32.0	32.8	32.1	32.0	67.5	36.2	51.3	106.8	80.3	32.0	33.7	32.1
	March	32.0	38.7	32.7	32.0	61.5	37.2	64.2	106.8	85.9	32.0	38.2	32.7
	April	34.2	54.9	42.8	34.6	56.6	45.4	64.8	100.5	87.5	34.3	54.1	44.3
	May	52.5	68.9	62.8	48.8	70.0	61.0	67.5	107.0	92.0	49.5	68.4	60.9
	June	67.2	78.5	72.6	66.2	79.8	72.5	93.5	101.9	101.1	66.7	76.8	72.4
	July	74.0	81.9	78.0	72.8	81.9	77.8	110.0	117.5	106.7	73.6	82.6	78.5
	August	70.2	81.8	76.0	69.3	82.1	75.5	78.2	119.5	102.8	67.5	82.9	75.3
	September	C			63.5	77.5	69.8	C			65.0	85.0	72.4
	October	48.2	65.1	52.9	48.0	65.1	54.6	76.5	92.7	84.9	[illegible]	67.5	54.3
	November	35.0	54.5	43.2	33.6	50.3	41.7	63.4	95.7	82.6	33.3	52.4	41.6
	December	32.0	36.4	33.3	31.7	39.1	33.4	32.0	92.8	68.1	30.3	35.3	33.4

[a]Temperatures were recorded by a sensor located approximately two feet above the bottom.

[b]Data was not collected because of construction.

[c]Sensor inoperative.

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Section II

316(a) Demonstration Supplement

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A. Hydrological and Thermal Investigations

1. Critical Flow and Water Temperature Conditions for the Mississippi River at Quad Cities Nuclear Station

by

Dr. P. K. Kitanidis

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Critical Flow and Water Temperature Conditions

for the

Mississippi River at Quad Cities Nuclear Station[1]

<u>I. Description of the Upper Mississippi River (above Lock and Dam 14)</u>. The Mississippi River rises at Lake Itasca in north-central Minnesota and flows in a general southeasterly direction to Lock and Dam 14 which is situated a short distance upstream from the Quad Cities of Moline and Rock Island, Illinois, and Bettendorf and Davenport, Iowa. Major tributaries in this reach include the Minnesota River in Minnesota; the St. Croix River in Minnesota and Wisconsin; the Black, Chippewa and Wisconsin Rivers in Wisconsin; and the Turkey, Maquoketa and Wapsipinicon Rivers in Iowa. The topography of the basin consists for the most part of rolling farmland, except in the upper parts of the basin in Minnesota and Wisconsin where forests and lakes abound.

Six Federal dams and reservoirs, built during the period 1884-1913, are located in the headwaters area above the mouth of the Minnesota River. The total storage capcity of these reservoirs between their operating limits is somewhat less than one million acre-feet (1)*. The reservoirs were constructed to provide supplemental flow for navigation needs of the Mississippi River during periods of low runoff. Since the completion of the system of locks and dams on the Upper Mississippi River in 1938 (1), regulation of the reservoirs for navigation needs is no longer of primary importance, and they are now operated principally for flood control, recreation, and related purposes (2).

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[1]Prepared by Dr. Peter K. Kitanidis, Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa.

*Numbers is parentheses refer to items listed in the bibliography at the end of this report.

Flow in the Wisconsin River is regulated by 23 reservoirs and several hydroelectric power plants. Usable storage in the reservoir system is approximately 29 billion cubic feet (666,000 acre-feet). Five of these reservoirs, with total storage of 337,000 acre-feet, have gone on line since 1935. Most of the others have been in use since the early 1900's. The reservoirs usually are drawn down for the late fall and winter periods and restored to normal pool levels in the spring freshet season.

Nine reservoirs, having a total storage of about 528,000 acre-feet, have been constructed along the Chippewa River basin in Wisconsin. Two of these, with total storage of 364,000 acre-feet, were completed in the mid-1920's. The others were completed between 1880 and 1917.

During the 1930's, 13 locks and dams were constructed on the Upper Mississippi River between St. Paul, Minnesota, and Clinton, Iowa, in connection with the 9-foot navigation channel project. Clinton is approximately 12 miles upstream from Quad Cities Station, which is situated along the River between Dams 13 and 14. These locks and dams are operated by the United States Department of the Army, Corps of Engineers. The navigation dams maintain nearly constant pool elevations during low and medium low flows. During these periods, the movable gates in the dams are set so that there is a small (about 2 or 3 feet) opening between the bottoms of the gates and the gate sills. During medium and high flows the gates are taken entirely out of the water (1). It is general operating practice to draw the pool above each navigation dam down about one foot at the close of the navigation season. The usual period of navigation closure by ice is from about December 1 to April 10 (1). During severe winters, however, navigation can be stopped as early as November 10,

and may not be resumed until late April. The flow regulation incident to closure of the navigation season has had a significant effect upon the low-flow regime of the Mississippi River at Clinton, as will be discussed subsequently.

II. Streamflow of the Mississippi River at Clinton, Iowa. U.S. Geological Survey streamflow records are available for the Mississippi River reach of interest at Le Claire and Clinton, Iowa (497 and 512 miles above the Ohio River, respectively), for the period 1873 to date. Prior to 1939, the gaging station was located at Le Claire. Because of backwater caused by Lock and Dam 14 at Le Claire, the gaging station was transferred to Clinton in 1939. The drainage area above Le Claire is approximately 88,600 square miles. The watershed of the Wapsipinicon River, which enters the Mississippi between the two stations, accounts for most of the difference.

The temporal distribution of river flow is distinctly seasonal. Annual high flows usually occur between April and June, and the annual low flows occur between December and February. The highest annual flow at Clinton (95,000 cubic feet per second (cfs)) occurred in 1882, and the lowest (18,500 cfs) in 1934. The minimum daily flow of record, 6,500 cfs, occurred December 25-27, 1933. The average flow for the period 1874 through 1939 is 47,700 cfs, and for the period 1940 through 1977 is 46,400 cfs. The average flow of the Wapsipinicon is 1,400 cfs, accounting for the difference between the average flows for the two periods, as noted in the preceeding paragraph.

Water pollution control agencies in Iowa and Illinois both use the 7-day, 10-year low flow (denoted by 7Q10) in the application of water quality

criteria. This is the lowest average flow for 7 consecutive days that occurs with an average frequency of once every 10 years. Stated another way, it is the 7-day-averaged low flow that has a 10 percent probability of not being exceeded in any year. Because of the significance of this discharge, an analysis was made to determine if significant changes in the low-flow regime of the River have occurred as a result of increased development of the main stem and tributaries.

The 7-day, 10-year low flow at Clinton (Le Claire) for several periods is as follows:

Period prior to navigation dams (station at Le Claire)
(climatic years 1875-1939) . . . . 9,000 cfs

Period after navigation dams (station at Clinton)
(climatic years 1940-1977) . . . . 13,400 cfs

This tabulation shows that 7Q10 was significantly greater in the recent 39 years than in the preceeding 62 years, even though the average flow for the recent period (46,400 cfs) was less (see Figure 1) than that for the 64-year period (47,700 cfs).

By summing the flow of the Mississippi River at Clinton and the flow of the Wapsipinicon River (as measured by the USGS near DeWitt, Iowa), 7Q10 for the period 1940-1977 was found to be 13,700 cfs at Quad Cities Nuclear Station. Note that the value is slightly larger than the 7Q10 of 13,200 cfs for the period through 1969 used by Kennedy and Jain in the diffuser-system analysis.

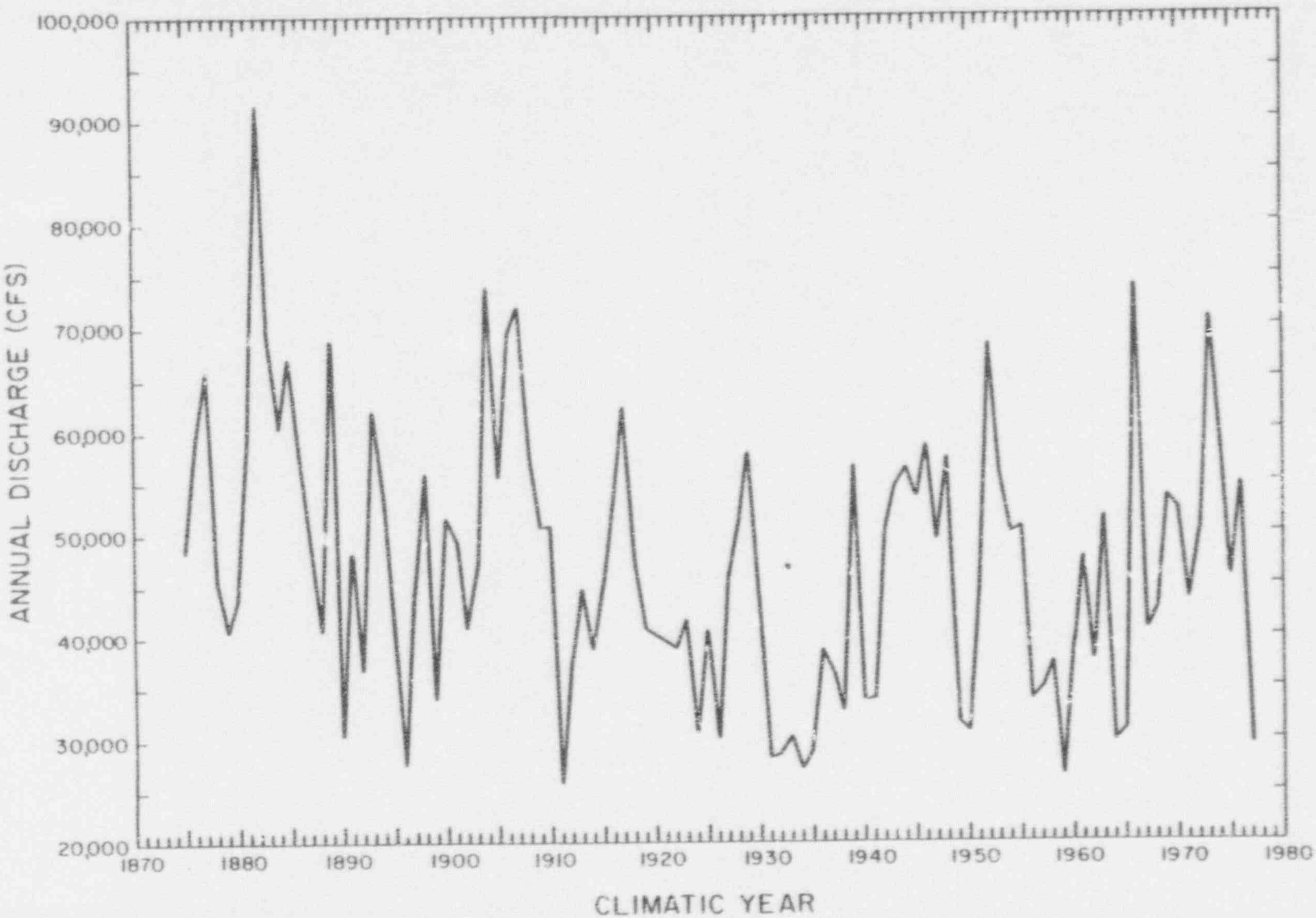

Figure 1. Annual Discharge of the Mississippi River at Clinton (Le Claire)

Since 1940, the minimum annual daily flow at Clinton was less than 10,000 cfs in only one year (9,600 cfs in December 1976). Between 1875 and 1939, the minimum annual daily flow was equal to or less than 10,000 cfs in 12 years (Figure 2). The minimum recorded 7-day low flow was 9,000 cfs in the period 1940-1977, and 7,400 cfs in the period 1875-1939 (Figure 3).

One of the factors contributing to the substantial increase in 7Q10 in the recent period is the seasonal navigation-pool drawdown, which coincides with the period when most low flows occur. Thus, storage from the system of navigation pools is released to augment natural flows during a critical period each year. In the period prior to operation of the navigation dams, most of the annual 7-day flows occurred in the month of December. Since 1940, however, the distribution of the occurrences of the annual 7-day low flow has changed drastically. Now they are fairly well distributed in the period between August and February. On a seasonal basis, 7Q10 is as given in Table 1.

Period	7Q10 (cfs)
October-December	
Period 1875-1939 (Le Claire)	9,700
Period 1940-1977 (Clinton)	14,500
January-March	
Period 1875-1939 (Le Claire)	11,200
Period 1940-1977 (Clinton)	14,500
April-June	
Period 1875-1939 (Le Claire)	24,900
Period 1940-1977 (Clinton)	22,700
July-September	
Period 1985-1939 (Le Claire)	16,000
Period 1940-1977 (Clinton)	14,500

Table 1. Seasonal distribution of 7Q10, Mississippi River at Le Claire and Clinton (without including the Wapsipinicon River)

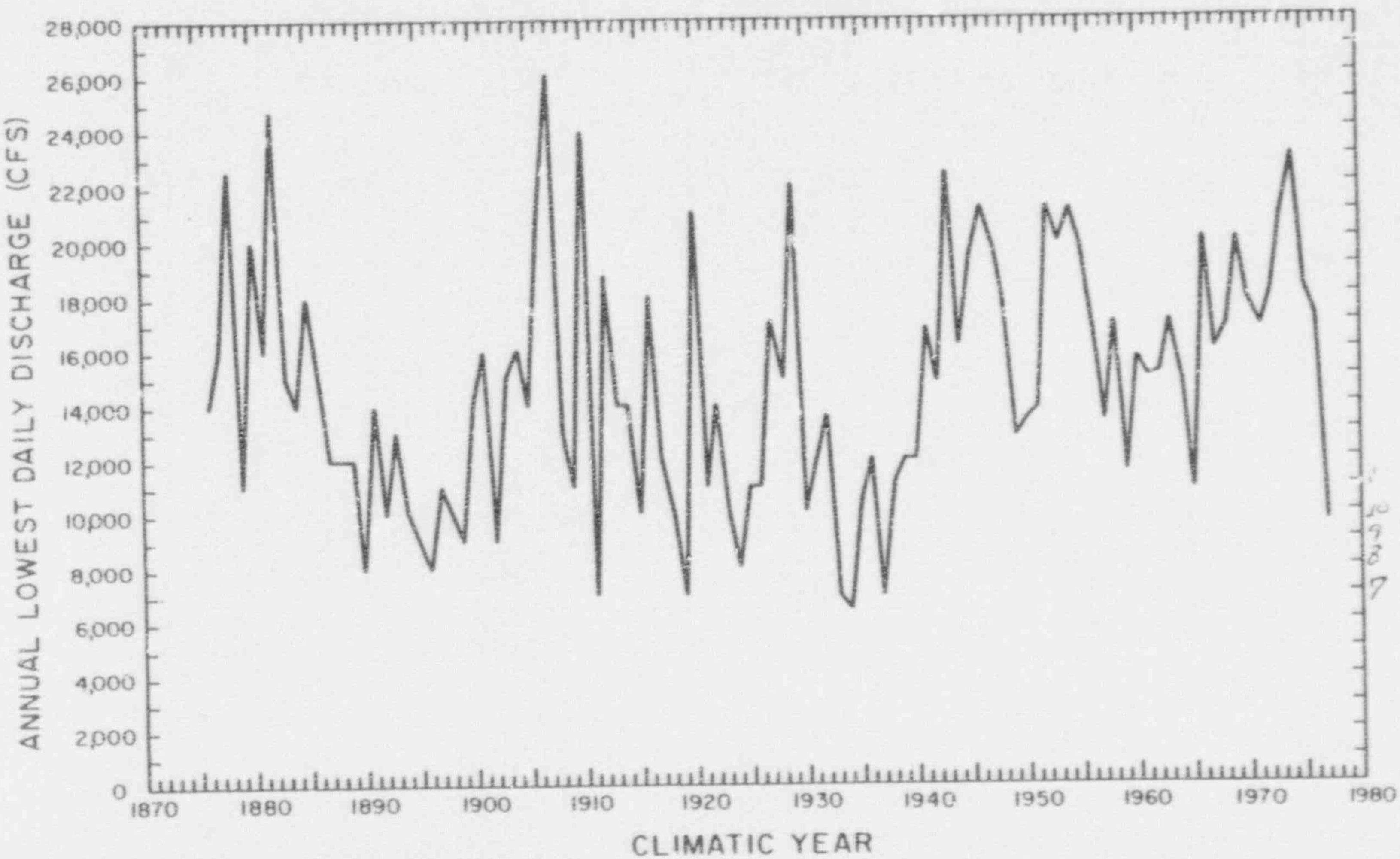

Figure 2. Annual Lowest Daily Discharge of the Mississippi River at Clingon (Le Claire)

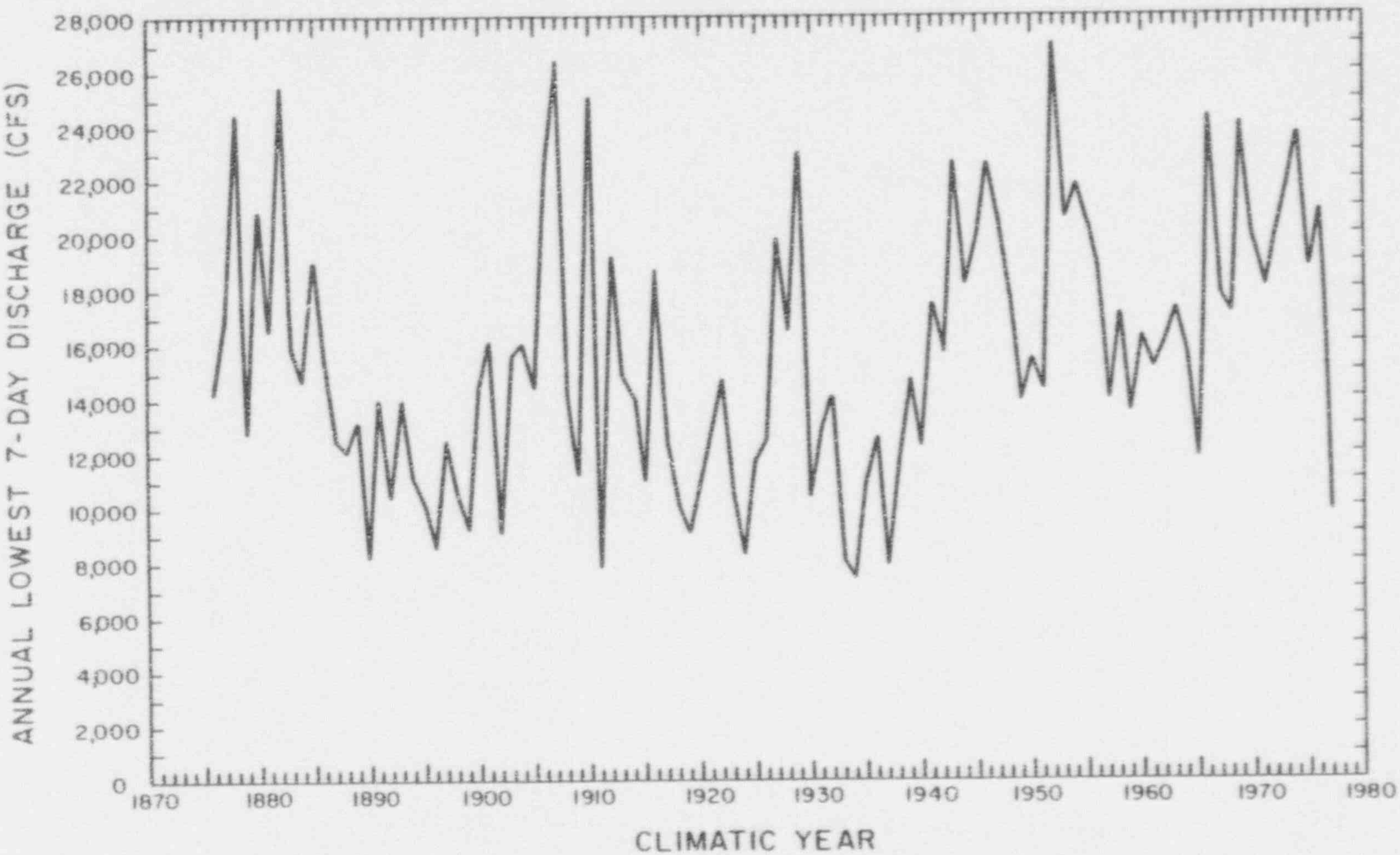

Figure 3. Annual Lowest 7-Day Discharge of the Mississippi River at Clinton (Le Claire)

The flow at Quad Cities Nuclear Station is the sum of the flow of the Mississippi River at Clinton with the flow of the Wapsipinicon River at DeWitt. The quantity 7Q10 of the Mississippi River at the Station for the period 1940-1977 is given in Table 2.

Period	7Q10 (cfs)
October-December	14,700
January-March	14,700
April-June	23,200
July-September	14,900

Table 2. Seasonal distribution of 7-day, 10-year low flows, Mississippi River at Quad Cities Nuclear Station (including the Wapsipinicon River).

Flow-duration curves, which show the percent of time that indicated discharges have been equalled or exceeded, are a convenient means of illustrating the entire flow regime for a particular period of record. Flow-duration curves for mean daily discharge of the Mississippi River at Quad Cities Nuclear Station are presented in Figure 4 on annual and seasonal bases and on a monthly basis in Figure 5. The flow-duration curves for the Mississippi River at Clinton (Figure 6) confirm that low flows for the period since 1940 are substantially higher, and medium and high flows somewhat lower, than those for the period prior to 1940. The reasons for this are set forth above.

As pointed out above, about 337,000 acre-feet of usable storage has gone on line in the Wisconsin River basin since 1935. Two of the largest of these reservoirs--the dams on the Petenwell and Castle Rock Flowages--were placed in operation in 1950. Analysis of flow records for the period since 1938 have indicated that storage releases in the Wisconsin River basin

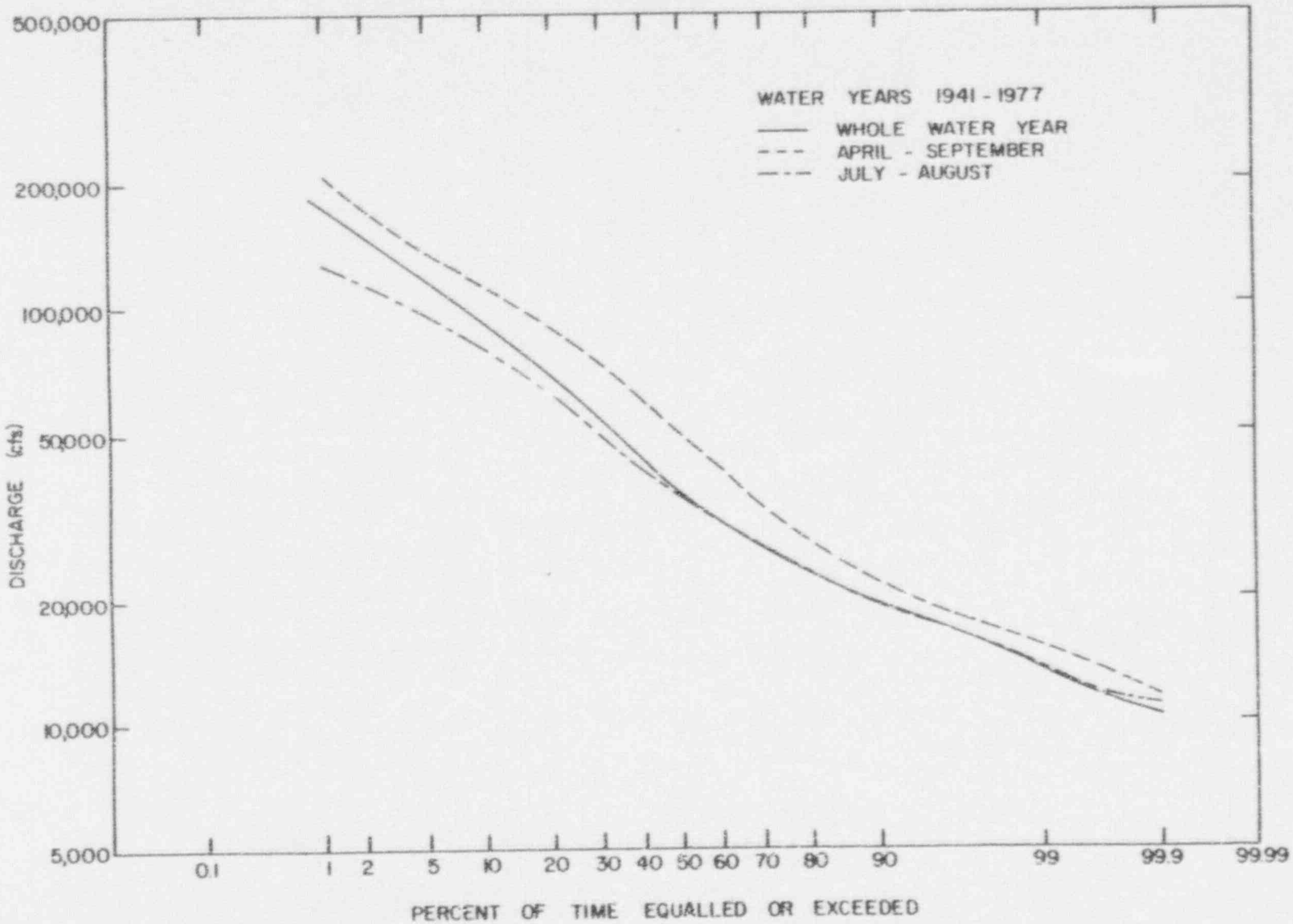

Figure 4. Duration Curves of Mean Daily Discharge, Mississippi River at Quad Cities Nuclear Station (including flow of the Wapsipinicon River)

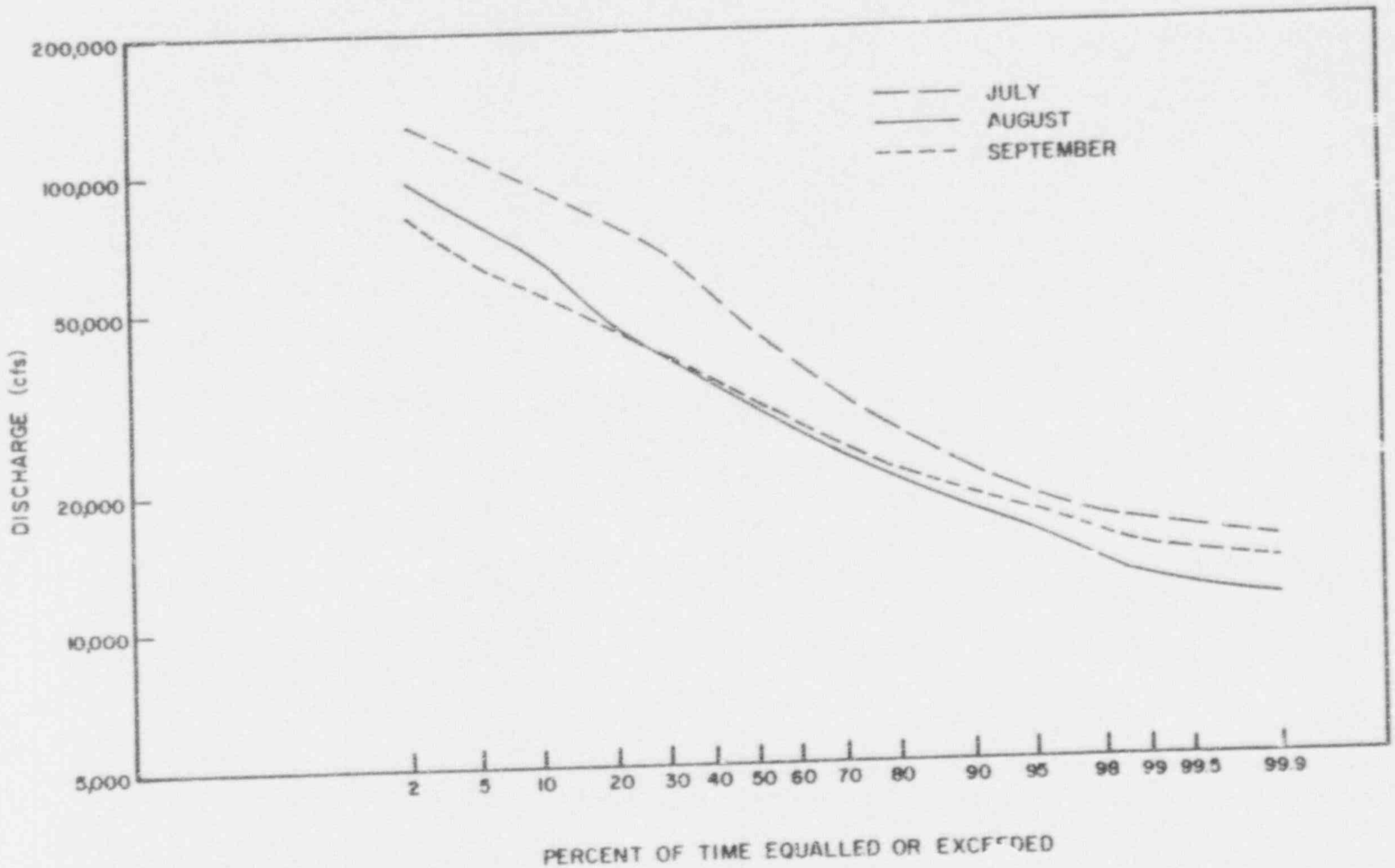

Figure 5. Duration Curves of Mean Daily Discharge on Monthly ..ses, Mississippi River at Quad Cities Nuclear Station (including flow of the Wapsipinicon River)

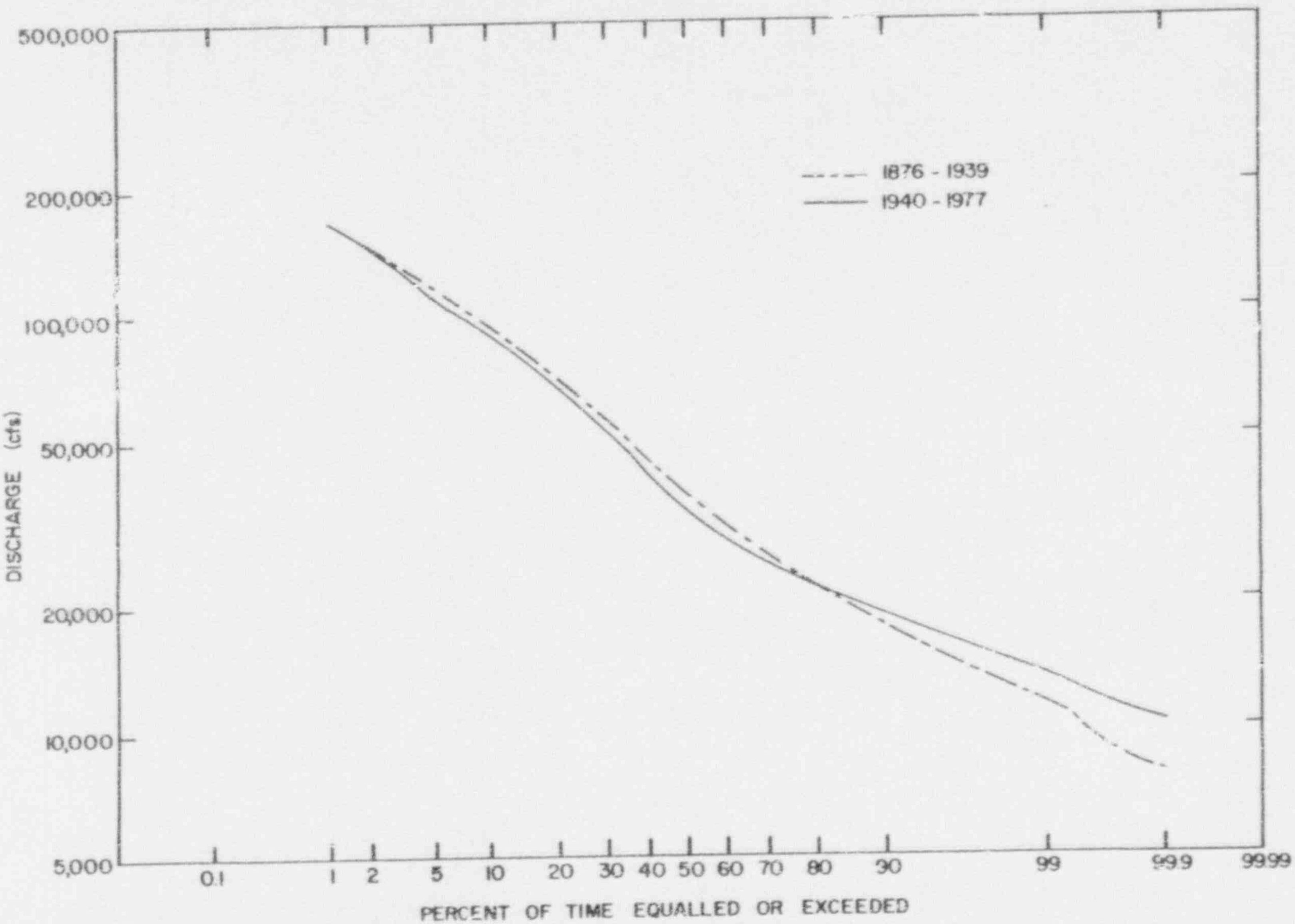

Figure 6. Duration Curves of Daily Discharge, Mississippi River at Clinton (Le Claire)

are the principal causes of increased Mississippi River flows in January and February. Storage releases from the navigation pools on the main stem have the greatest effect on flow in early winter.

In order to determine whether the period since 1940 is representative of a longer-term period, flow-duration and 7-day low-flow frequency curves for the Cedar River at Cedar Rapids, Iowa; Pecatonica River at Freeport, Illinois; and La Crosse River near West Salem, Wisconsin, were studied. Records at these stations extend back to 1902, 1914, and 1913, respectively. Analysis of these records indicated that there is practically no difference between the flow patterns for the long-term periods and the period since 1940. If these discharge records for these other sites are representative of the Mississippi River basin between St. Paul and Clinton, then the record at Clinton since 1940 should also be representative of a long-term period. It was concluded that this is indeed the case.

The combination of the operation of a series of navigation dams on the main stem and development of storage reservoirs in the Wisconsin River basin have materially altered the low-flow regime of the Mississippi River at Clinton. Since these control structures will continue to function for the foreseeable future, the flow selected for application of water quality criteria should be based on the period of record since 1940. Based upon the analyses discussed here, 7Q10 for the Mississippi River is 13,400 cfs at Clinton and 13,700 cfs at the Quad Cities Nuclear Station, as determined from the low-flow frequency curve for the period since 1940.

III. Temperature Data, Mississippi River in the Vicinity of Quad Cities Nuclear Station.

A. Description of Stations. The U.S. Geological Survey operates three continuous-record water temperature gaging stations on the Mississippi River within 20 miles of the location of Quad Cities Nuclear Station (506 miles upstream from the Ohio River, or R.M. 506). The exact locations of the data-acquisition points and the lengths of river-temperature records are given in Table 3.

Station Name	Number	River Mile	Length of Record
Clinton, Iowa	05420500	518	1974-1977
Hampton, Illinois (Dam 14)	05422400	493	1973-1978
Fulton, Illinois (Dam 13)	05420400	522	1969-1978

Table 3. USGS water-temperature stations along Mississippi River near Quad Cities Nuclear Station.

Other USGS continuous-record water temperature gaging stations on the Mississippi River are at McGregor, Iowa (R.M. 633.4), Keokuk, Iowa (R.M. 364.2), Alton, Illinois (R.M. 202.7), Kellogg, Illinois (R.M. 201.9) and Chester, Illinois (R.M. 176.8). However, due to their relatively large distances from the Station, these data were not used in the analysis.

1. Clinton, Iowa: This site is 12 miles upstream from Quad Cities Nuclear Station. Due to certain problems, operation of the temperature record was discontinued in 1977. Temperature data for 1978 were collected at the

Fulton station at Dam 13 (station no. 05420400). For the period of record (water year 1974 to 1977), temperature was usually recorded once daily.

2. Hampton, Illinois: This site is 13 miles downstream from Quad Cities Nuclear Station. The records are not complete, with some data from the most critical periods (April and summer months) missing. However, the periods of record coincide with the period Quad Cities Nuclear Station was in operation, and consequently the water temperature at this location has been influenced by the thermal discharges from the Station.

3. Fulton, Illinois: This site is approximately 16 miles upstream from Quad Cities Nuclear Station. A temperature recorder has been in operation there since June 1969. These measurements are considered to be more reliable than measurements taken at the Clinton or the Hampton station, and were used in the present analysis.

B. Verification. The temperature recorder is located at Lock and Dam No. 13 (R.M. 522.5). Its exact location is indicated by an asterisk in Figure 7. Before analyzing the records one must establish that the records are representative of the ambient River temperature in the vicinity of Quad Cities Nuclear Station. Thermal stratification as well as lateral and longitudinal variation of temperature must be examined.

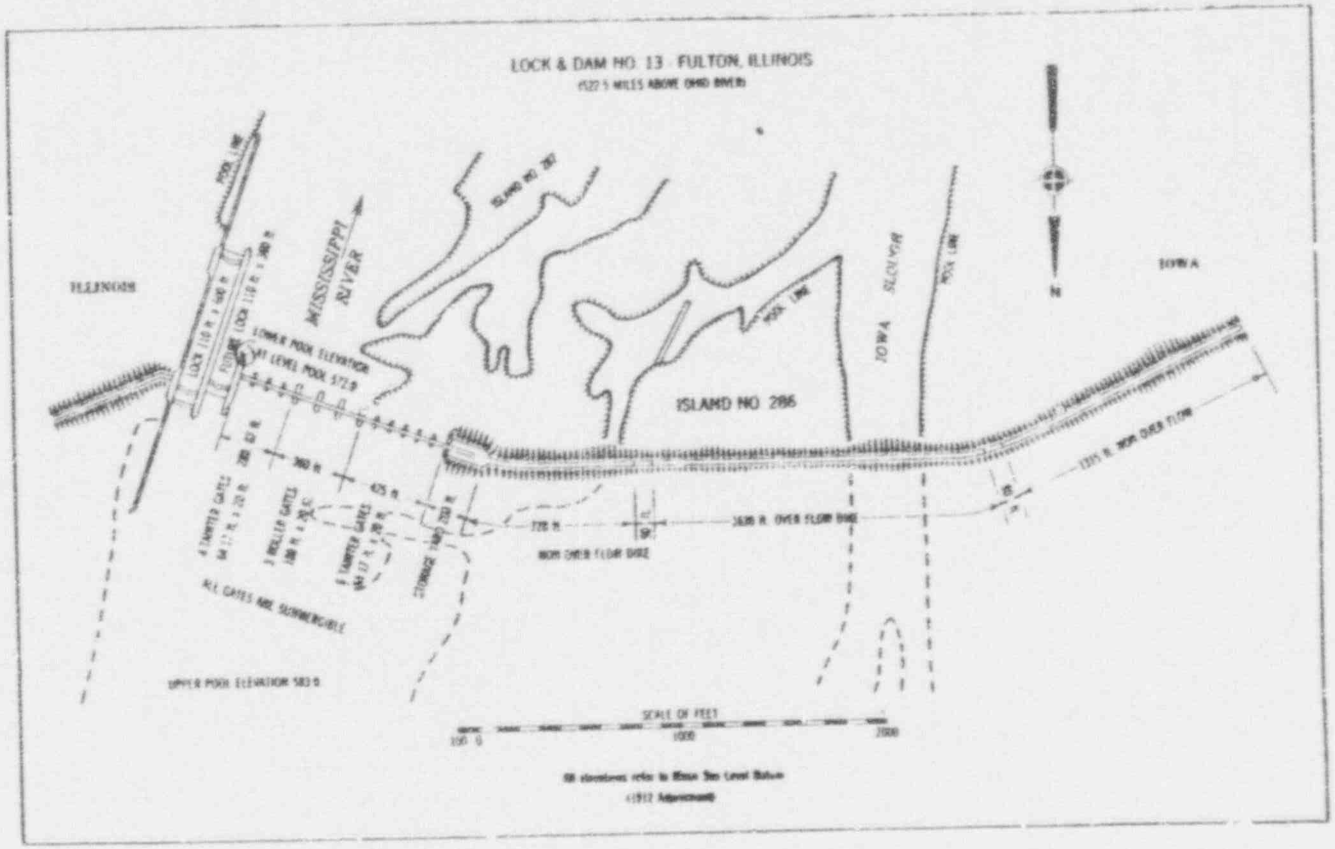

Figure 7. Position of the Temperature Gage

1. Stratification characteristics: With the exception of the slough areas, which may exhibit thermal stratification during the summer months, practically no stratification occurs in the River in the vicinity of the Quad Cities Station (3, 4). Thus, although the temperature is measured at a depth slightly below the low-flow pool, the recorded values should give a good estimate of the depth-average temperature even in periods of low flow.
2. Lateral (across the River) variation: Temperature differentials across the Mississippi River are often pronounced, because of the large width of the River and the slow rate of lateral mixing. This variation makes evaluation of the average cross-sectional ambient temperature rather difficult.
3. Streamwise temperature increase: The average temperature of the Mississippi River water increases as the water moves downstream. This is the result of the variation of ambient air temperature and solar radiation associated with the change of latitude, and also a result of mixing with the generally warmer water of the tributaries.

The natural (no plants operating) temperature increase along the Mississippi River between Fulton gaging station, where data are available, and Quad Cities Nuclear Station has been estimated using a computer-based numerical model (3) for average River discharge and weather conditions, with the results given in Table 4. The calculated natural

(no plants operating) temperature increase for 7Q10 combined with average weather conditons is also given in Table 4.

Month	ΔT (for average Q)	ΔT (for 7Q10)
February	0 °F	0 °F
May	0.2 °F	(not available)
August	0.15°F	0.20°F
November	0.2 °F	0.15°F

Table 4. Temperature increase along the Mississippi River between Fulton and Quad Cities Nuclear Station.

With the existing plants the temperature increase between Fulton and the Station is smaller than the corresponding natural increase.

The Wapsipinicon River flows into the Mississippi River downstream of the Fulton gaging station and a short distance upstream of the Station, and probably accounts for the largest part of the water-temperature increase between the two locations. The mean flow of the Wapsipinicon at DeWitt, Iowa, is less than 4 percent of the mean flow of the Mississippi River at Clinton. On the basis of USGS data from gaging stations on rivers with drainage areas, topography, and geographical settings similar to those of the Wapsipinicon River, it was established that one should expect the temperature of

the Wapsipinicon River to be within ±4°F of the temperature of the Mississippi River at the point of confluence. Consequently, for average flow conditions, the Wapsipinicon River should not affect the average temperature in the Mississippi River by more than ±0.16°F. This effect should be even smaller in the case of the low flows, since the contribution of the Wapsipinicon River to the Mississippi River 7Q10 at the Quad Cities Nuclear Station is less than 3 percent of the Mississippi River discharge.

Temperature measurements from the Fulton station were compared with some temperature measurements taken just upstream from Quad Cities Nuclear Station. The results of this comparison are presented in Table 5. It is seen that for all dates for which data were available the difference between the temperature which has been recorded at Fulton by the USGS and the temperature which has been recorded just upstream from Quad Cities Nuclear Station by the Iowa Institute of Hydraulic Research and Hazleton Environmental Sciences Corporation (formerly NALCO Environmental Sciences) is within the anticipated (3, 4) lateral (across the River) temperature variation.

Date	Daily Average Temperature Recorded at Fulton (°F)	Average Ambient Temperature at Quad Cities-- IIHR Measurements (°F)	Daily Average Temperature at Quad Cities-- HESC Measurements (°F)
11-02-72	44.5	46.5	
11-09-72	42.5	44.1	
11-28-72	32.5	34.5	
07-23-73	75.0	74.5	
07-25-73	76.5	78.0	
07-31-73	75.5	77.5	
08-17-73	77.0	79.0	
08-30-73	78.0	80.0	
09-12-73	67.5	71.0	
10-18-73	61.5	63.0	
10-31-73	48.5	51.5	
11-14-73	40.0	40.5	
12-03-73	40.0	40.5	
01-16-74	32.0	32.0	
01-21-74	32.0	32.5	
03-14-74	37.5	37.5	38.5
07-15-76	81.5	81.0	81.0
09-16-76	66.0	68.5	67.0
09-30-76	61.0	62.0	61.5

Table 5. Comparison of temperature measurements at Fulton with temperature measurements just upstream of Quad Cities Nuclear Station.

IV. Mississippi River Temperature at Fulton, Illinois. The principal temperature variations of the Mississippi River at this site are seasonal. The average temperature during the climatic year is given in Figure 8. The annual high temperature usually occurs in July. The highest daily temperature recorded in the period June 1967 to September 1977, 85°F, occurred in July 1977.

The percent of time a given temperature is equalled or exceeded at Fulton is presented in Figure 9. The percent of time a given temperature is equalled or exceeded is presented in Figures 10 and 11 on a monthly basis, for the months April through September. The period of record used in the development of these figures is June 1967 to September 1977. These figures indicate that an average daily River temperature of 82°F is equalled or exceeded at Fulton one percent of the time on an annual basis. However, the same temperature is equalled or exceeded seven percent of the time during the month of July.

V. Evaluation of the River Heat-Assimilation Capacity. Water pollution control agencies in both Iowa and Illinois have adopted maximum temperatures which cannot be exceeded more than one percent of the hours in the 12 month period ending any month. These maximum permissible temperatures prescribed by Iowa and Illinois are given in Table 6.

	Iowa (°F)	Illinois (°F)
January	45	45
February	45	45
March	57	57
April	68	68

	Iowa (°F)	Illinois (°F)
May	78	78
June	85	86
July	86	88
August	86	88
September	85	86
October	75	75
November	65	65
December	52	52

Table 6. Maximum permissible temperatures at Fulton.

The data summarized in Figures 10 and 11 indicate that the River temperature at Fulton does not exceed these limits more than one percent of the time. However in order to identify critical combinations of River discharge and River temperature which may result in the violation of these standards at Quad Cities Nuclear Station, the following analysis was performed.

The permissible heat-assimilation capacity of the river is defined here as the maximum rate of heat input which will not increase the River water temperature above the permissible maximum. This analysis does not address the question of whether the discharge of waste heat satisfies the other water quality standards, such as time-rate of temperature increase, mixing-zone characteristics, etc.

The heat-assimilation capacity of the Mississippi River at the location of the Quad Cities Nuclear Station can be calculated from the River discharge and the permissible temperature increase using the following formula:

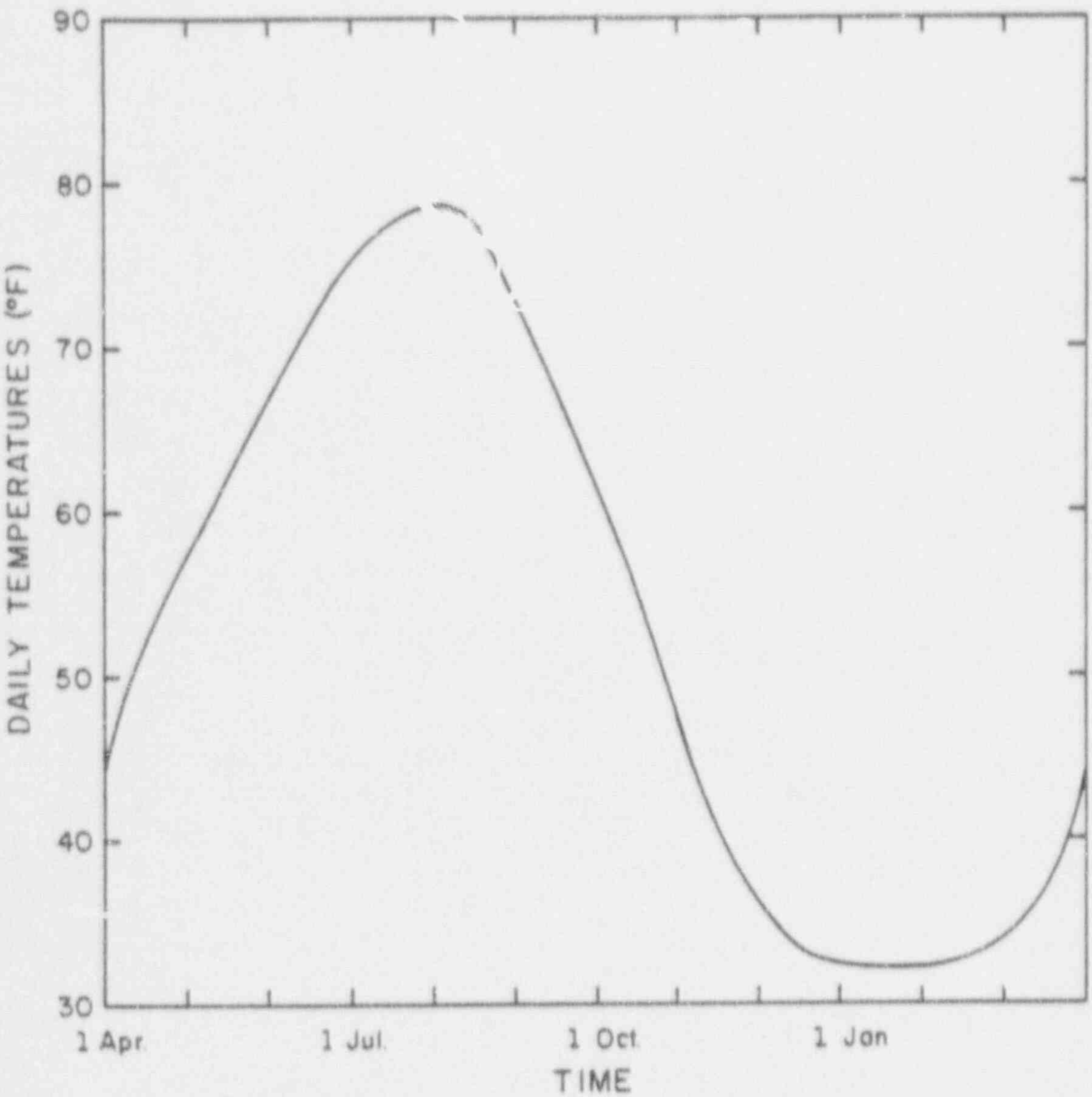

Figure 8. Average Mississippi River Water Temperature during the Climatic Year

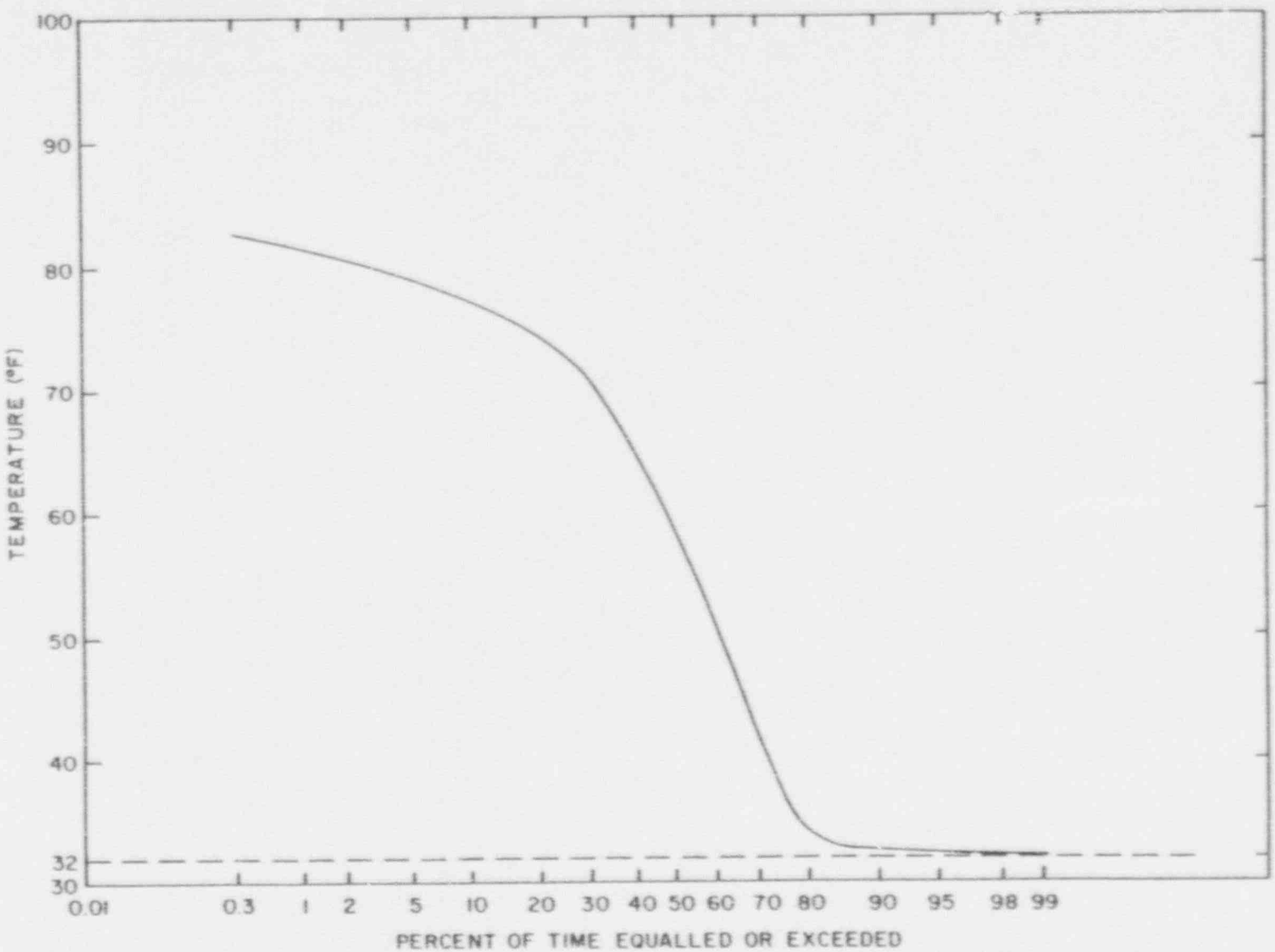

Figure 9. Duration Curve of Daily Temperature of Mississippi River at Fulton

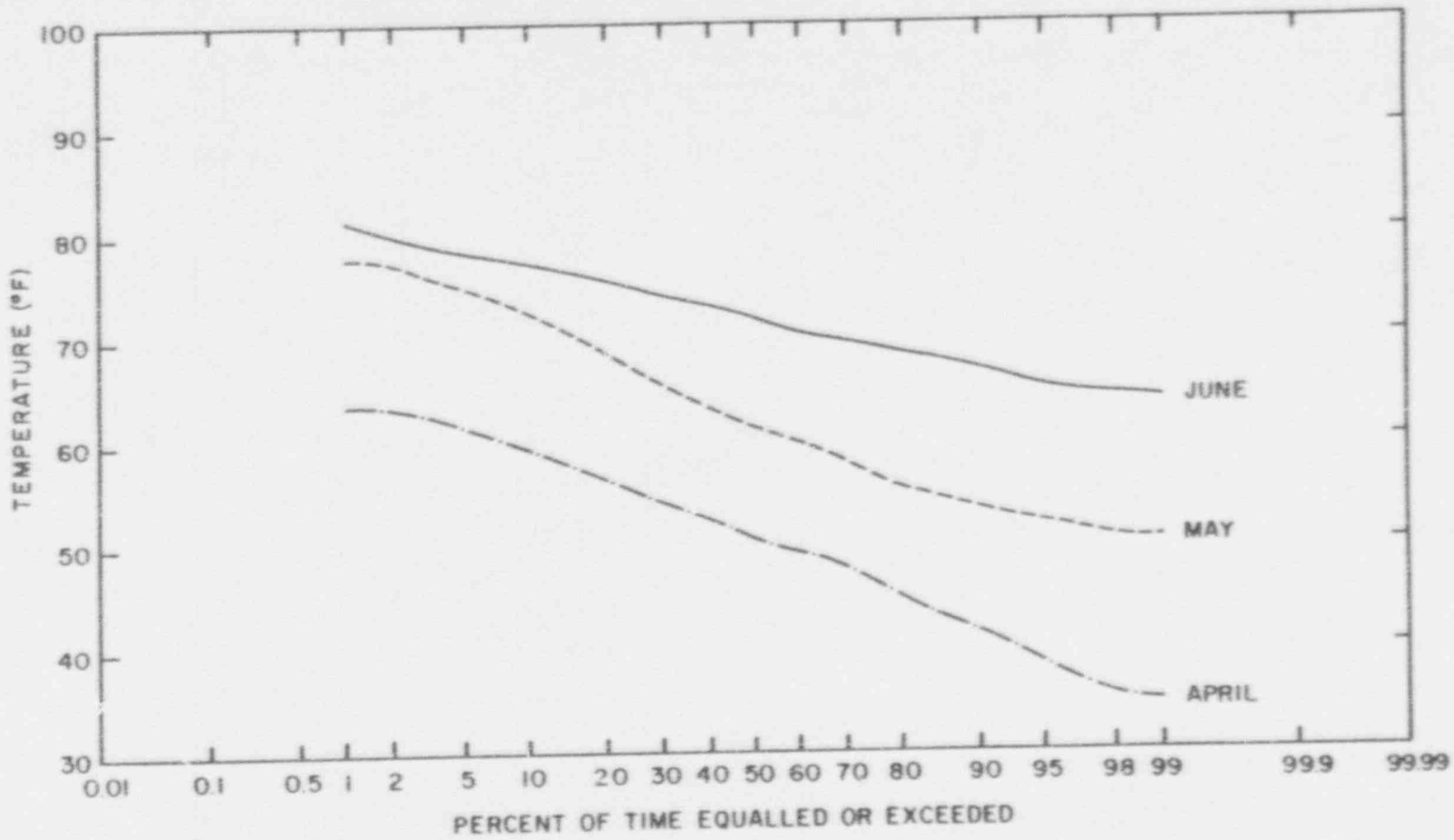

Figure 10. Duration Curves of Daily Temperature of Mississippi River at Fulton (on a monthly basis)

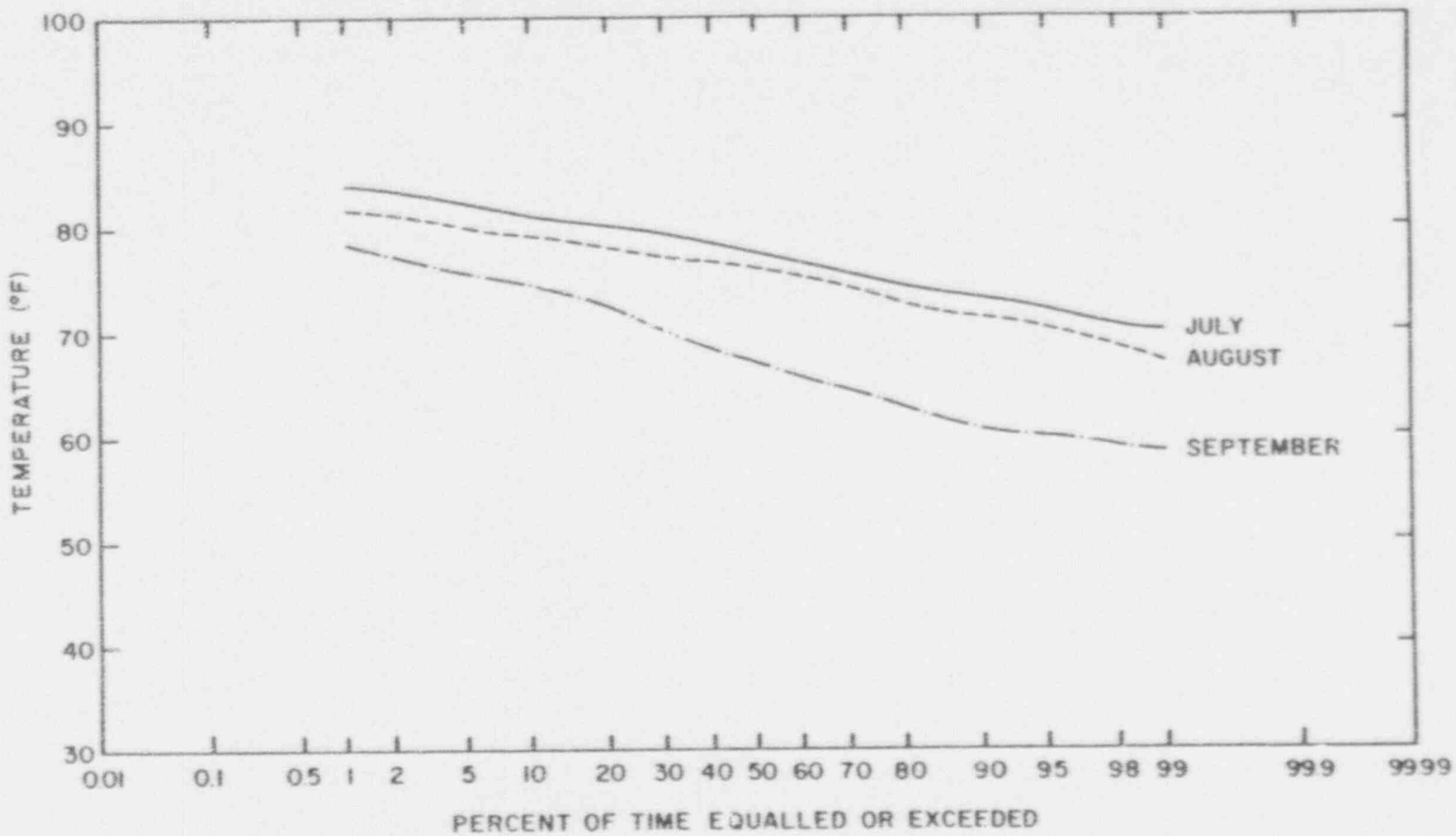

Figure 11. Duration Curves of Daily Temperature of Mississippi River at Fulton (on a monthly basis)

$$HAC = 62.4\ Q(\Delta T)$$

where

HAC = the heat-assimilation capacity (Btu/sec) of the Mississippi River at the location of the Quad Cities Nuclear Station.

Q = the River discharge (cfs) at the Station, calculated as the sum of the discharge of the Mississippi River at Clinton, and the discharge of the Wapsipinicon River at DeWitt.

ΔT = the maximum permissible temperature increase (°F), given by

$$\Delta T = \begin{cases} 0, & \text{IF } T_{ML} - T_F - 0.2 < 0 \\ T_{ML} - T_F - 0.2, & \text{if } 0 < T_{ML} - T_F - 0.2 < 5 \\ 5, & \text{if } T_{ML} - T_F - 0.2 > 5 \end{cases}$$

where T_{ML} is the maximum permissible temperature (°F) and T_F is the River temperature (°F) at Fulton. The correction term, 0.2°F, accounts for the difference between the River water temperatures at Fulton, and Quad Cities Nuclear Station.

Using measured daily temperatures and discharges for the period June 1969 to September 1977, and the Iowa water-temperature limits, adopted in the NPDES Permit, the heat-assimilation capacity of the Mississippi River was statiscally analyzed. The percent of time a given HAC is equalled or exceeded is depicted in Figure 12. The heat-assimilation capacity of 3,200,000 Btu/sec, corresponding to the full load waste-heat discharge rate from Quad Cities Nuclear Station, is equalled or exceeded 99.2 percent of the time. Consequently the data indicate that heated discharge from the Station, operating continuously at full load, will cause River-water temperature increases which are within the limits set in the NPDES Permit 99.2 percent of the time. When

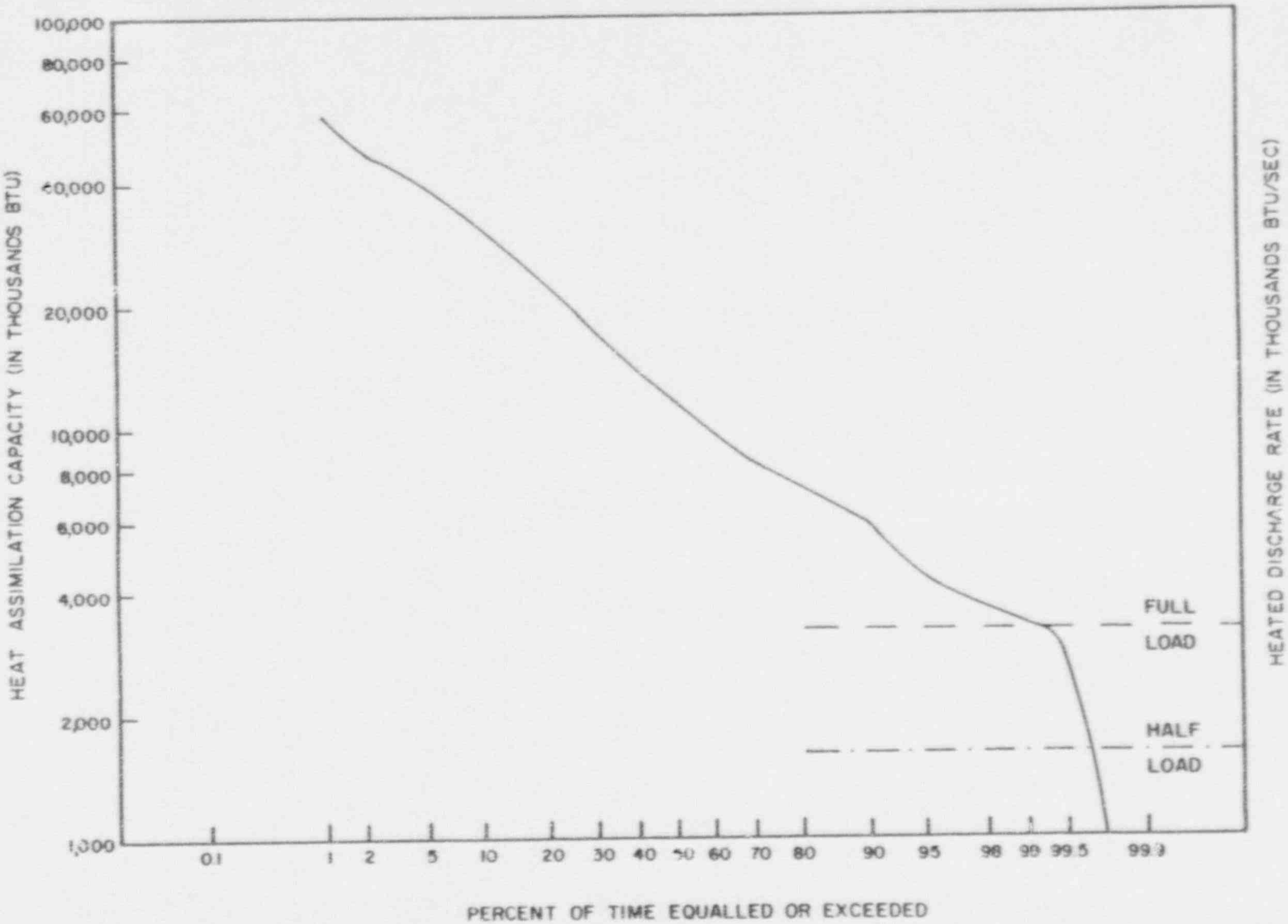

Figure 12. Duration Curve of Heat Assimilation Capacity of Mississippi River at the Quad Cities Nuclear Station

the Station operates continuously at half load, the maximum temperature limits set in the NPDES Permit will be exceeded only 0.3 percent of the time.

In the period of record, the River heat-assimilation capacity has been less that 3,200,000 Btu/sec 21 times, all of them during the low-flow water year 1977. In the period of record the River heat-assimilation capacity was less than 1,600,000 Btu/sec eight times, all of them in May 1977. Natural temperature exceeded the temperature limit adopted in the NPDES Permit two times in the period of record, both in May 1977.

An analysis of actual plant operating data performed by Commonwealth Edison Company indicates that during the 21 times that the heat-assimilation capacity was less than 3,200,000 Btu/sec, the plant exceeded the temperature standard a total of 77 hours which is 0.9% of the hours in a twelve month period. At no time did the plant exceed the maximum allowable temperature which is 3°F above the monthly temperature standard.

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2. Thermal and Hydraulic Performance

of the

Quad Cities Nuclear Station

Waste Heat Diffuser System

by

Dr. J. F. Kennedy

and

Dr. S. C. Jain

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Thermal and Hydraulic Performance

of the

Quad Cities Nuclear Station

Waste-Heat Diffuser System[1]

I. Introduction and Background. The Quad Cities Nuclear Station (QCNS) was designed and constructed during the second half of the 1960's and early 70's, and was completed in 1971. At the time it was under design, no thermal-discharge standards had been established for the Mississippi River, and, accordingly, a very simple system was designed and constructed to discharge heated water to the River from the condensers. The discharge structure was an open channel which intersected the shoreline about 750 ft downstream from the intake structure and was inclined about 30° to the perpendicular from the shoreline. It was anticipated that the submerged spur dike immediately downstream from the discharge would be modified to direct the heated water toward the deepest part of the river channel, which is nearer the Iowa (west) bank. The overriding criterion in the design of the discharge structure was to minimize heated-water recirculation from the discharge into the intake. This was a paramount consideration in the design of all power-plant discharge and intake systems in the 1960's.

At about the time the plant was completed, in 1971, river thermal standards were promulgated. One of the principal provisions of these standards was that an artificial heat load imposed on the Mississippi River could not produce a temperature rise greater than 5°F outside a mixing zone with area equal to that of a 600-foot-radius circle (or about 26 acres), for a River discharge equal to the seven-day-average River flow such that a smaller flow

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[1]Prepared by Drs. John F. Kennedy and Subhash C. Jain, Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa.

occurs (on the average) once in ten years. This discharge is referred to as the 7Q10 flow. The condenser flow from QCNS has a design discharge (flow rate) of 2,270 cfs (cubic feet per second) and a temperature rise (above the plant's intake-water temperature) of 23°F. Analysis of the river-discharge records through water year 1969 for Clinton, Iowa, which is located about 15 miles upstream from QCNS, led to a 7Q10 value of 13,200 cfs at QCNS. Note that different values of 7Q10 are used in Kitanidis' analysis of River discharge and water temperature (Section II-A-1). The differences arise from use of a longer period of record, through water year 1978, by Kitanidis. A value of 7Q10 = 13,200 cfs is used in this Section, because that value was utilized in the design of the diffuser pipe, thermal analysis, and field-data program.

The fully mixed temperature rise corresponding to this 7Q10 is

$$\Delta T_{Q10} = 23(°F)\ \frac{2,270\ (cfs)}{13,200\ (cfs)} = \quad 3.95°F.$$

This is the river-temperature rise that would result if the QCNS thermal discharge were completely mixed with the 7Q10 flow. This value is so close to the maximum permissible value at the mixing-zone boundary, 5°F, that it was clear that a structure would have to be devised which would achieve virtually complete mixing of the plant and River flows within a very short distance from the discharge structure. It was also realized that the then constructed river-bank outfall likely would not meet the standards. Nevertheless, because the shoreline structure already was in place, an intensive laboratory and theoretical study was undertaken to determine the temperature-rise distributions it produced in the River, and to investigate modifications to the structure which would improve its mixing characteristics. This study is

described in a Universit[illegible]port (1)*. Suffice it here to say that no practical modifications [illegible] structure were found which would enable the plant to meet the thermal standards under conditions of low River flows. However, a simple means [illegible]ntly enhancing the mixing of the plant's discharge from the rive[illegible] with the River flow was developed and subsequently used during [illegible] the diffuser system was under design and construction. This modification consisted of a narrowing of the discharge-channel exit, by means of sheet-pile walls, to produce a jet with higher velocity and which therefore penetrated farther into the River, and in the process became more diluted. This modified river-bank discharge structure is described by Jain *et al* (1).

The requirement that the plant's discharge be virtually completely mixed with the River within a very small area dictated the following requirements for the discharge system:

1. Structural means be utilized to convey the heated water into the River. Figure 1 shows a map of the area. The deepest part of the channel, indicated by the numbered (river miles) line with arrows, is seen to be closer to the Iowa shore. A jet discharge from the Illinois shore loses its momentum before reaching this part of the channel, where the River's flow is concentrated.
2. The release from the structure be staged across the River to be proportional to the product of local River

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*Numbers in parentheses refer to items listed in the bibliography at the end of this report.

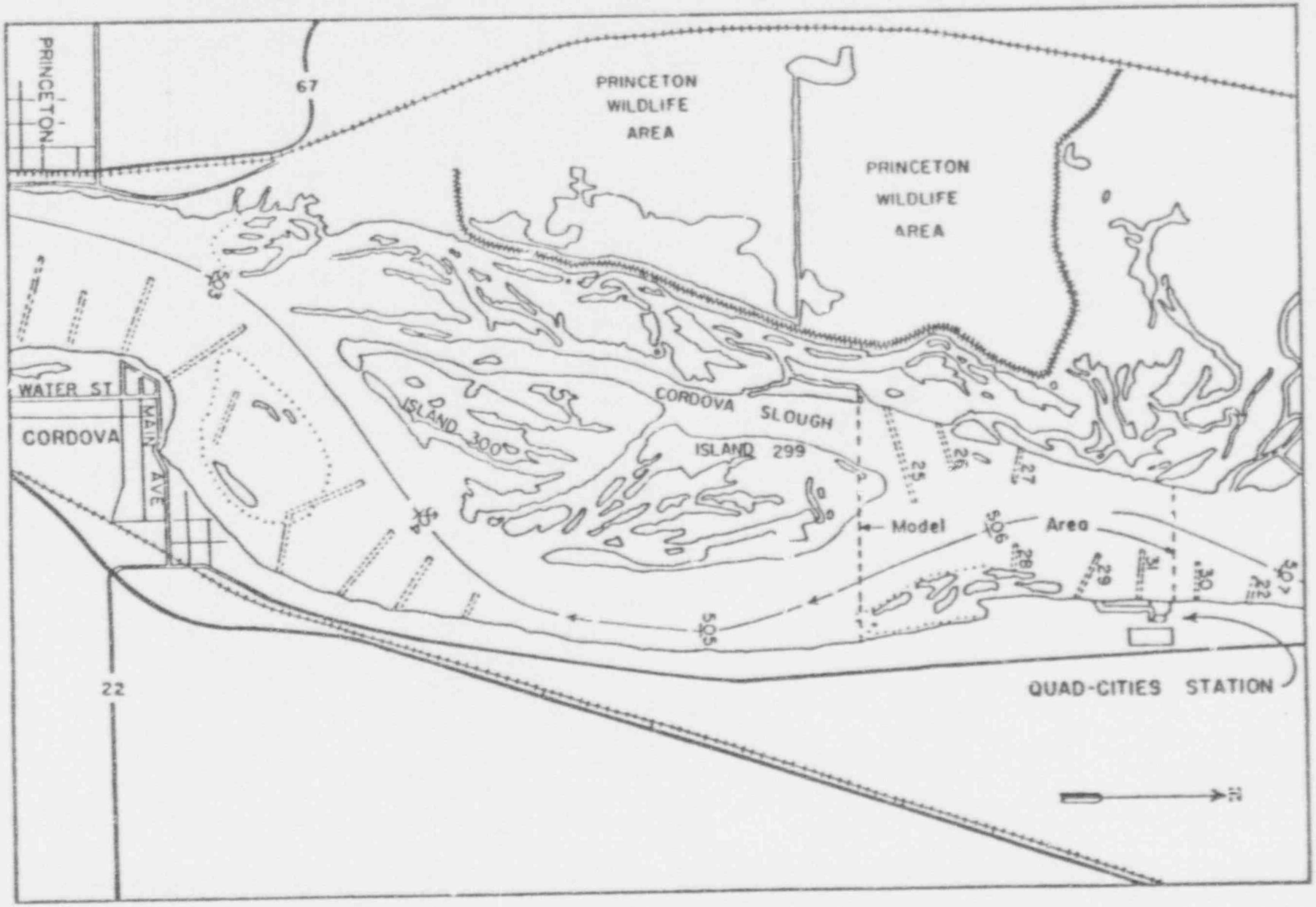

Figure 1. Site of Quad Cities Nuclear Station.

depth and velocity (= local unit discharge), to achieve nearly complete mixing of effluent and River flows.

3. The releases from the structure be virtually fully mixed with the River flow within a very short distance from the release ports, to satisfy the mixing-zone and zone-of-passage requirements.

It was concluded that a multi-port diffuser-pipe system would be optimal for QCNS. The system designed and constructed is described in the next section.

II. Description of the QCNS Diffuser System. The QCNS diffuser system is depicted in Figures 2 and 3, and Figure 4 shows a cross-section of one of the manifolds and risers. The two manifolds are 16-foot-diameter buried pipes, one about 2,100 ft long and the other about 1,700 ft long. Riser ports of 24 in. and 36 in. diameter are spaced at intervals of 19 ft-8 in. and 39 ft-4 in., in an array that gives locally averaged unit discharge (i.e., port discharge divided by port spacing) from the manifolds that is nearly proportional to the unit River discharge (i.e., local River discharge per unit of channel width). This distributes the heated-water release across the channel so as to be proportional to the local heat-assimilation capacity of the River, as determined from measurements and calculations of distributions of River velocity and depth across the channel, with the result that an almost laterally uniform River-temperature rise is produced. The risers extend vertically upward from the manifolds to above the River bed, and then are inclined 20° above the horizontal, as shown in Figures 3 and 4. Provision for later adjustment or "tuning" of the system was made in two ways. First, some flanged stubs were installed on the manifolds, to which risers can be

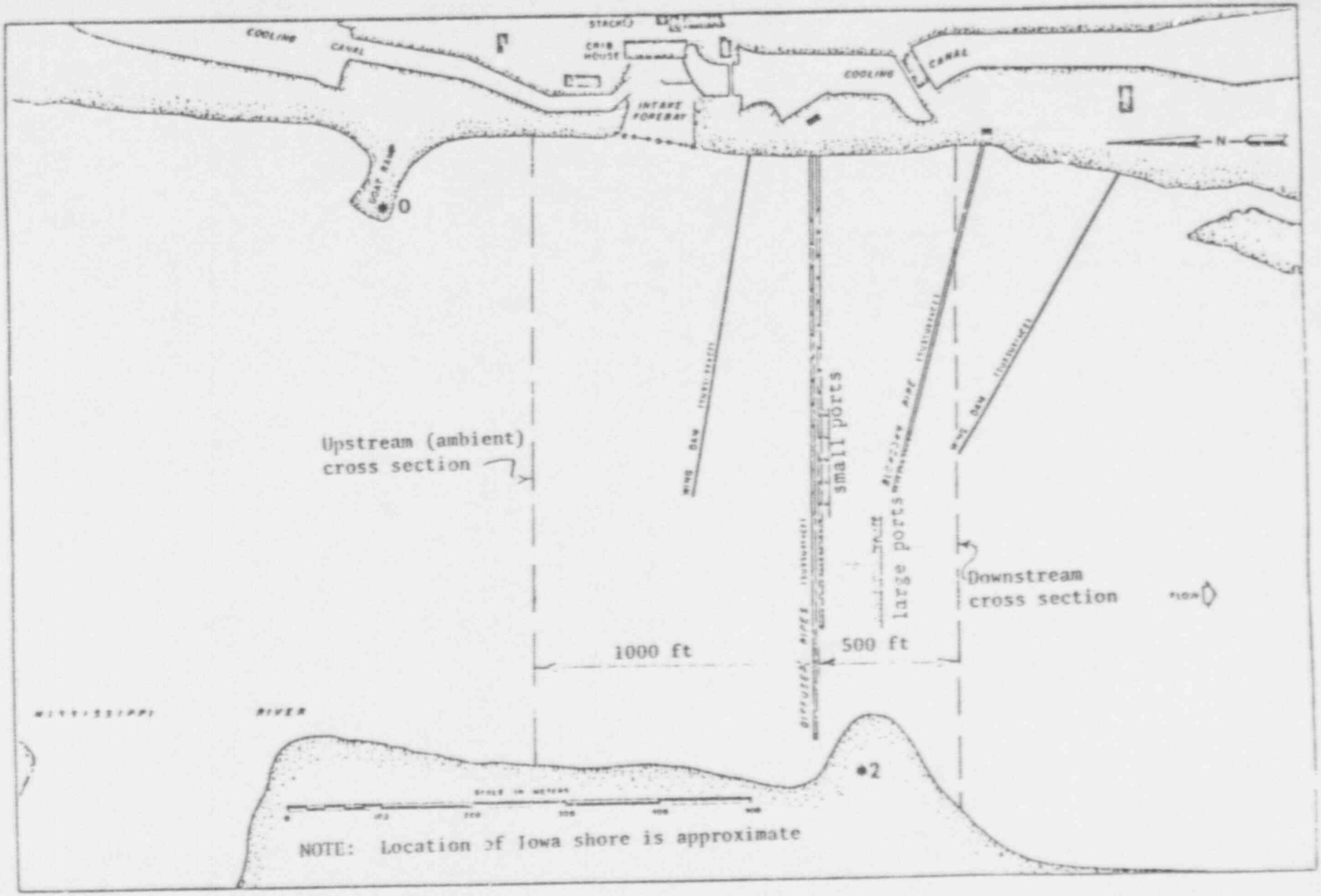

Figure 2. Layout of the diffuser system for Quad Cities Nuclear Power Station.

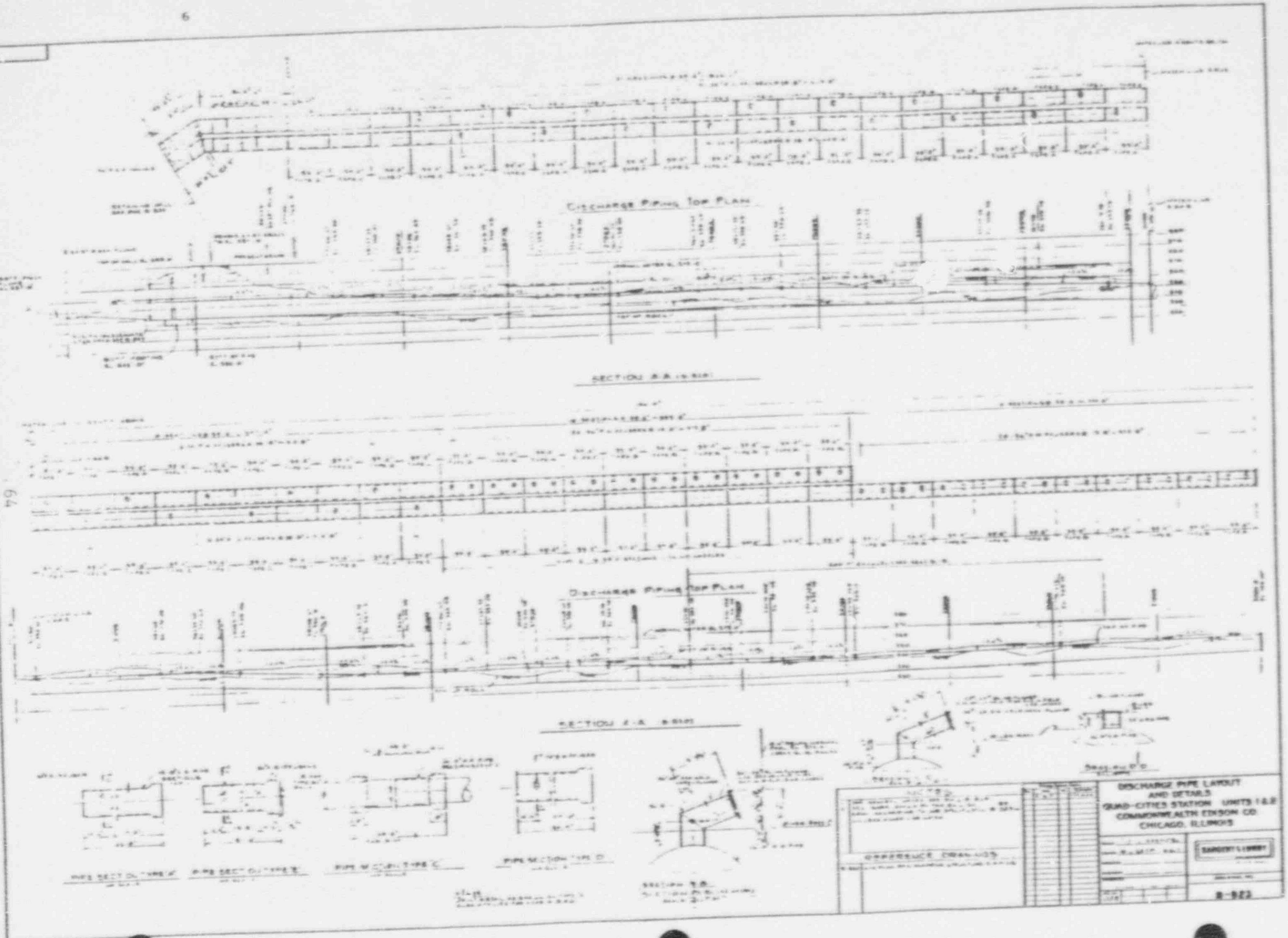

Figure 6. Plan and sectional views of the QCNS diffuser system.

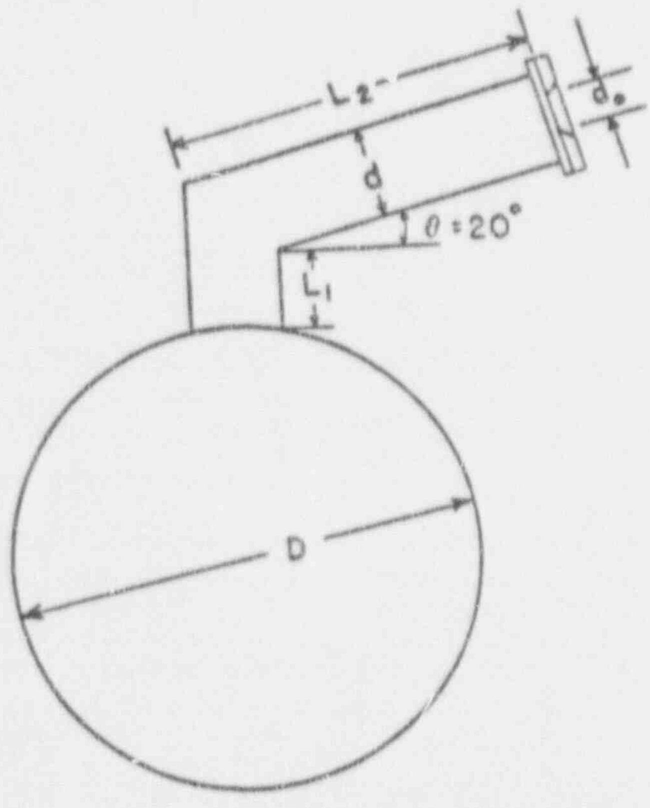

Figure 4. Sectional view of diffuser system manifold and riser.

attached if it is found to be necessary to release additional water at some locations. Second, the discharge end of each riser was fitted with an orificed flange which is bolted to the riser. The diameter of each orifice is 0.9 of its riser diameter. The discharge distribution across the River can be modified by replacing the flanges with others with different orifice diameters. The design and laboratory testing of the system were described by Jain *et al* (1), Parr (2), and Parr and Sayre (3). Field testing of the system is reported by Parr (2) and Parr and Sayre (3). Representative results which demonstrate the thermal and hydraulic characteristics of the system are included herein.

III. Field Testing of the QCNS Diffuser System. The QCNS diffuser system was placed in operation in late 1972. During the period 2 November 1972 to 15 July 1976, 19 sets of detailed data on the distributions of temperature rise and velocity across River cross-sections were obtained at sections located various distances downstream from the diffuser pipes. Temperature- and velocity-distribution data were obtained also at a cross-section upstream from the pipes, to provide definition of the ambient flow and water-temperature conditions. Subsequent to this period of intensive study, a set of data on cross-sectional distribution of temperature has been obtained during each calendar quarter, except for periods when high-flow or river-ice conditions made it dangerous or impossible to obtain flow and temperature data from a boat.

Field data on River temperatures and velocities were measured from a specially equipped boat that is outfitted with an instrumentation boom, special anchors, reflectors to permit positioning from a shore-stationed infra-red range meter, etc. Velocities were measured by means of a 10 cm Ott

propeller-type current meter, and temperatures with thermistors and a special electronic system designed and built at the Institute of Hydraulic Research. The velocity meter responds to velocities down to 3 cm per sec, and the temperature-measuring system has resolution of 0.01°C. River discharges were obtained from the U.S. Geological Survey for its gaging station at Clinton, Iowa (approximately 15 miles upstream), and from integration of measured velocities at the plant-site study sections. Data on plant load, condenser discharge, and condenser temperature were obtained from Commonwealth Edison Company.

Full details of the instrumentation, data-collection procedures, and results of the measurements obtained during the period of intensive study (November 1972-March 1974) are reported in Parr's doctoral thesis (2) submitted to The University of Iowa, and in a University of Iowa report by Parr and Sayre (3). The results of the subsequent quarterly and special measurements have been submitted to Commonwealth Edison Company by the Institute in letter reports. Typical results which demonstrate the hydraulic and thermal performance of the system over a wide range of conditions are presented here.

IV. Presentation of Results. There are three p   pal scales within which the thermal and hydraulic data on the diffuser discharge should be examined: The near field, in which the temperature and velocity distributions produced by individual jets are measured and analyzed, extends downstream to about the section where the jets start to merge or intersect the water surface. Near-field data are required for evaluation of the zone of passage, which is the fraction of the channel cross-sectional area or river discharge in which the temperature does not exceed a specified value. The next scale

of interest is the far-field, which extends downstream from the end of the near-field to the section where the heated jets become more or less fully mixed with the River flow. In the case of the QCNS diffuser system, the far field persists several hundred feet from the diffuser pipes. In the far field the mixing characteristics of the whole diffuser-pipe system are of interest. Finally, it is revealing to examine the global field, in which the heat transfer from the River to the atmosphere becomes important. Study of the River from th[illegible] perspective yields estimates of the rate of decay of artificially induced temperature rises, and comparisons of induced and natural temperature variations. The global field extends downstream for distances equal to several hundred river widths--typically several miles--to the section where the artificially induced temperature rise becomes insignificant. Also always of interest, of course, are the ambient conditions, and in particular the river-water temperature and its distribution across the channel at cross-sections upstream from the section where the artificial heat load is imposed.

A. Upstream temperatures. Definition of the ambient or upstream temperature in a large river is by no means a straightforward task, because of the wide variations in temperature, not only vertically (due to gravity-induced thermal stratification during low river flows), but also, and often more importantly, laterally. Two examples of temperature distributions measured upstream from the diffuser system are presented. The background data for these are included in Table 3, which is presented later. Figure 5 shows temperature distributions measured on 3 December 1973, 200 ft upstream (at two different times) and 500 ft downstream from the diffuser pipes; and Figure 6 shows the upstream distributions before and after the downstream measurements on 15 July 1976. On both dates the maximum lateral temperature variations are seen to be about 1°C. The strategy utilized in determination

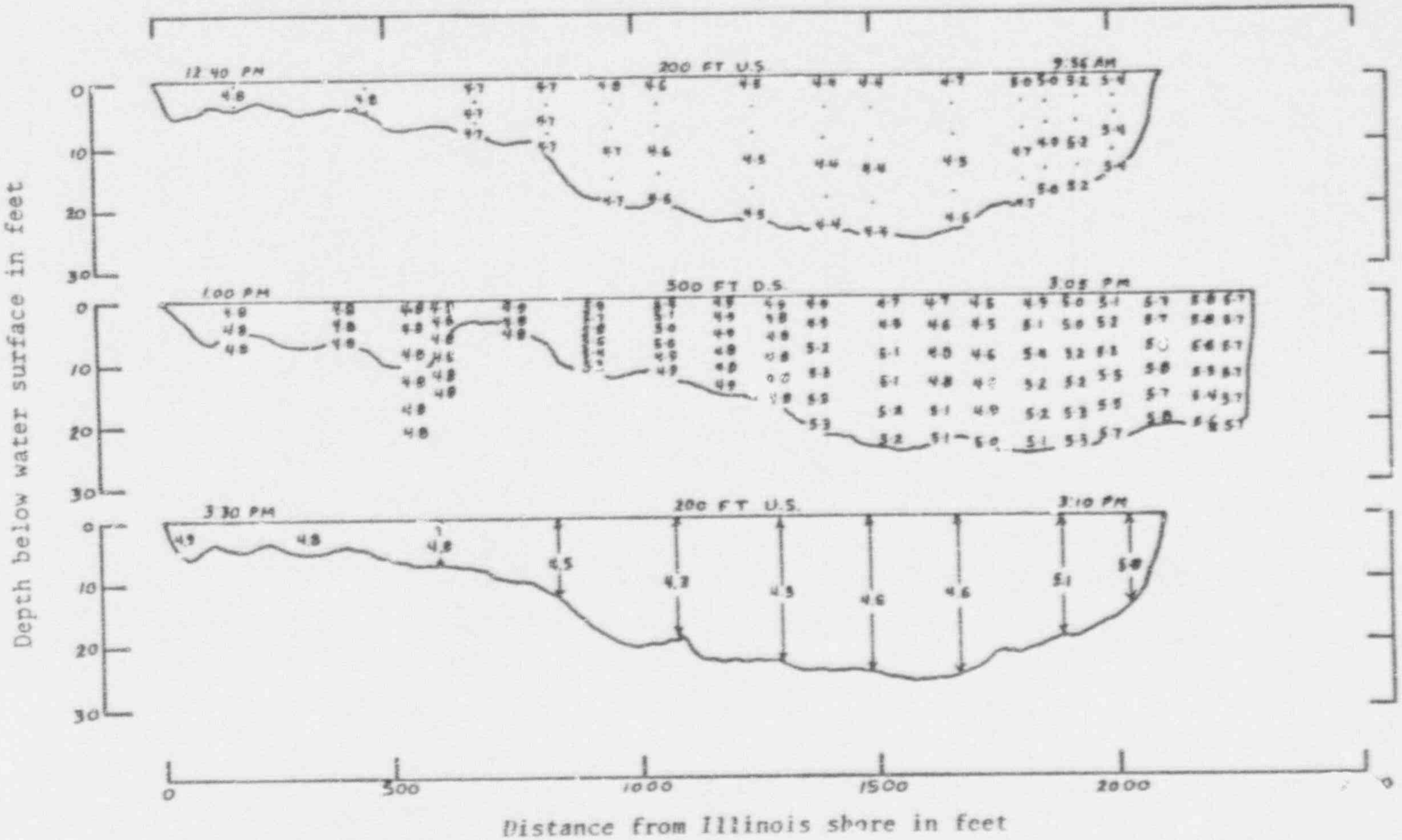

Figure 5. Observed temperature, in $^{\circ}C$, 200 ft upstream and 500 ft downstream from diffuser system, 3 December 1973.

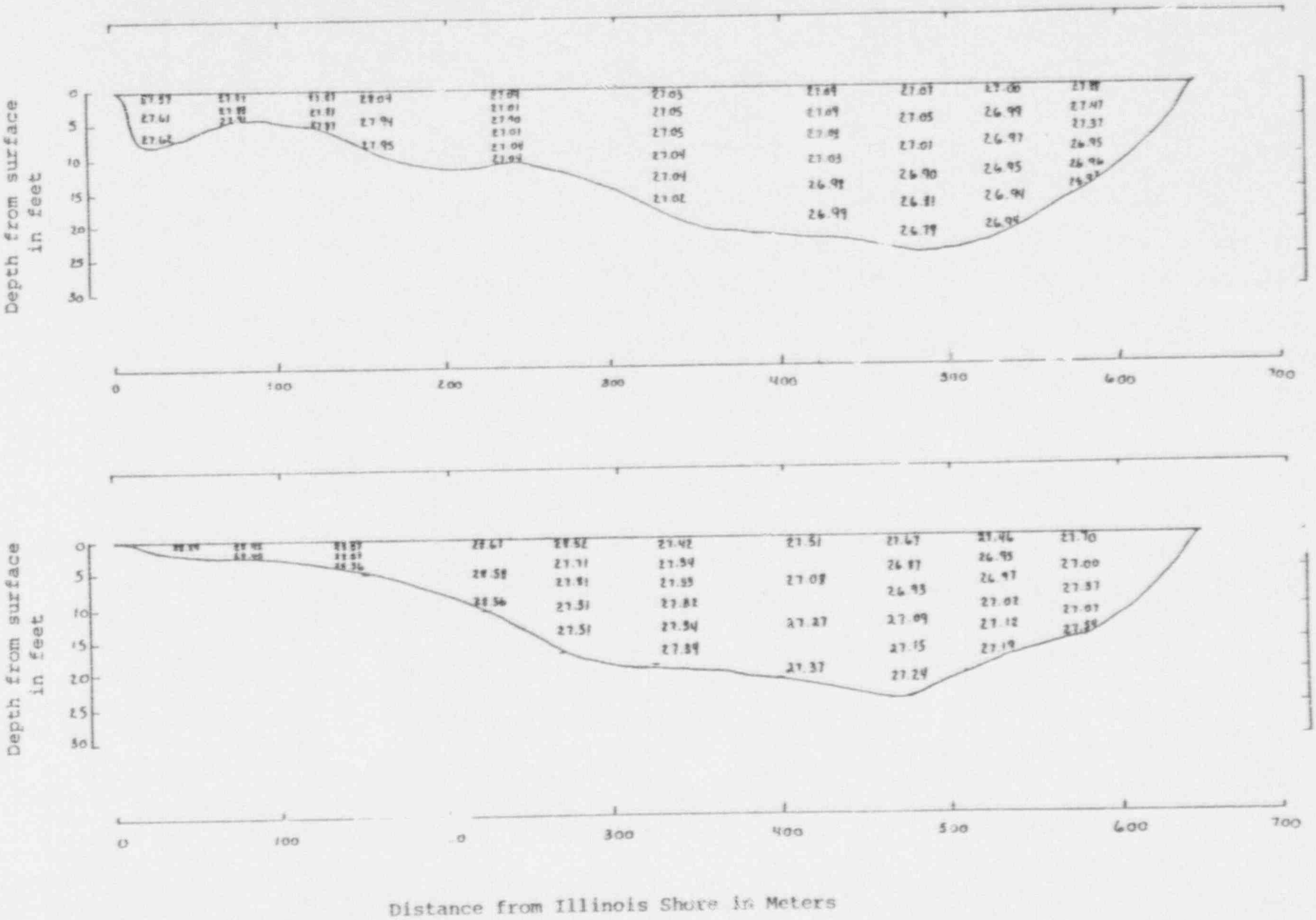

Figure 6. Measured temperatures, in ^{o}C, 200 ft upstream from the diffuser system before and after downstream measurements, 15 July 1976.

of ambient temperatures from these somewhat variable upstream temperatures is described in Section C.

Note in the River cross-sections shown in Figures 5 and 6 that the deeper part of the channel, and therefore also the larger flow velocities and unit discharges (discharge per unit of width), are near the Iowa shore, across the River from QCNS, as discussed above.

B. Near-field surveys. Near-field temperature and velocity measurements were made just downstream from individual ports on seven different dates. These measurements were made primarily to obtain definition of the zone of passage, both with respect to area and with respect to discharge. For the present study, zone of passage is defined as the fraction of area of discharge, at a river cross-section, with a temperature rise less than 5°F. The background data for and the results of these measurements are presented in Tables 1 and 2, respectively, and Figure 7 presents a typical set of field data. It is seen in Table 2 that at even the relatively low River discharge of 30 October 1974, the zones of passage with respect to both area and discharge are above 75 percent.

Because of the time requirements for and great expense of field measurements, and because the River discharge cannot be controlled, it was not practical to obtain zone-of-passage data for all ports over a wide range of River discharge. Instead, scale-model laboratory-flume experiments were made by modelling longitudinal "slices" of the River. Some laboratory experiments included only a single port, while others included three ports. Experiments were made over the ranges of nondimensional parameters (velocity ratio, U_j/J_a, where U_j = jet velocity, U_a = ambient velocity; depth ratio, H/D,

Table 1. Background data for single-port diffuser-system studies in 1973 and 1974.

Date	River Discharge	Distance from Illinois Shore	Outlet Diameter of Port	Distance Downstream from Port	Percent of Full Plant Load	Local Ambient Temp.	Plant Effluent Temp.	Estimated Discharge from Single Port	Estimated Velocity from Single Port
	Q_R	z	D	x	P	T_a	T_E	Q_j	U_j
	(cfs)	(ft)	(ft)	(ft)	(%)	(°F)	(°F)	(cfs)	(ft/sec)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11-16-73	39,600	1774	2.7	35 65	88.5	40.2	65.5	42.1	7.35
3-12-74	82,210	1345	2.7	15 45	91.2	37.2	61.4	46.7	8.16
3-13-74	82,900	968	1.8	35 65 95	89.5	38.1	61.4	19.9	7.82
7-24-74	26,900	1313	2.7	15 45 75	50.0	79.5	94.7	46.3	8.09
10-01-74	28,600	1273	2.7	15 45 75	78.0	57.2	96.0	27.3	4.77
10-25-74	25,900	1293	2.7	15 45 75	91.0	53.5	104.5	24.0	4.19
10-30-74	25,200	1391	2.7	15 45 75	87.8	56.1	106.8	25.3	4.42

Table 2. Results of single-port studies on prototype diffuser system.

Operation	Date	Distance Downstream from Port x (ft) (2)	Local Average Ambient Velocity U_a (ft/sec) (3)	Local Average Depth H (ft) (4)	Port Spacing L (ft) (5)	Estimated Effluent Discharge from Single Port Q_j (cfs) (6)	Estimated Mixed Temperature Rise ΔT_m (°F) (7)	Zone-of Passage wrt Area ZPA (%) (8)	Maximum Observed Temperature Rise $(T-T_a)_{max}$ (°F) (9)	Zone-of Passage wrt Discharge ZPD (%) (10)
Full open-cycle operation	11-16-73	35 65	1.52	23.4	19.67	42.1	1.44*	99.2 100	5.4	98.3 100
	3-12-74	15 45	2.88	21.7	19.67	46.7	0.89*	97.3 99.7	7.7 5.6	96.5 99.6
	3-13-74	35 65 95	2.18	17.9	39.33	19.9	0.30*	100 100 100	4.4 1.7 1.4	100 100 100
	7-24-74	15 45 75	1.06	18.8	19.67	46.3	1.31#	100 100 100	4.9 2.4 1.9	100 100 100
Partial closed-cycle operation	10-01-74	15 45 75	1.18	22.0	19.67	27.3	2.31#	89.5 94.4 100	14.8 6.7 4.0	86.2 91.9 100
	10-25-74	15 45 75	1.07	20.0	19.67	24.0	2.64#	6.1 86.7 97.5	19.0 8.9 6.0	81.2 81.5 97.0
	10-30-74	15 45 75	1.09	20.4	19.67	25.3	2.71#	87.1 87.2 98.6	20.0 8.7 5.7	76.2 85.3 98.5

*Calculated from $\Delta T_m = Q_j \Delta T_E/(LHU_a)$.
#Computed from data measured at section 75 ft. downstream.

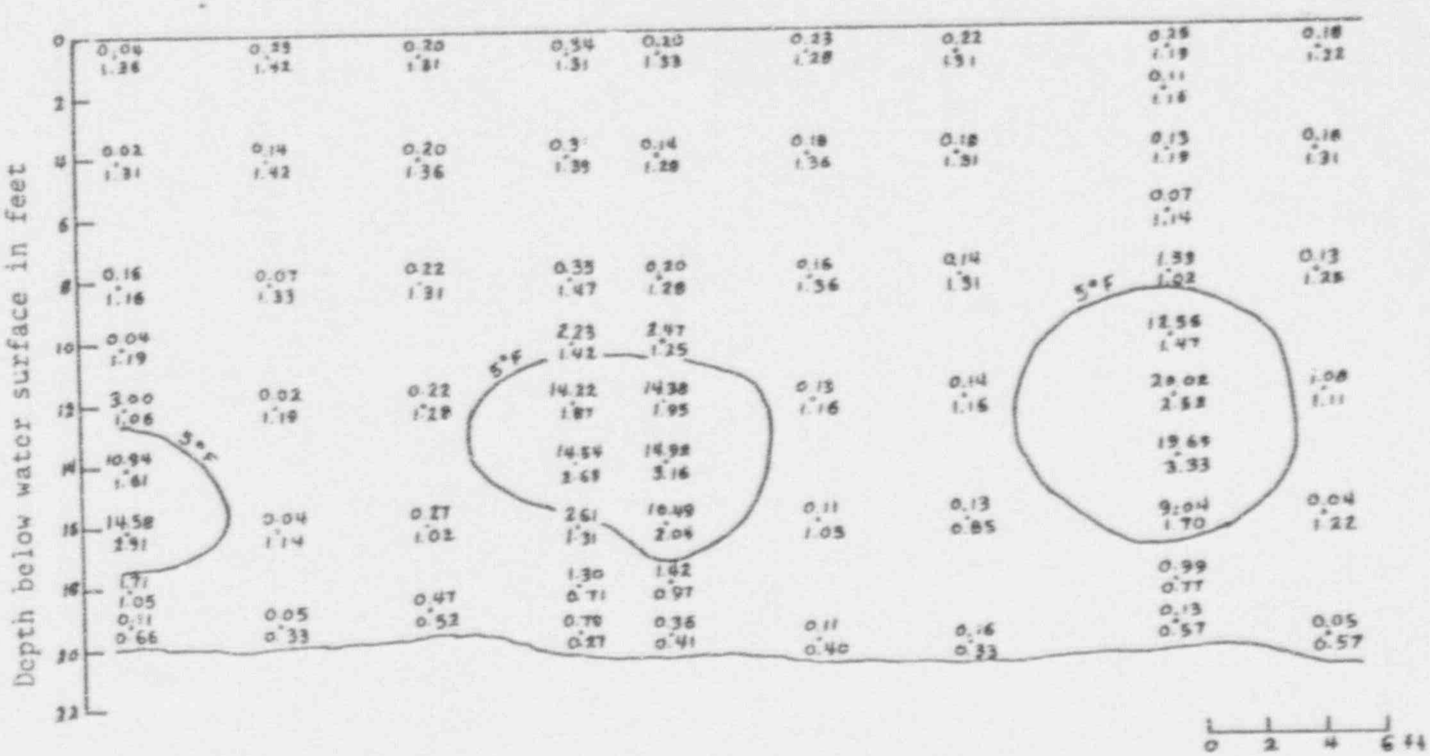

Figure 7. Plant temperature rises, in ^{o}F, and velocity, in ft/sec, measured 15 ft downstream from a main-channel diffuser-pipe port, 30 October 1974.

where local H - flow depth, D = jet diameter; and density deficiency, $(\rho_a - \rho_j)/\rho_a$, wi re ρ_a = ambient-flow density, ρ_j - jet density) that occur in the prototype. De' iled measurements of temperature and velocity were made in the laboratory f me downstream from the model ports. Corresponding laboratory and ata (discussed above) were compared and found to be in good agre zones of passage calculated from the laboratory data on valocity ture at various downstream sections then were compared to determi mum zone of passage with respect to discharge for the whole Rive the case in which both of the Station's units are operating at full ca and being cooled through the two diffuser pipes. This was do. the discharge in the sector (river slice) of each jet with temperature less than 5°F (including effects of jet interference or "overlap"), summing these discharges for all ports, and dividing by Q_r. This process was repeated for several downstream sections, and the one giving the minimum zone of passage with respect to discharge was selected as critical, and used in the subsequent analysis. The result is shown in Figure 8, where it is seen that the areal zone of passage for full-load operation of the plant is expected to exceed 75 percent for all River flows greater than about 15,300 cfs. In Table 2 it is seen that the zone of passage with respect to area exceeds that with respect to discharge (as was verified in the laboratory experiments), so the latter, given in Figure 8, is the limiting value.

Complete details of the laboratory experiments and procedures used in calculation of zone of passage are given by Parr and Sayre (3).

C. Far-field surveys. The background data for these surveys are given in Table 3. For the far-field studies, the plant was being fully cooled

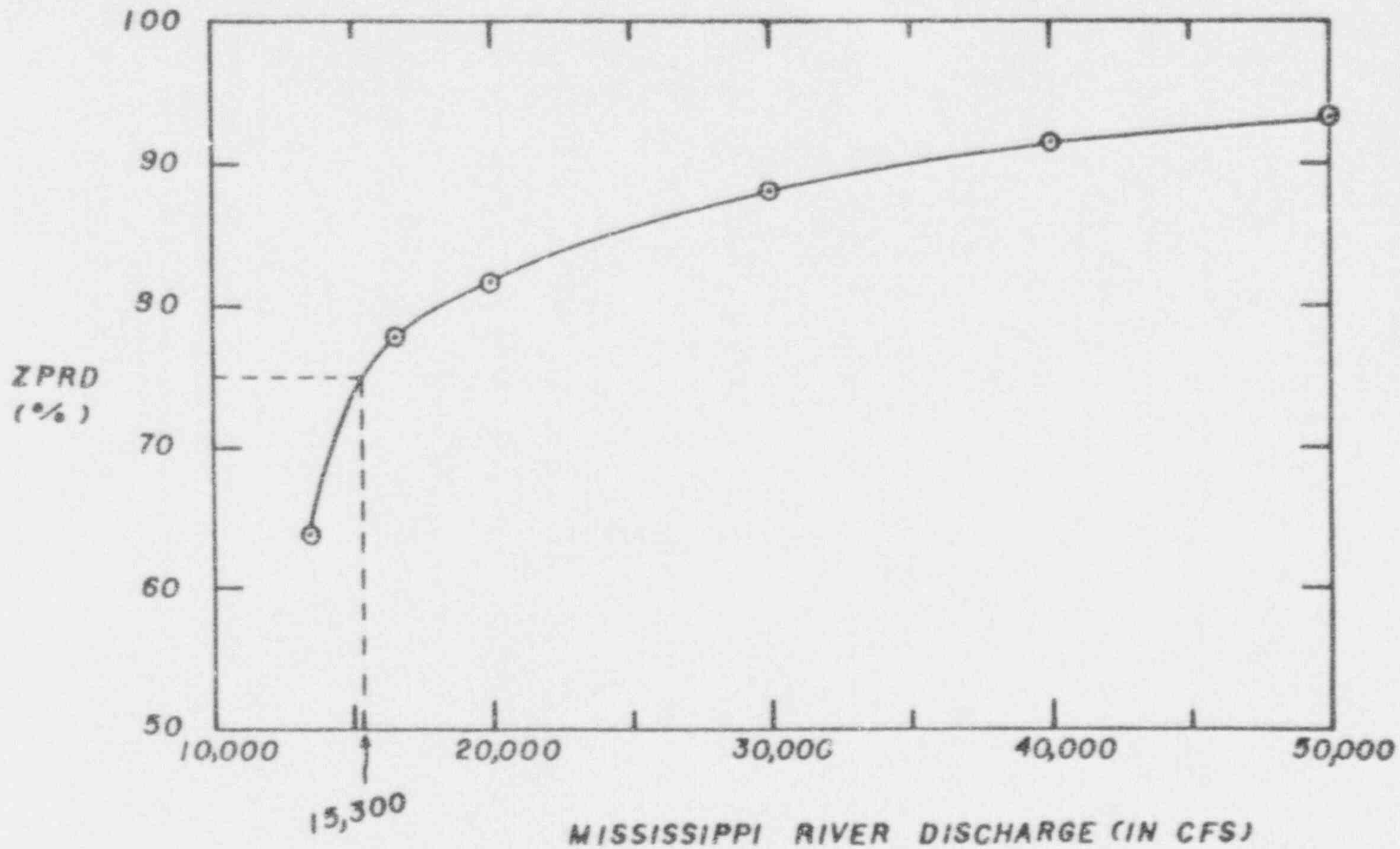

Figure 8. Minimum zone of passage with respect to total river discharge for the case of plant operation at full capacity.

in the open-cycle mode through the two-pipe diffuser system. The plant was operating at nearly full load during all surveys except the one made during low River flow, in July 1976. Most of the measurements were made 500 ft downstream from the diffuser pipes, because a section 500 ft long extending across the full 2,200-foot width of the River contains approximately 26 acres. Field and laboratory data indicated that the jet diffusion and mixing of the effluent with the River flow was practically completed upstream from this section. Figure 9 shows, as an example, the downstream temperature distributions measured on two different dates. The temperature-rise distributions then were calculated from the measured upstream and downstream temperatures, such as those presented in Figure 9, in the following way. The upstream temperatures measured before and after the downstream measurements at each vertical were both depth-averaged, and then time-interpolated to obtain a background temperature at the time of measurement at each downstream-section vertical. This depth-averaged, time-interpolated background temperature at the lateral position across the River corresponding (as a fraction of River width) to a downstream measurement vertical then was subtracted from the point temperatures measured along that downstream vertical. An example of a temperature-rise (or excess-temperature) distribution so determined is shown in Figure 10. This example is from the 1976 low-flow period; temperature-rise isotherms corresponding to Figure 10 are shown in Figure 11. On this Figure the regions within which the temperature rise exceeds 2.08°F (which would be very nearly the areas within which the temperature would exceed 5°F for full-load operation of both units) are cross-hatched, and the corresponding area ratio is shown. The 5°F zones of passage for the flow of Figure 11 is about 88 percent.

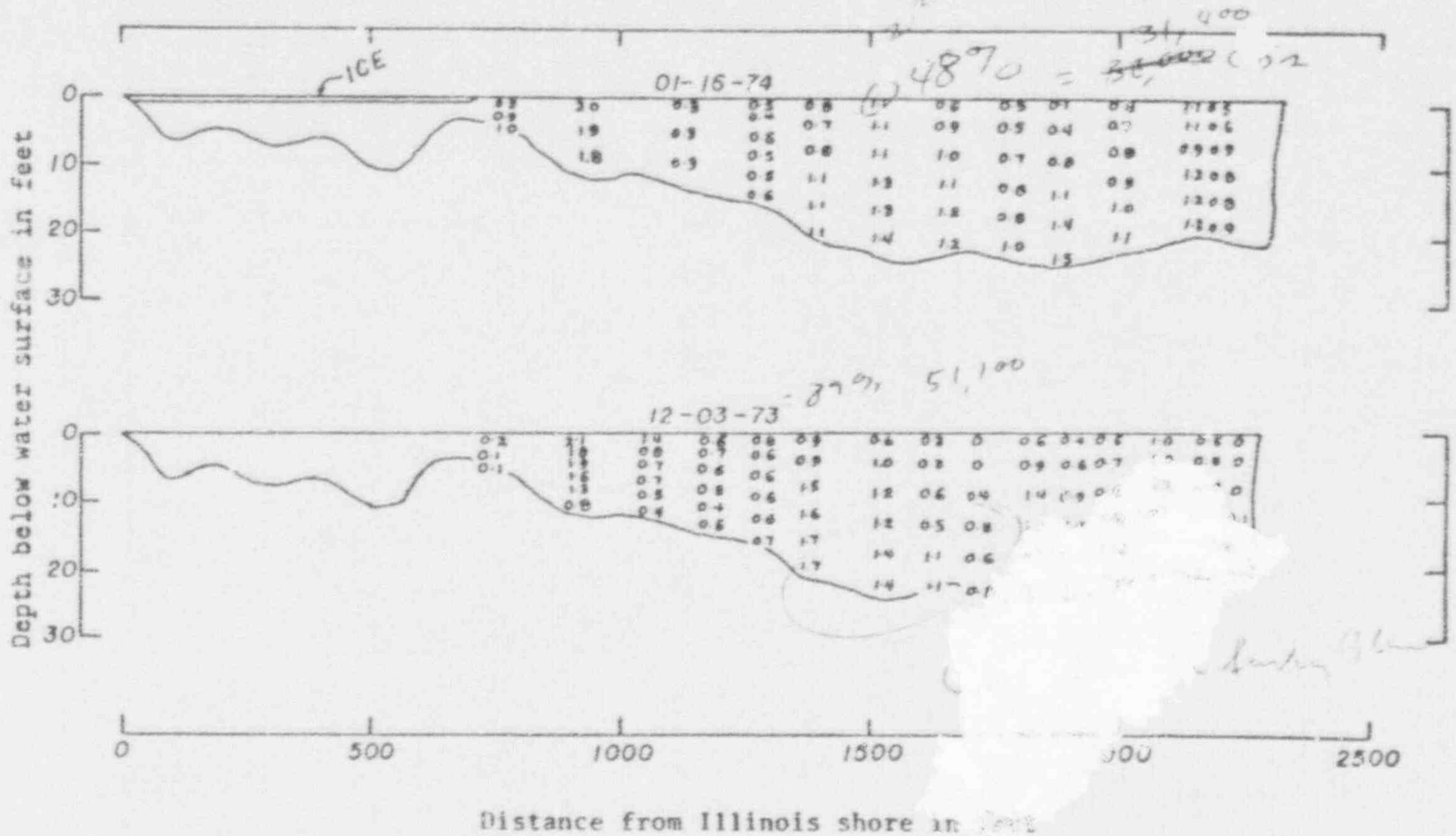

Figure 9. Observed point-temperature rises, in ^{o}F, 500 ft downstream from the diffuser system, 3 December 1973 and 16 January 1974.

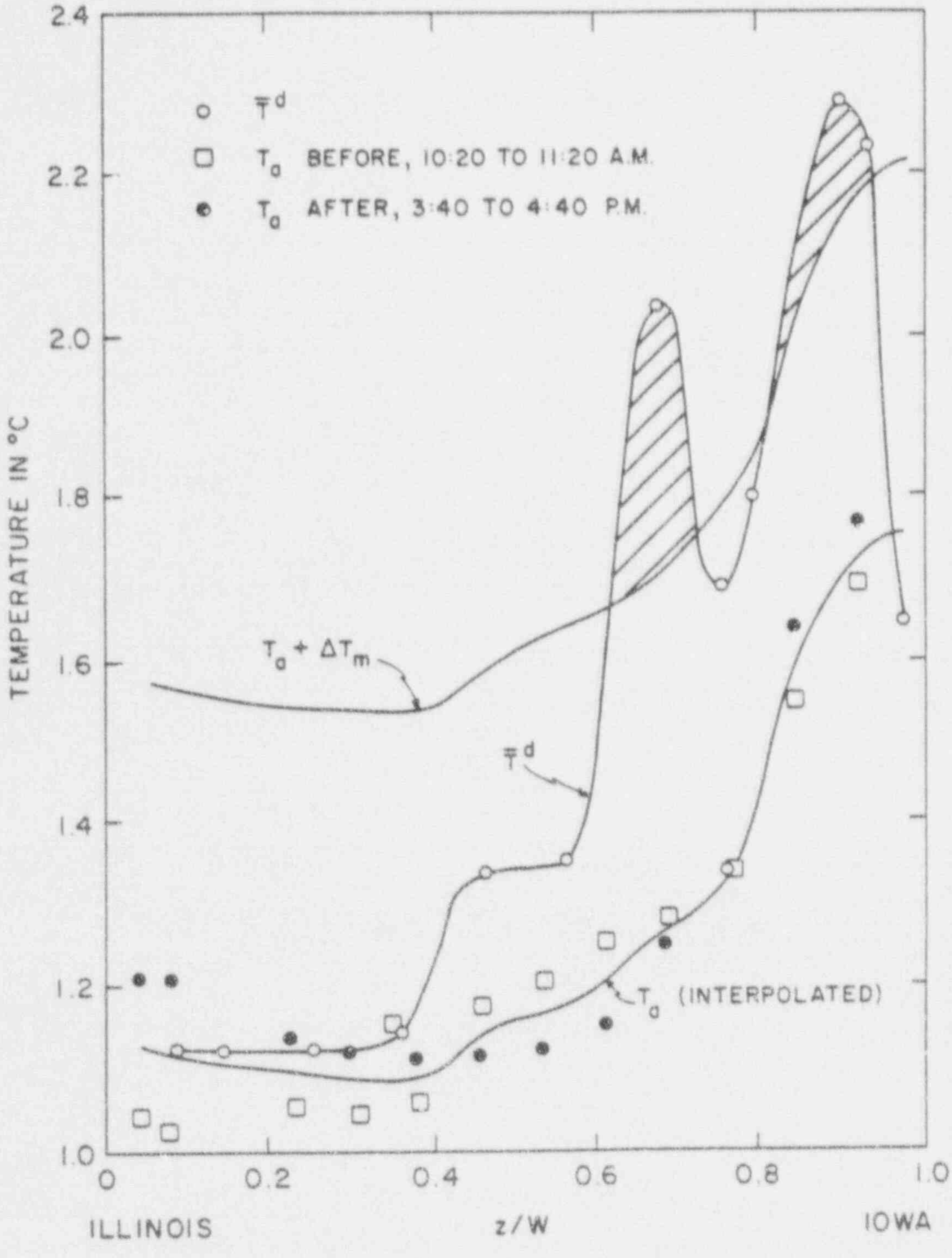

Figure 13. Transverse distribution of depth-averaged temperature, in °C, 500 ft downstream and ambient temperature, in °C, 1000 ft upstream from diffuser system, on 28 November 1972.

diffuser system is failing to achieve fully mixed conditions. It is seen that the temperature difference between these two curves is no greater than the natural ambient-temperature variation across the River upstream from the diffuser.

Finally, it is pointed out that the performance of the diffuser system could be improved, if this were deemed worthwile, through "tuning", by adjusting the orifice sizes in the port flanges and installing additional risers to redistribute the effluent discharge across the River.

D. Summary. The diffuser-pipe system is yielding virtually complete mixing of the effluent with the River flow within a reach of the River that extends about 500 ft downstream from the diffuser pipe. A distance of 500 ft corresponds to about 25 river depths or one-fifth river width at this section, and the area included between this section and the diffuser system is about 26 acres. The practically instantaneous mixing of the effluent with the receiving water is a consequence of the well known dispersion processes that occur in jets. A jet discharged into an otherwise quiescent or slowly moving body of water produces very strong velocity shear-zones or velocity gradients around the jet boundary. This region of strong shearing motion produces very large vortices or eddies which burst outward from the jet boundary, envelop surrounding fluid, and entrain it into the jet. The slower moving fluid which is entrained into the jet causes the jet to lose some of its velocity. The net result of this self-induced, rapid entrainment of surrounding fluid is for the jet fluid to become very rapidly mixed with its surroundings, while in the process dissipating its own velocity and accelerating the fluid which it entrains.

V. Further Detailed Analysis of Discharge through and from Diffuser-Pipe System. This section presents results of further, detailed analysis of the jets discharged by the diffuser ports, which leads ultimately to a determination of the water-surface mixing zone (area with T > 5°F). These results are based on a mathematical model developed by Parr and Sayre (3) to predict the performance of the diffuser system. The results of their mathematical model have been demonstrated to be in good agreement with prototype observations, as was discussed above.

Figures 14 and 15 show the decay with time of excess temperature and velocity, respectively, along the jet certerline for small and large ports. These figures are for a river flow of 13,200 cfs (7Q10), a condenser fow of 2,270 cfs, and an excess temperature of 23°F (full-load plant operation). The results are based on the following two equations developed by Parr and Sayre (3) in their experimental and theoretical investigation of the QCNS diffuser-pipe system. These equations give the jet centerline excess temperature and velocity at a distance x downstream from the port:

$$\frac{T_e - T_a}{T_{\mathrm{CL}} - T_a} = 0.28\,\frac{x}{D_p} + 0.7$$

and

$$\frac{U_j - U_{\mathrm{CL}}}{U_{\mathrm{CL}} - U_a} = 0.23\,\frac{x}{D_p} + 0.6$$

in which T_e = effluent temperature; T_a = ambient temperature; T_{CL} = jet centerline temperature; U_j = initial jet velocity; U_a = ambient flow velocity, U_{CL} = jet centerline velocity; x = distance downstream from the port; and D_p = port diameter. The jet centerline temperature reaches the fully mixed

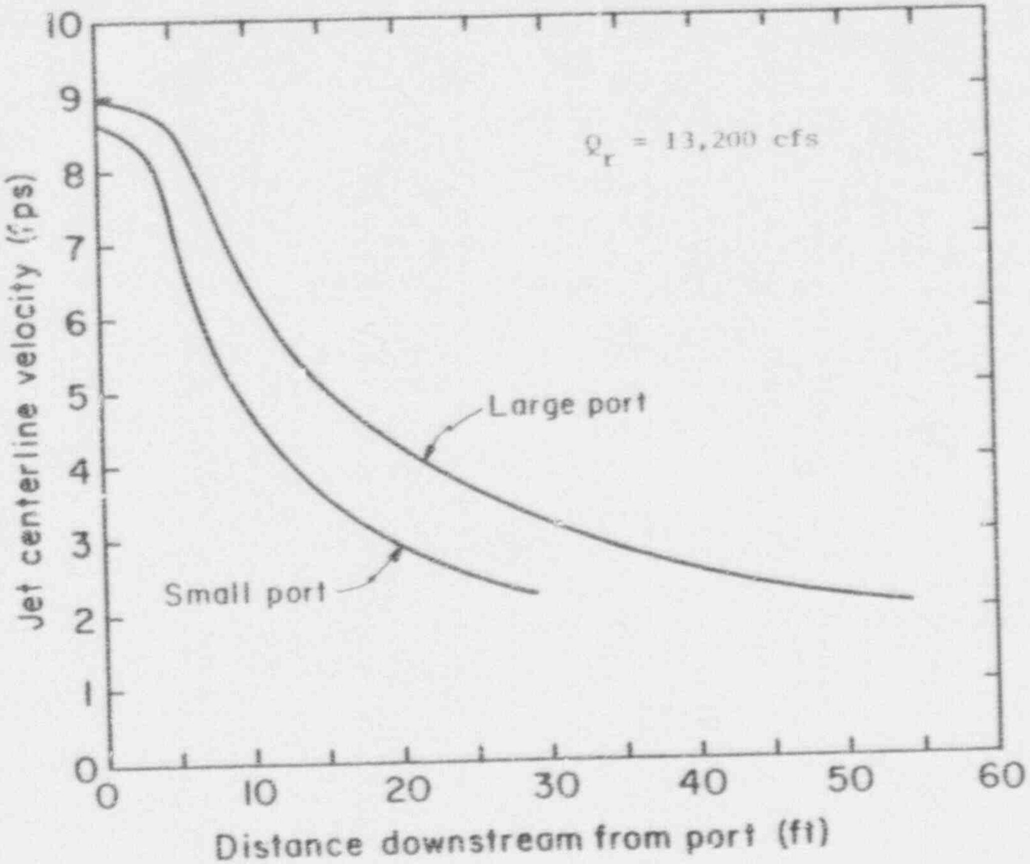

Figure 14. Decay of jet centerline velocity.

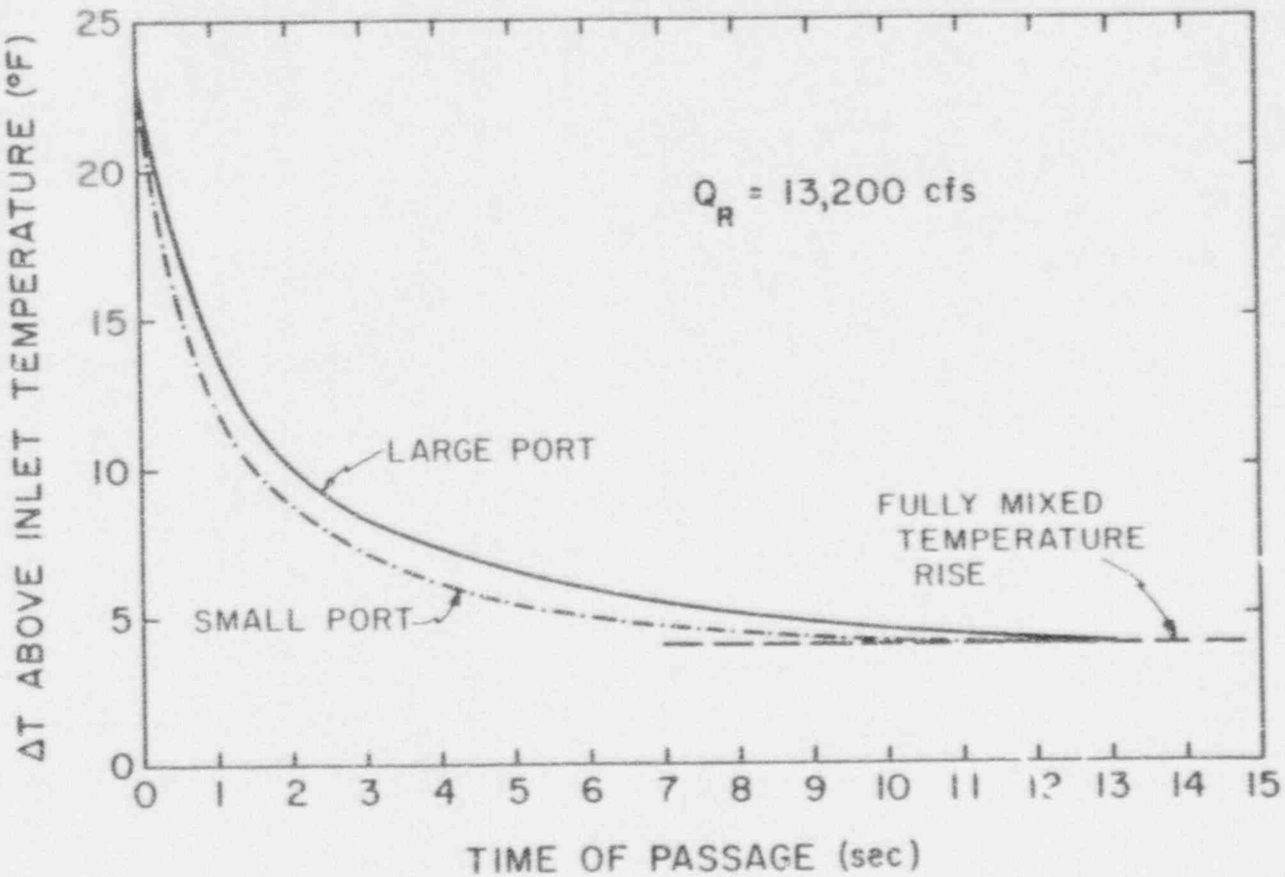

Figure 15. Decay of excess temperature along jets.

temperature in a very short time, as can be seen from Figure 14. At higher river flows this time would be even smaller. The jet centerline velocity decays in a short distance (Figure 15): The effect of the river velocity on the decay rate of the jet-centerline velocity is not large.

The variation of the discharge with excess temperature of 5°F or more, Q_5, as a function of distance x from the port exit is shown in Figure 16. The value of Q_5 at $x = 0$ is equal to the condenser water discharge (2,270 cfs). As one would expect, Q_5 first increases, reaches a maximum, and then decreases to zero. The maximum value of Q_5 for a River flow of 13,200 cfs is about 3,700 cfs, which is about 28 percent of 7Q10. The maximum value of Q_5 in terms of percent of river flow decreases with increasing river flow.

An analysis conducted to determine the river-water surface area covered by the 5°F isotherm of excess temperature for a condenser flow of 2,270 cfs at 23°F excess temperature revealed that this surface area is zero, if $q_j/q_a < 3.8$ for the large ports, and $q_j/q_a < 6.0$ for the small ports (q_j and q_a are the jet and local river discharges per unit width, respectively). The measured velocity distribution in the River at low River flow indicates that most of the ports satisfy these conditions; a conservatively high estimate is that five small ports and ten large ports will not meet these conditions. Further computations for a River flow of 13,200 cfs showed that the length of the upstream thermal wedge and of the downstream plume where the excess temperatures exceed 5°F are 20 ft and 100 ft, respectively, for the small ports; and 20 ft and [illegible] ft, respectively, for the large ports. For these values, the surface area included within the 5°F excess-temperature isotherm was found to be less than two acres.

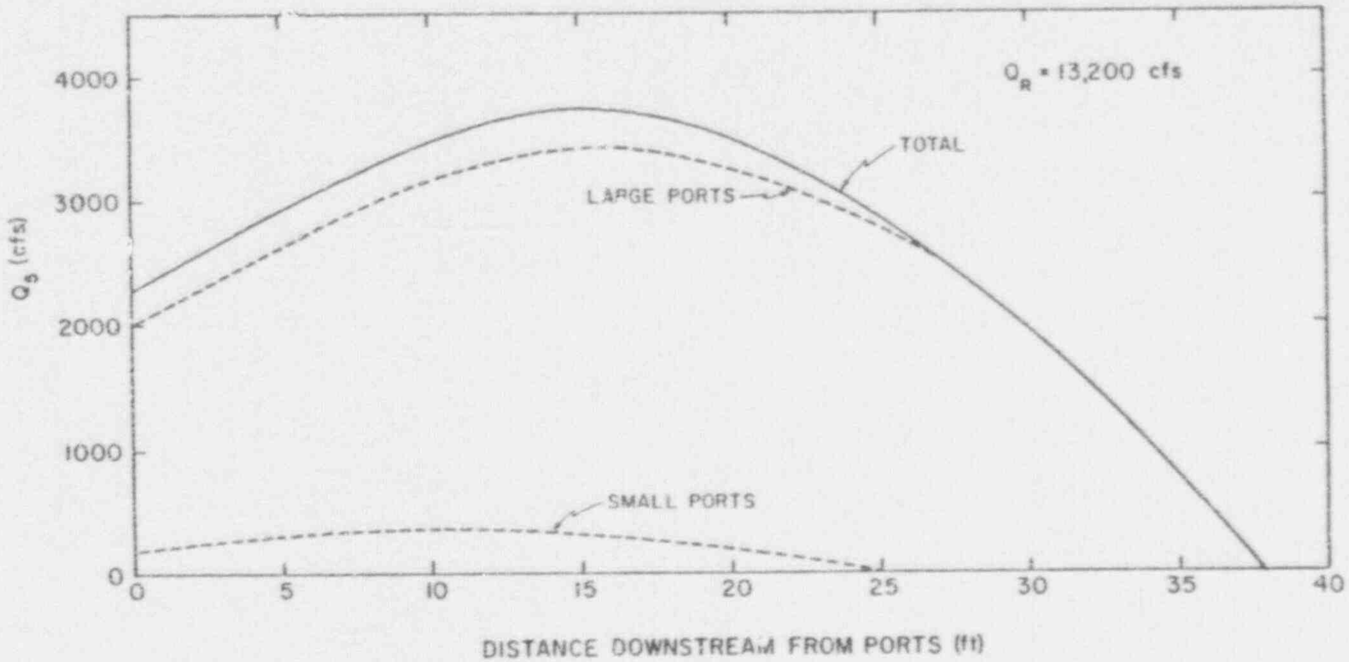

Figure 16. Variation of the discharge with excess temperature of 5°F or more.

VI. Global-Field Perspective. A natural body of water is in thermal equilibrium with its surroundings, in the sense that, over a sufficiently long period of time, it gives up as much heat as it receives. The principal natural source of heat is solar radiation. Heat is lost from the body of water through the processes of evaporation, convection, conduction, and radiation. The rate of heat loss due to each of these processes increases as the water temperature increases. In this way the temperature increase produced by an artificial heat load imposed on a body of water, as in the case of the QCNS heated discharge, leads to rates of heat loss from the water body that are higher than the natural vlaue, and cause the water temperature to return to its equilibrium value. Thus the heat injected into the water eventually is transferred to and through the atmosphere by the aforementioned processes, and the river-water temperature approaches its natural value as the flow proceeds downstream. It is illuminating to examine the variation of natural temperatures along a river, and also the rates at which induced-temperature rises are dissipated along the flow.

Studies recently completed by the Iowa Institute of Hydraulic Research for the Mid-Continent Area Power Pool (4) and the U.S. Department of Interior (5) developed a computer-based model for calculation of river temperatures, and applied it to the calculation of the thermal regimes of the Mississippi and Missouri Rivers. The numerical model utilizes historical hydrological, meteorological, and channel-geometry data, as well as data on the magnitudes of artificial heat loads imposed on the River. Figures 17 and 18 show temperature distributions along the Upper Mississippi River for average February and May flow and meteorological conditions, respectively, for several different thermal loadings. The heated discharge from QCNS

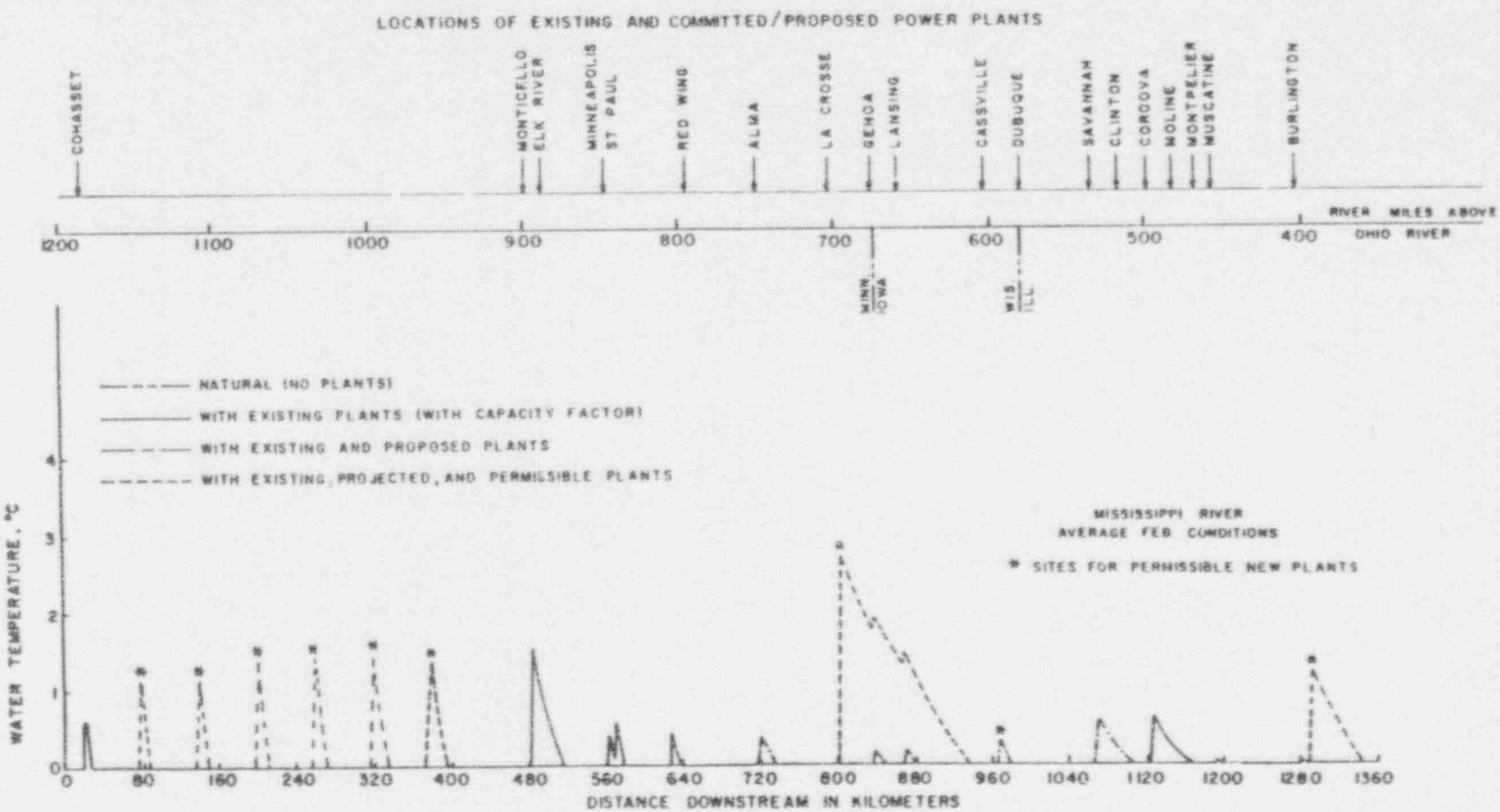

Figure 17. Temperature distributions, in ^{o}C, along the Mississippi River for average February flow and meteorological conditions and 1974 power-plant capacity factors; and permissible new plants based on predicted natural temperatures.

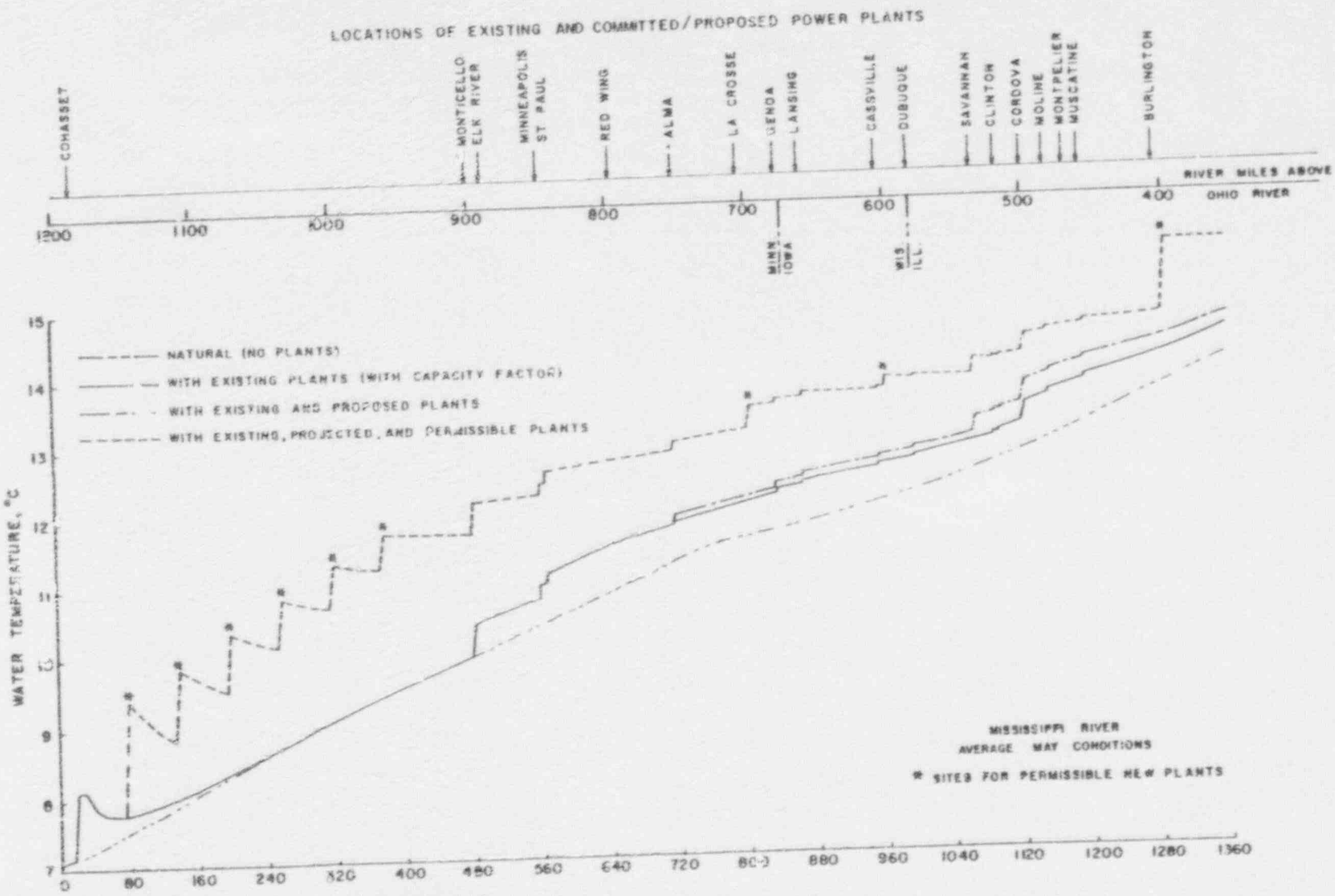

Figure 18. Temperature distributions, in °C, along the Mississippi River for average May flow and meteorological conditions and 1974 power-plant capacity factors; and permissible new plants based on predicted natural temperatures.

produces the abrupt temperature rises at Cordova, at about R.M. 500. For February conditions it is seen that the temperature rise is completely dissipated within about 50 km downstream from the Station. In the case of May conditions, the Station-induced temperature rise is comparable to that which would occur naturally along a river reach of some 60 to 80 km, and is insignificant compared to the natural temperature variation along the Upper Mississippi River.

The point to be emphasized here is that the temperature rise induced in a river by an artificial heat load does not persist indefinitely. The mechanism responsible for maintaining the temperature balance in a water body come into play and quite rapidly transfer the excess heat to and through the atmosphere, with the result that the temperature rise rapidly attenuates in the downstream direction and is completely dissipated within a rather short distance (about 50 km in the case of QCNS).

VII. Summary and Conclusions. The diffuser-pipe system for the Quad Cities Nuclear Station has been investigated exhaustively, both through laboratory testing and collection and analysis of field data for a wide range of River discharges, with the plant operating at full load and at various partial loads. With the plant operating at full load in the open-cycle mode, the maximum local temperature rise produced 500 ft downstream from the diffuser pipes is less than 5°F and the zone of passage is greater than 75 percent for all River flows greater than about 16,000 cfs. The Mississippi River at the location of QCNS has flows greater than 16,000 cfs about 98 percent of the time. At a river discharge of 13,200 cfs, the 7Q10 used in this study, the

surface area with a temperature rise greater than 5°F is less than two acres when the plant is operating at rated capacity and is fully cooled through the diffuser-pipe system.

The design of the diffuser-pipe system includes several features which permit it to be adjusted, or "tuned", to modify the distribution across the River of the diffuser-pipe discharge. No adjustments of the pipe have been made since it was installed. With the present configuration of orificed flanges installed in the diffuser system, the diffuser-pipe system is producing deviations of up to about 0.4°F from fully mixed temperatures at a section 500 ft downstream from the diffuser pipes (see Figure 13). It is estimated that by "tuning" the pipes, this deviation from the fully mixed temperature could be reduced to about 0.2°F.

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B. Summary of Biological Studies

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B. Summary of Biological Monitoring Studies

Environmental studies began in 1968, over three years prior to Quad Cities Station operation and several of these programs still continue. Water quality, as well as the nature and abundance of the biota of Pool 14, has been evaluated. Monitoring was conducted in major habitats upstream and downstream of the Station, including sloughs, main channel, main channel borders, side channels and major tributaries.

An important component of these studies has been a continuing evaluation of the specific sampling and analytical procedures, to assure adequate sensitivity to detect changes between control and potentially impacted sampling locations. The programs were sensitive enough to have detected short or long term effects that Station operation might have had on the water quality or aquatic biota of the Pool. This is demonstrated by the fact that natural variation between seasons, years and major habitat types could be defined with confidence, Station operation notwithstanding. Also, numerous localized effects which were expected have also been detectable.

This summary is based on a review of the monitoring and special programs conducted through 1977, except for ichthyoplankton and adult and juvenile fish for which data was available through 1979. Two major reports form the basis of this summary, "Preoperational and Operational Environmental Monitoring in the Mississippi River near Quad Cities Station", August, 1969-December, 1978 (Hazleton Environmental Sciences, 1979a) reviews results of all studies through 1978. The second report entitled, "Quad Cities Aquatic Program, 1979 Annual Report" (Commonwealth Edison Company, 1980), reviews ichthyoplankton, adult and juvenile fish monitoring and special studies conducted in 1979.

1. Water Quality Studies

This summary is based on Hazleton Environmental Sciences (1979a) pp. 2.1 to 2.81. A summary of water quality parameters measured from 1968 through 1977 is presented in Table 1. Water quality of Pool 14 is generally good although pollution exists immediately downstream from some major cities and towns bordering the river. There are also periods of degraded water quality apparently due to upstream industrial discharges, which have resulted in occasionally high levels of total iron, mercury, manganese, copper, hexane soluble materials and phenols. Increased concentrations of these substances were not attributed to the operation of the Quad Cities Station.

Annual high flows associated with rainfall or snow melt and subsequent runoff from agricultural land frequently resulted in increased concentrations of nutrients and solids and increased bacterial numbers within the pool. This [illegible], in association with periodic large changes in these variables attributed to the Wapsipinicon River, has resulted in much of the spatial variability in water quality observed in the immediate vicinity of Quad Cities Station. Differences in water quality between sampling locations throughout the rest of the pool were usually negligible.

Low flow conditions do not appear to adversely affect the water quality of the Mississippi River in Pool 14. Monitoring on an extremely low flow day (approximately 10,000 cfs) in August, 1977, did not indicate any significant differences from the usual water quality conditions other than a slight increase in ammonia concentrations. The ammonia increase was possibly due to reduced dilution of upstream waste discharges.

Table 1

Summary of Water Quality Monitoring Parameters, Pool 14 of the Mississippi River near Quad Cities Station, 1968-1977.

Alkalinity, total
Ammonia
Bacteria, fecal coliform
Bacteria, fecal streptococci
Bacteria, total coliform
Bacteria, standard plate count
Biochemical oxygen demand (BOD - 5 day)
Calcium, soluble
Calcium, total
Chemical oxygen demand (COD)
Chlorine, total
Color, true
Conductance, specific
Copper
Current Velocity
Cyanide
Hardness, total
Hexane - soluble materials
Iron - soluble
Iron - total
Lead
Magnesium, soluble
Magnesium, total
Manganese, soluble
Manganese, total
Mercury
Nitrate
Odor, threshold
Odor, description
Organic carbon, total
Orthophosphate soluble
Oxygen, dissolved
Oxygen, percent saturation
pH
Phenols
Phosphorus, total
Residue, filterable (total dissolved solids)
Residue, non-filterable (total suspended solids)
Silica, soluble
Temperature
Turbidity
Zinc

There were no appreciable differences in natural seasonal patterns of the various parameters between the Quad Cities preoperational and operational investigations. For the water quality variables considered, there appears to be a general long term trend toward improvement in water quality in the Pool.

With the exception of the period of interim side-jet discharge, the effects of Station operation were confined to the immediate area of the Station discharge and were not observed in the river downstream of this area. Operation of the interim side-jet discharge during April-July, 1972, resulted in major differences between the intake forebay and discharge canal for water temperatures and dissolved oxygen concentrations as would be expected. This was the only period of Station operation when temperature increases greater than 5°F above ambient were observed outside the mixing zone. For diffuser operation, water temperatures and dissolved oxygen concentrations exhibited significant differences between the intake and discharge bays. However, effective mixing at the diffuser discharge ports allowed for only slight increases in water temperatures immediately downstream of the diffuser pipes in the main river channel. There was no measurable effect on the various other water quality parameters monitored within the river during open-cycle operation.

As expected, there were a considerable number of water quality changes between the Station's intake bay and discharge bay associated with closed-cycle operation. Water temperatures and dissolved oxygen concentrations, on occasion, were slightly affected by Station operation. Water temperatures were higher and dissolved oxygen concentrations were lower in the discharge bay than in the intake forebay. Higher levels of some water quality consitutents were occasionally observed in the Station discharge bay and spray

canal than in the intake forebay or river, although differences were not statistically significant. These constituents include specific conductance, filtrable residue, total residue, nonfiltrable residue, turbidity, soluble orthophosphate, total phosphorus, soluble silica, standard plate count bacteria, total and fecal coliform bacteria, fecal streptococcus bacteria, cyanide, copper, lead, total manganese and mercury. The increases relate primarily to concentration as a result of evaporation in the spray canal or to differences in biological activity which occur at higher water temperatures and were expected for closed cycle operation.

2. Phytoplankton Studies

This summary is based on Hazleton Environmental Sciences (1979a pp. 3.1 to 3.37). Seasonal trends in phytoplankton occurrence and densities were comparable during all (preoperational and operational) sampling years. Diatoms composed the majority of the total phytoplankton during all study periods; centric diatoms were the predominant form. An increase in populations of green and blue-green algae was observed during the 1976 period of very low flows. Diatoms remained dominant during these lower flow periods; however, the populations were less abundant than usual and not as diverse. Peak densities occurred in spring (April and May) and in fall (October and November). Seasonal lows occurred in winter (January and February).

The slough habitats generally supported the largest and most diverse phytoplankton populations. These relatively quieter areas are generally recognized to be biologically important areas of high production. As water levels increase, the backwater habitats and slough areas are inundated and, as flow

declines, the drainage contributes to temporarily increased densities of plankton in the river. There were few differences in the density or composition of plankton assemblages between the main channel and main channel border locations. Differences in phytoplankton assemblages between the Wapsipinicon and Mississippi Rivers were, however, evident.

No consistent significant changes in species composition or distribution of organisms in this group were observed between control and potentially impacted sampling locations in the river. Most importantly, phytoplankton densities and community compositions were not measurably different between the areas upstream and downstream of the diffuser pipe during open cycle operation. Effects of condenser passage on phytoplankton were evident for operation with both the side-jet and diffuser. The effects on entrained phytoplankton were, however, inconsistent. Slight increases in phytoplankton productivity and chlorophyll a concentrations were periodically observed at locations immediately downstream of the diffuser pipe. However, these slight increases were not measureable outside the immediate discharge area.

3. Zooplankton Studies

The summary is based on Hazleton Environmental Sciences (1979a, pp. 4.1 to 4.29). Zooplankton reach their maximum seasonal abundance between April and June with relatively smaller pulses occurring in the summer and late fall. Rotifers and immature copepods usually account for the majority of the zooplankton. Differences in zooplankton abundance were noted between the various slough, main channel and main channel border locations. In addition, assemblages in the Wapsipinicon River were noticeably different than the

Mississippi River assemblages. There were no appreciable changes in the natural seasonal patterns of the zooplankton populations of Pool 14 throughout the monitoring program.

Consistent significant alterations in species composition or distribution of zooplankton were not observed between control and potentially impacted sampling locations in the river. In particular, zooplankton densities and community compositions were not appreciably different between areas upstream and downstream of the diffuser pipe during open cycle operation. The program designed for assessing the effects of Station operation on this group of organisms would have detected any major change in this community since differences between seasons, locations and years and the two rivers sampled were observed.

4. Periphytic Algal Studies

This summary is based on Hazleton Environmental Sciences (1979a pp. 5.1 to 5.68). Diatoms were the most commonly encountered periphyton with species of Navicula, Gomphonema, Nitzschia and Melosira generally the most common forms. Dominance by green and blue-green algae occasionally occurred during the summer. Seasonal trends of periphyton density were generally comparable throughout the monitoring program with peaks occurring from mid-summer through early fall. Lowest production occurred during December through March. This seasonal succession within the periphyton community was undoubtably affected by changes in chemical and physical factors such as water temperature and nutrient concentrations.

Blue-green and green algae were more abundant in 1976 than during the other years of monitoring. As with phytoplankton, diatoms remained dominant during this low flow period. The slightly different physiochemical factors associated with the extraordinarily low river flow in the year, were probably responsible for the prevalence of these algal components.

Periphyton abundance, as measured by total biovolume and biomass and chlorophyll a production values, was variable among sampling locations, both between and within years. The differences between these three measures are attributed primarily to seasonal changes in both photoperiod and chemical and physical factors. Differences in abundance and composition between the Wapsipinicon and Mississippi Rivers were especially pronounced and were attributed to differing water temperatures, current velocities, turbidity and nutrient levels.

Periphytic algae biomass values and chlorophyll a concentrations were reduced in the discharge bay and in the immediate discharge area during side-jet operation. These differences were expected and attributed to Station operation. No differences were found in the river, however, during diffuser pipe operation. The lack of differences was attributed to the translocation of the plume to the main channel and to the rapid mixing of the discharge with river water. This is especially significant in view of the effects observed during closed-cycle condenser cooling which results in the occurrence of a thermal plume escaping from the intake bay. This plume occupies an extremely small fraction of the river's cross sectional area along the Illinois shoreline. Some very localized and minimal effects on periphyton production and composition patterns were attributed to this intake plume.

No consistent significant alterations in species composition or distribution of organisms in this group were observed between control and potentially impacted sampling locations in the river due to operation of the Station. Furthermore, it is unlikely that any significant differences could occur since the warm water discharge for open-cycle operation is to the main channel outside any area where periphyton attachment would naturally occur.

5. Benthic Macroinvertebrate Studies

This summary is based on Hazleton Environmental Sciences (1979a pp. 6.1 to 6.148). Benthic macroinvertebrate monitoring of Pool 14 has been accomplished through the sampling of natural and artificial substrates and drift sampling. The various sampling techniques have collectively provided for a complementary monitoring of all of the various life history stages and habitat preference of the macroinvertebrates of this area of the Mississippi River.

The composition of the benthos community is highly dependent on the river flow, sediment type and season at the time of sampling. The dominant organisms collected were the aquatic worms (Naididae and Tubificidae), burrowing mayflies (Hexagenia spp.), net-spinning caddisflies (Hydropsychidae) and midge flies (Chironomidae).

The most consistent spatial difference in abundance and composition was between the main channel and main channel border habitats. The main channel which receives the highest temperature rise for open cycle operation is characterized by a shifting sandy bottom and has lower abundance and less diversity. In addition, the thermal plume from the diffuser system is

bouyant which results in little, if any, temperature increase in the area. Main channel border locations on the other hand, are usually characterized by a higher proportion of silt and clay in the substrate and have more tubificids, chironomids and Hexagenia. In addition, the more widespread occurrence of Hexagenia was commonly noted during extended low flow periods, possibly due to increased siltation.

Freshwater mussel (Pelecypoda) populations differed between upstream and downstream locations in the main channel border habitat in the vicinity of the Station. Species occurrence and densities of mussels were greater at the downstream locations than at the upstream locations. These differences were apparently related to the more favorable hydrologic conditions at the downstream locations which were characterized by having a continuous current and a silty gravel substrate. Since these locations are not impacted by the plume from the diffuser system, no association of these differences with Station operation would be expected.

Naididae (aquatic worms), Hyalella azteca (amphipods), Hepta-genidae (mayflies), Hydropsychidae and Psychomyiidae (net spinning caddisflies) and Chironomidae (midge flies) were the predominant organisms collected on artificial substrates. Community composition and density on the artificial habitats fluctuated at all sampling locations presumably due to changes in annual river flow and season as well as local sediment character and current velocities. Recruitment or drift of organisms from the Wapsipinicon River also affected populations downstream from the river's confluence with Pool 14.

There were no measurable effects of Station operation on the benthic macroinvertebrate community downstream from the Station resulting from open-

cycle (diffuser) operation. Dredging operations during the installation of the diffuser pipe system in 1972, resulted in a temporary downstream change in sediments and community composition but both sediment characteristics and community structure returned to normal after dredging was completed. The ability to detect and follow the progression of change associated with dredging demonstrates the sensitivity of the monitoring program.

Entrained macroinvertebrates suffered mortalities in the discharge bay at high water temperatures. No significant detrimental effects were observed, however, in the Mississippi River when drifting macroinvertebrates passed across the mixing zone of the diffuser pipe system.

Benthic macroinvertebrates on both natural and artificial substrates were affected by the thermal plume escapement from the intake bay during closed cycle operation. These effects were restricted to a limited area outside the intake and along the Illinois shoreline.

Operation of the diffuser pipe during combination cycle also appeared to have no measurable effect on benthic macroinvertebrates on natural substrates downstream of the Station. As indicated earlier, this finding was expected because of where the diffuser discharges (main channel) and the bouyant nature of the thermal plume. Populations colonizing artificial substrates, however, appeared to be altered by increased densities of Nais bretscheri (naidid) and Glyptotendipes (midge). These increased numbers were attributed to drift of these organisms out of the spray canal through the diffuser pipes since similar increases were not found during

open-cycle operation. Qualitative sampling conducted in 1977 showed these two species to be very common in the spray canal. This finding is considered to be an artifact since the artificial substrates were located in the water column off the bottom and is probably not applicable to natural substrates in the area of the discharge. Once again, no consistent significant alterations in species composition or distributions of organisms in this group were observed between control and potentially impacted sampling locations in the river associated with diffuser operation.

6. Ichthyoplankton Studies

This summary is based on Hazleton Environmental Sciences (1979a pp. 8.1 to 8.74) and Hazleton Environmental Sciences (1979b). Larval fish populations in Pool 14 of the Mississippi River near Quad Cities Station have been monitored since 1971 through the use of towed net samples. Comparisons of data from 1971 through 1974 were difficult to make because sampling frequencies, techniques and locations were inconsistent among years. Since the sampling design was more consistent from 1975 through 1979, data comparisons were made for these years only for this Demonstration.

Freshwater drum eggs have been the predominant fish eggs collected during each of the five years and have proportionally increased each year from 66% of the total eggs collected in 1975, to 98% in 1978, and 97% in 1979. Freshwater drum egg densities peaked when ambient river temperatures were about 68 to 71.6°F during each of the five years. Usually these temperatures (and high densities) occurred during late May to early June.

The taxa of fish larvae collected have remained constant with freshwater drum, carp and cyprinids (minnows other than carp) being the most

abundant taxa during the five years of study. Other abundant taxa included catostomids (suckers), white bass and gizzard shad. Ichthyoplankters typically appeared in the drift in mid to late April each year, with the greatest numbers occurring in mid-June. Few remained in the drift after July. Ambient river water temperatures appeared to directly influence the density of ichthyoplankton. Most of the total ichthyoplankton drift occurred when ambient river water temperatures ranged from 64.4 to 71.6°F. However, there was no obvious correlation with river flow. The only exception to this was in 1977, when it appeared that low river flow influenced spawning success. As a result, most ichthyoplankton were collected later than during other years.

In 1978, an intensive sampling program was conducted during the period of peak larval abundance with special emphasis on the freshwater drum (Hazleton Environmental Sciences, 1979b). This study demonstrated that there was little difference between average day and night abundances. There were also no great differences in vertical distribution of all larval stages combined. There were, however, consistent horizontal differences with the main channel and Illinois side of the river exhibiting somewhat higher total larval abundance.

The above conclusions were based on analyses in which all larval stages were combined. In 1978, diel, vertical and horizontal density differences by larval stage (yolk-sac, post yolk-sac and juvenile) were also investigated (Hazleton Environmental Sciences, 1979b). In general, the various stages were distributed similarly to the total except for yolk-sac larvae which at night exhibited much higher abundances in the bottom samples.

During 1978 and 1979, samples were collected at a location immediately below Clinton Lock and Dam, another -tion between the Station and Clinton Lock and Dam, and a location in the Marais D'osier Slough (Commonwealth Edison Company, 1980). The location farthest upstream (Clinton Lock and Dam) was used to measure contributions of freshwater drum eggs and larvae to Pool 14 from Pool 13. The other two locations were needed to determine whether the usual sampling area (immediately above the Station) was unique with respect to being a freshwater drum spawning and nursery area. Freshwater drum eggs and larvae were abundant at all locations in both years demonstrating that Pool 13 and all of Pool 14 above the Station are spawning and nursery areas.

7. Adult and Juvenile Fish Studies

This summary is based on Hazleton Environmental Sciences (1979a pp. 7.1 to 7.145) and Commonwealth Edison Company (1980, pp. 3-1 to 3-52). Adult and juvenile fish monitoring has been conducted in the area of the Quad Cities Station since 1971. The program was modified several times in the interval 1971 through 1977, to address specific objectives related to Station operation. In 1978, results of the previous years' studies were reviewed, and those sampling techniques (electroshocking and bottom trawling) and sample locations which had the greatest continuity since 1971, were selected for incorporation in a long-term monitoring program that is currently underway. In 1978, an additional method of sampling, haul seining, was incorporated into the long-term program to provide relative abundance and standing stock estimates for several species not adequately sampled in previous studies. This was done at the suggestion of the Iowa Conservation Commission. Finally, at the suggestion of the Illinois Department of Conservation, fall fish standing stock estimates for slough habitats based

on a cove rotenone technique of sampling, were initiated in 1979.

Electroshocking

Fifty taxa of fish have been collected by electroshocking during the nine years of investigation (1971 through 1979). Of these 18 or 36% were captured every year. The number of species collected in a particular year has not varied significantly and has ranged between 27 (1975 and 1977) and 35 (1973). Differences in species occurrence during these years resulted primarily from the sporadic occurrence of taxa which are uncommon or are generally not vulnerable to electroshocking. Eight taxa were collected at least once between 1971 and 1974, but were not captured thereafter; these were yellow bullhead, tadpole madtom, brook silverside, yellow bass, green sunfish, yellow perch and log perch. Paddlefish, goldeye and blue sucker were captured only sporadically after 1973. The five most abundant species collected over the nine years of study were gizzard shad, carp, bluegill, river carpsucker and freshwater drum. In terms of the more abundant species, there has not been any continuously progressive increase or decrease in ranking.

Total catch-per-efforts (CPE's) from earlier years were calculated both with and without gizzard shad because sampling efficiency for this species varied. Collection efficiency of stunned gizzard shad prior to 1976, was insufficient to adequately represent true abundances of this species and electroshocking results underestimated their relative importance in the study area. An extra effort was made from 1976 through 1979, to collect all shocked gizzard shad. To allow better comparability between years, relative abundances discussed here are "without gizzard shad." Numbers,

CPE and relative abundance (%) of fishes collected by electroshocking for 1971 through 1979, are given by location and habitat in Commonwealth Edison Company (1980 Appendix C, Tables C-4 through C-30).

The annual total CPE values (without gizzard shad) for the entire study area were similar among the one year of preoperational monitoring (1971) and the first two years of operational monitoring (1972 and 1973). During these first two years of operation, the Station operated open-cycle. From 1974 through 1979, when the Station principally operated closed-cycle (spray canal only) or partial open-cycle (single diffuser plus spray canal), there was a substantial reduction in cooling water utilization, but an overall decrease in annual CPE was observed. A successive decline in CPE was observed in 1974 and 1975, remained low in 1976, decreased in 1977 and 1978, and increased slightly in 1979 (Commonwealth Edison Company, 1980, Figure 3-5).

This pattern of decline in annual CPE values for the entire study area from 1971 through 1979, was also observed within each habitat type. In 1972, the total CPE increased slightly at the slough location and continued to rise in 1973. However, during the next four years (1974-1978) there was an overall decrease except during 1976, when this habitat was not sampled. CPE values for main channel border and side channel border generally were similar and, although lower than values recorded for the slough habitat, followed the same trend described earlier for the nine year period.

Some differences in CPE values were detected between comparable habitat locations upstream and downstream of the Station. Regardless, the yearly

pattern at these locations was similar with highest CPE's in 1971, 1972 and 1973, followed by a steady decline over the next five years except for slight increases in 1977 and 1979. These data indicate that factors affecting the fish community from 1971 through 1979, were similar within each habitat throughout the study area. Since the decrease was observed at both upstream (control) and downstream (potentially impacted) locations, it cannot be attributed to the thermal discharge associated with Station operation.

It is possible since catch-per-unit-effort was higher during the earlier open-cycle years than during the later closed-cycle years, that Station operation affected subsequent population levels because of entrainment and impingement losses. It is believed, however, that this is not the case as is discussed in the entrainment and impingement sections of the 316(b) Demonstration Supplement (this volume). Entrainment losses are expected to be about the same for larvae during open or closed-cycle operation. Impingement is also unlikely to result in population decreases of the magnitude seen over the study period because very low percentages of the total Pool 14 population are lost. Impingement losses can be considered to be inconsequential in terms of maintaining population levels. In addition, fluctuations in fish communities are common phenomena and may be caused by a variety of factors.

Bottom Trawling

A total of 34 fish species have been captured by bottom trawling from 1971 through 1979. Of these, carp, silver chub, channel catfish and freshwater drum have been collected each year. Very little annual change in species composition of the fish community has occurred during the nine year monitoring

program. The five most abundant species in decreasing order of abundance have been channel catfish, freshwater drum, shovelnose sturgeon, silver chub and carp. One western sand darter was collected in 1977. The State of Iowa (Roosa, 1977) considers this species to be threatened.

Bottom trawling data in conjunction with temperature were used to evaluate avoidance or attraction of fish to the vicinity of the diffuser system. Aside from decreased abundances at the diffuser location in 1972 (during installation of the system) there has been no correlation between temperature and fish catches in the diffuser area.

Haul Seine

In 1978, an additional sampling method was introduced into the long term monitoring program. Haul seine locations were established upstream of the Station in three habitats (side channel, slough and altered slough) to provide relative abundance estimates for several species which were not adequately sampled by trawling and shocking in previous studies. The haul seine was also introduced to provide a standing stock estimate for the side channel and slough habitats.

During the two years of monitoring, 24 species have been collected with species composition similar between 1978 and 1979 (Commonwealth Edison Company, 1980, Tables 3-6 and 3-8). Species abundance during 1979 was slightly lower than in 1978. During both years, freshwater drum was the most abundant species captured generally followed by gizzard shad, mooneye, white bass, river carpsucker, quillback, white crappie, smallmouth buffalo and sauger.

Results of the 1978 and 1979 haul seine collections were also used to estimate standing crop by species, number and weight for each of the three habitats surveyed. The estimated total standing stock for side channel and slough habitat was 88.0 and 260.0 lbs/acre in 1978, and 42.7 and 288.6 lbs/acre in 1979 (Commonwealth Edison Company, 1980, p. 3-43). The standing stock estimate for the altered slough habitat in 1979 was 18.6 lbs/acre. (This area has been altered by a sand and gravel dredging operation.) Haul seine standing crop estimates are certain to be low by a substantial but unknown margin. This is due in part to escapement of small fish through the 1-1/2" bar mesh of the haul seine. Some fish may also escape through gaps between the lead line and substrate.

Rotenone Survey

In 1979, the standing crop in the fall was estimated from a rotenone survey conducted in a cove in Marais D'osier Slough upstream of the Station. The area was blocked off with a net and electroshocked prior to application of the rotenone. Fish captured were marked and returned to the sample area. A total of 24 species was collected by rotenoning. Numerically, gizzard shad, white crappie and carp comprised 92% of the fish collected (84%, 6% and 3%, respectively). By weight, gizzard shad, carp, northern pike and white crappie contributed 93% of the catch (50%, 32%, 8% and 3%, respectively) (Commonwealth Edison Company, 1980, p. 3-37). Based on the results of the marking and subsequent rotenone sampling, the estimated standing crop of the surveyed slough was 5,398 fish/A with a biomass of 648.6 lbs/A.

In a previous study by Muench (1978) in 1977, one cove rotenone survey was conducted in an area near the site of the 1979 survey. Procedures were essentially the same as the 1979 survey, and results were similar for both species composition and abundance, standing crop estimates of 566.0 lbs/A for 1977, and 648.6 lbs/A for 1979 are not considered to be significantly different.

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C. Effects of Increased Temperatures on Fish

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Introduction

This chapter deals with the effects that elevated temperatures resulting from once-through or open-cycle operation of the Quad Cities Station might have on the fishes of Pool 14. The physical and hydrological nature of Pool 14 and the changes anticipated as a consequence of open-cycle operation of the Station have been discussed in detail by Drs. Kennedy, Jain and Kitanidis (this volume). Briefly, the main body of the pool has an annual temperature cycle that ranges from a mid-winter low of approximately 32°F to a mid-summer high of about 78°F. The Station discharges heated water from a paired diffuser system located on the bottom of the main channel and extending from the Illinois side of the river. The heated water is discharged from a series of ports or jets designed to promote rapid mixing with ambient temperature river water.

The heated plume downstream of the diffuser has three principal components. The near-field (in which the mixing of heated and ambient waters is driven by the process of jet entrainment) initiates at the individual ports and decays to form the far-field (in which any further mixing is driven by natural processes). The third component is the global-field, a region in which heated and ambient waters are completely mixed. It is from the latter two regions that most of the heat rejected by the Station is dissipated to the atmosphere.

Diffuser port exit velocities range from 8.5 to 9.0 ft/sec when the Station is operating all of its six circulating water pumps. The ΔT or temperature rise above ambient is 23°F when the Station is achieving its

maximum power output. The initial (near-field) time-temperature decay curve associated with entrainment mixing is shown in Figure 1. There is a proportional decay of temperature and velocity while the volume of heated water increases accordingly. Principal factors affecting the shape of the initial decay curve are exit velocity, discharge temperature, ambient temperature and river velocity. Each of these can vary within limits as discussed by Dr. Kennedy. However, as a general case, the near-field is defined at each port by a velocity decline from 8-9 ft/sec to about 2 ft/sec, a temperature decline from 23°F to about 4°F and an increase in plume volume due to jet entrainment of ambient water of about 6X.

The dimensions of the far-field and global-field are highly dependent on seasonal conditions that control the rate of heat loss to the atmosphere as well as on total river flow and ambient temperature. Under conditions of maximum power output and minimum river flows (7Q10), the entire main channel of the river downstream of the diffuser may be heated by as much as 3.95°F (Kennedy, this volume).

Effects of Temperature on Fish - General Summary

Temperature is the most extensively studied of the environmental variables that affect fish distributions and well-being (with the exception of geography). Recent and excellent reviews of the scientific literature have been prepared by Fry (1971 - Ecological relations) and Hochachka and Somero (1971 - Biochemical relations).

Discrete upper and lower boundary temperatures exist for all life functions. Temperatures that set limits for survival comprise the

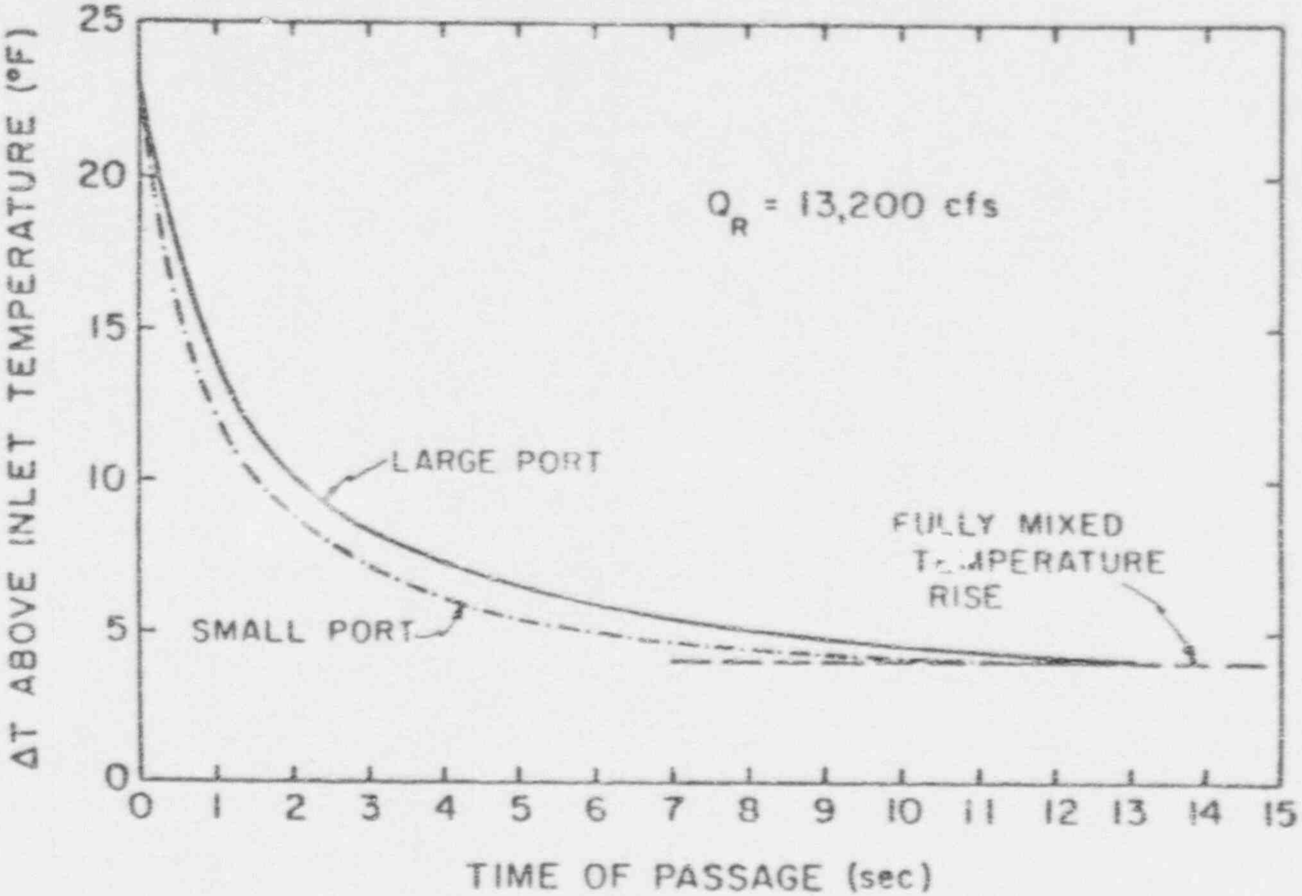

Figure 1. The decay of excess temperature from a single port of the Quad Cities diffuser.

widest boundaries with successively narrower limits for avoidance, attraction, growth, swimming performance and reproduction. The specific limiting values for each of these functions vary with species. In addition, there is a certain amount of plasticity (resistance, acclimation or acclimatization) associated with the life stage and previous thermal experience of the individual fish. The single exception appears to be reproductive function, for which thermal limits are fixed at the species or population level (Hokanson 1977). Any reproductive compensation for annual variation in temperature cycles seems to be restricted to alteration of the timing of the reproductive sequence.

Potential for Exposure of Fish to Increased Temperatures at Quad Cities Station

The physical and hydrological events described briefly above govern the circumstances of exposure of Pool 14 fishes to elevated temperatures. There are three principal cases of interest. The first two relate to the near-field and provide opportunity for exposure to elevated temperatures approximating (but never equaling) the station ΔT. First, fishes, and planktonic eggs or weakly swimming larvae in particular, may be swept into the plume by the process of jet entrainment. Second, strongly swimming fish may of their own volition actually penetrate the plume in an upstream direction, drawn by an attraction to the elevated temperature or velocity but limited in the extent of their penetration by an avoidance response to high temperatures, swimming capabilities and the relatively small volumes available. The third circumstance occurs when the far-field and global-field comprise a substantial portion of the river downstream of the diffusers. Fish resident to main channel habitats must then contend

with the events of day-to-day life in an environment that is slightly warmer (maximum of 3.95°F) than is normal for Pool 14.

There are also two secondary considerations relevant to fish exposure to the thermal plume. The first, the potential for cold death or shock following shut-down of the Station (termination of the heated plume) is pertinent to a situation in which fish reside in and acclimate to the heated effluent during the winter months. The second, gas bubble disease, is also a potential mid-winter problem for plume resident fish and relates to exposure to waters supersaturated with dissolved gases.

Fish Species of Concern

The Mississippi River has an ancient and extraordinarily diverse native fish fauna, which has subsequently been expanded by the introduction of exotics. More than 75 species representing 19 families have been collected from Pool 14 during the ten years that the Quad Cities Monitoring Program has been in progress. The distribution of these species within the Pool is complex, reflecting the availability of a variety of different habitat types as well as the seasonally changing ecological requirements of particular species or age groups.

The principal habitat types are the main channel, side channels, main channel borders, sloughs and tributary streams of various sizes. Since the Station discharges to the open river (main channel) habitat, fishes inhabiting that region and, to a lesser extent, the shallower areas peripheral to the main channel have the greatest probability of exposure to the heated effluent.

The open-river fish assemblage has two principal components: planktonic or semibuoyant forms (eggs and early larvae), which are immotile or only weakly motile and drift with the current, and nektonic or free-swimming fishes (juveniles and adults) capable of controlling their own distributions. The most common planktonic life forms include one species of egg (freshwater drum) and seven taxa of larvae (Table 1). The more common nektonic forms include 20 species (Table 2). The principal method of collection is also indicated in Table 2 as a means of discriminating species that are most often found on or near the bottom in open water (trawl) from those more commonly found in shallow water along shore (electroshocking).

Maximum Acceptable Temperatures for Prolonged Exposures

The design of the diffuser system places stringent limits on the opportunities of fishes for prolonged exposure to elevated temperatures. Since the majority of the near-field regions are unavailable to fish for other than brief periods, concerns for prolonged exposure are limited primarily to the far-field and global-field, regions no more than 4°F warmer than ambient waters.

The areal extent of the far- and global-fields varies widely depending on river flow and ambient air and water temperatures, parameters reflective primarily of seasonal climatic conditions. In addition, fish response to temperature or temperature fluctuations varies in relation to seasonal cycles, and we have chosen to structure our consideration of the effects accordingly.

Winter: Winter is a period of low to intermediate flow and minimum ambient air and water temperatures. The rapid loss of excess heat to the

Table 1. Planktonic life stages of fish commonly occurring in main channel habitats in Pool 14 of the Mississippi River.[1/]

TAXON	PERIOD	WATER TEMPERATURE
EGGS		
Freshwater drum	Late May - Mid-June	57 - 72°F
LARVAE		
Walleye/Sauger	Mid-April	48 - 52°F
Carp	Late April	52 - 59°F
Freshwater drum) Cyprinidae (minnows)) Catostomidae (suckers)) Gizzard shad) White bass)	Late May - Late June	61 - 72°F

1/ H.E.S. 1979. Ichthyoplankton Studies. Chapter 8. Environmental Monitoring in the Mississippi River near Quad Cities Station. May 1975 through July 1978. Report to Commonwealth Edison Co., Chicago, Illinois. 74pp.

Table 2. Major components of the main channel fish assemblage in Pool 14 of the Mississippi River.

TAXON	COLLECTION TECHNIQUE
Acipenseridae (sturgeons)	
Shovelnose sturgeon	Trawl
Clupeidae (herrings)	
Gizzard shad	Electroshocker
Hiodontidae (mooneyes)	
Mooneye	Electroshocker-Trawl
Cyprinidae (minnows)	
Carp	Electroshocker-Trawl
Silver chub	Trawl
Emerald shiner	Trawl
River shiner	Trawl
Catostomidae (suckers)	
River carpsucker	Electroshocker-Trawl
Smallmouth buffalo	Electroshocker
Bigmouth buffalo	Electroshocker
Ictaluridae	
Channel catfish	Electroshocker-Trawl
Stonecat	Trawl
Percichthyidae (temperate basses)	
White bass	Electroshocker
Centrarchidae (sunfishes)	
Bluegill	Electroshocker
Largemouth bass	Electroshocker

Table 2. Continued

White crappie	Electroshocker
Black crappie	Electroshocker
Percidae (perches)	
Sauger	Electroshocker
Walleye	Electroshocker
Sciaenidae (drum)	
Freshwater drum	Electroshocker-Trawl

atmosphere results in a small (generally absent) global-field and reduced far-field plume relative to the other seasons. In spite of the small extent of the heated areas relative to available habitat, most if not all species inhabiting Pool 14 could be attracted to temperatures exceeding ambient during this period. Numerous laboratory studies (McCauley 1977, Otto et al. 1975, Coutant 1975, Rice *et al.* 1974, Barrans and Tubbs 1973, Coutant and Goodyear 1972) and field investigations (Yoder and Gammon 1976, Gibbons *et al.* 1972, Gammon 1971, Ferguson 1958) have demonstrated this attraction, raising the possibility that fish may seek out or be reluctant to leave the warmed areas immediately downstream of the diffusers. In addition to the generalized distributional shift, prolonged low level thermal experience during winter months would increase metabolic costs during a period of low food availability and potentially influence endocrine or metabolic aspects of the reproductive maturation process (Brungs and Jones 1977). Additional concerns specific to the winter period include cold shock and gas bubble disease. Both require that fish maintain residence within the confines of the heated areas for extended periods (days to weeks).

The general concern for body condition and reproductive impairment of fish that have access to unseasonally warm waters during the winter months relates particularly to those species, such as the yellow perch, for which a chill period is required for successful gonadal maturation (Brungs and Jones 1977, Hokanson 1977, Jones *et al.* 1977, Hokanson *et al.* 1973). However, an elegant study of seasonal fish distribution in the vicinity of a thermal effluent has addressed this problem directly and done much to eliminate it as a pertinent concern for open-field discharges (Ross and Sinif 1980).

Ross and Sinif evaluated the movements of four species (yellow perch, walleye, northern pike and largemouth bass) in Pokegama Reservoir, Minnesota, an impounded section of the Mississippi River that receives a thermal effluent from two 75 MWe generating units ($\Delta T = 27°F$). Most of the effort was directed to the yellow perch, a species with a mid-winter preferred temperature under laboratory conditions of 54 to 65°F (McCauley 1977, Barrans and Tubbs 1973, Otto *et al.* 1975) and a winter chill period requirement for optimal spawning success of 185 days at 39°F or less (Jones *et al.* 1977). Observations on the walleye, northern pike and largemouth bass were restricted to a consideration of mobility and home range dimensions relative to the heated effluent.

The results are in accord with the intuitively obvious (but difficult to confirm) concept that field distributions of fish reflect the interaction of numerous factors, each having its own (dynamic) directional aspect and intensity (see also Kaufman *et al.* 1980, Andrewartha and Birch 1954). Of the species studied, only the largemouth bass (two individuals) stayed within the thermally impacted area throughout the winter period. Observations of walleye, northern pike and yellow perch demonstrated that factors other than or in addition to access to seasonally elevated temperatures were of importance in determining distributions. Elevated thermal experience for these species was found to be transitory (incidental) in nature.

The more extensive evaluation of yellow perch distributions showed that only a small portion of the potentially impacted population experienced any (even a low level) increase in winter temperature exposure. Body size

(condition) and reproductive parameters (gonadal somatic indices) were similar for perch collected from thermally impacted areas and adjacent, ambient temperature areas. The authors concluded that gonadal development and maturation (during the required winter chill period) are protected, even in the vicinity of a thermal effluent if the fish have access to thermally unaltered habitat. Certainly such a situation exists in Pool 14.

Several mid-winter fish kills at power plants have occurred, which can logically be attributed to cold shock following plant shut-down (Smithsonian Institution 1972, Commonwealth of Pennsylvania 1971, Trembley 1965). Such incidents are most likely to occur in situations in which a low velocity discharge is directed to a semi-enclosed embayment or canal or in water bodies where the winter survival of exotic or introduced species is dependent on the presence of the heated effluent (for example, southeastern reservoirs stocked with threadfin shad). Neither situation is analogous to the Quad Cities Station, where high velocity diffusers are employed in an open-field context and where no thermally sensitive, exotic populations exist.

Fishes resident to Pool 14 are generally incapable of maintaining themselves within the diffuser near-fields for a sufficient period to acclimate (days). Most fish have long-term swimming capabilities (cruising speeds) of two to four times their body length (Otto *et al.* 1975, Webb 1975). In addition, swimming capability is reduced with both increasing size and decreasing temperatures. Assuming that most fish inhabiting Pool 14 are one foot or less in length (or that fish larger than one foot long have progressively reduced relative swimming capabilities) and referring to

the discussion by Dr. Kennedy (this volume) on the rates of temperature and velocity decay in the near-field plume, fish will generally be unable to experience elevated temperatures exceeding 4 to 8°F for more than brief periods. Available data on cold tolerance of fish species that occur in Pool 14 (summarized in Brungs and Jones 1977) indicate that resident fishes can readily tolerate a decline of this magnitude should any individuals actually undergo such acclimation (which we consider improbable - see also Ross and Sinif 1980) and should it be necessary to reduce Station load or shut down both generating units simultaneously.

Prolonged exposure to elevated temperatures of 4 to 8°F during the winter months could result in a coincident exposure to dissolved gas supersaturation levels of 110% at most (assuming the worst case situation: ambient water temperature of 32°F, water fully gas-saturated prior to condenser passage). This level of supersaturation is below that generally considered necessary to cause gas bubble disease (Otto 1976, Parametrix 1973). In addition, the effective level of gas supersaturation (that existing where the fish are) will be substantially reduced by hydrostatic pressure (Klots 1961). Solubilities of gases (using solubility to imply a critical concentration above which a bubble can form) are approximately doubled for each 30 foot increase in water depth. Thus, fish within the Quad Cities diffuser near-fields at elevated temperatures of 4 to 8°F but also at depths of greater than 3 to 4 feet will not experience effective gas saturation levels exceeding 100%.

Spring: Spring is the period of maximum River flow and low to moderate air and water temperatures. The resultant rapid dilution and loss

of heat to the atmosphere prevent the development of a measurable global-field and strongly limit the areal extent of the far-field regions. Any prolonged exposure of fish to elevated temperatures is therefore unlikely to occur. Spring is, of course, the spawning and incubation period for all but a few of the fishes that inhabit the Pool. The potential for entrainment of the spawn and early life stages into the thermal plume is considered in the following section.

Summer: Summer is the period of minimum flows and maximum ambient air and water temperatures. As such, rates of dilution and atmospheric cooling are minimized, and it is the seasonal worst case situation with regard to potential effects of elevated temperatures on resident fishes. During this period, the entire main channel of the river downstream of the diffuser may be warmed as much as 3.95°F. Specific concerns are (1) whether resident species are able to survive the maximum possible mid-summer temperature rise of 4°F (to an approximate maximum value of 82°F), (2) whether global-field temperatures will exceed preferred levels (resulting in loss of habitat) and (3) whether growth of fishes residing within the global-field will be reduced, an indication of less than optimal thermal conditions for various physiological functions (Brungs and Jones 1977).

The most compelling evidence that the fishery of Pool 14 will suffer no adverse effects as a result of warming of a portion of the main channel is the observation that all species of fish found to reside in the region potentially impacted by the global-field plume have geographic distributions that extend considerably farther south than Pool 14 (Smith 1979, Eddy 1969), reaching latitudes where natural warming processes raise ambient mid-summer temperatures above 85°F. In other words, natural

populations occur further south in the Mississippi drainage under natural mid-summer conditions as severe or more severe than those that could periodically occur in Pool 14 downstream of the diffusers under open-cycle operating conditions at the Quad Cities Station.

These concerns can also be addressed on the basis of existing field and laboratory studies, a less direct but more "conventional" procedure. Maximum short term global-field temperatures (ambient or 78°F + 3.95°F or about 82°F) are well below mid-summer upper lethal temperatures for all resident species that have been studied (Table 3, Brungs and Jones, 1977). Maximum near-field temperatures (ambient 78°F + 23°F or about 101°F) exceed long-term lethal limits for most of the species. However, the areas (volume) involved are very small relative to available habitat, and fish will be protected from harm by the high velocities as well as by innate, high temperature avoidance capabilities (Meldrium and Gift, 1971).

The mid-summer, global-field plume may exert some influence on fish distribution in the pool (however, see Ross and Sinif 1980). Final preferred temperatures as determined by laboratory and field studies are available for a number of species (Table 3). To the extent that fish distributions are influenced solely by temperature, these data indicate that 14 of the species studied (those with preferred temperatures of 86°F and above) might be attracted to the region downstream of the diffusers even during the warmest months of the year. Five of the species for which data are available might be expected to remain downstream of the heated region or move upstream of the diffusers (those species with preferred temperatures less than 86°F).

Table 3. Preferred temperatures, maximum weekly average temperatures for growth (MWAT) and ultimate upper lethal temperatures for fishes occurring in Pool 14 of the Mississippi River.

Species	Temperature (°F)		
	Preferred[1/]	MWAT[3/]	Lethal[1/]
Carp	95		108
Longnose gar	95		
River carpsucker	93		
Buffalo	93		
Bluegill	91	90	97
Largemouth bass	91		
Quillback carpsucker	90	90	
Channel catfish	90	90	100
Green sunfish	88		
White bass	88		
Gizzard shad	88		99
Skipjack herring	86		
White crappie	86	82	
Spotfin shiner	86		97
Bluntnose minnow	84		90
Mooneye	84		
Yellow Perch		84	
Walleye	80[3/]	84[4/]	93[2/]
Northern pike	79[3/]	82	91[3/]

1/ From Yoder and Gammon (1976) except as noted.

2/ From Hokanson (1979).

3/ From Brungs and Jones (1977) except as noted.

4/ Estimated from 1/ and 2/.

U.S. EPA has recommended a procedure for calculating maximum weekly average temperatures (MWAT) acceptable for particular species based on the temperature that provides optimum or metabolically most efficient conditions for growth (Brungs and Jones 1977). The proposed calculation is:

$$\text{MWAT} = \begin{matrix}\text{Optimum Growth}\\ \text{Temperature}\end{matrix} + \frac{1}{3}\left[\begin{matrix}\text{Upper Lethal}\\ \text{Temperature}\end{matrix} - \begin{matrix}\text{Optimum Growth}\\ \text{Temperature}\end{matrix}\right]$$

The temperatures downstream of the Quad Cities Station for open-cycle operation are not expected to exceed 82°F after complete mixing of the cooling water discharge with river water. This temperature is based on low flow conditions (7Q10) and 100% operating capacity. The species for which appropriate data are available are also shown in Table 3. Examination of the MWAT relative to what is known about fish distributions and temperature exposures under field conditions (i.e., Barrans and Tubbs, 1973, Gammon, 1971, Ferguson, 1958) demonstrates the conservative nature of this parameter. Fish are commonly found to inhabit and flourish in environments as warm or warmer than this arbitrary limit for extended periods of time. However, the temperatures downstream of the Station to which even the most sensitive species would be exposed would not exceed the MWAT for those species during extreme conditions of low flow and 100% Station operating capacity. Some species listed in Brungs and Jones, 1977, such as the sauger, have recommended MWAT's that are lower than those in Table 3, but these are believed to be due to artificial conditions associated with laboratory testing. There is a close correspondence between preferred temperature and the MWAT's, as would be expected on the basis of studies by Brett (1956), Strawn (1969, 1961) and others, which relate preferred and optimum temperatures for a number of physiological criteria. The general conclusions on distributional responses during summer months are unchanged.

Fall. Fall is a period of intermediate flows and declining ambient air and water temperatures. As in spring, the global-field plume should be greatly reduced or absent, and opportunities for prolonged exposure of fish to elevated temperatures are limited. On a single factor basis, near-field temperatures will be preferred over ambient levels (Table 3). However, the restricted areal extent of the plume as well as the expected tendency of local fish populations to respond in a distributional sense to the total environment rather than to temperature alone (Ross and Sinif, 1980) suggests that no measurable effects on the fishery of the pool should exist.

Maximum Acceptable Temperatures for Short-Term Exposures

The diffuser system has been designed to promote very rapid dispersal of excess temperature by entrainment-mixing. However, as a consequence of this high velocity/entrainment process, some portion of the planktonic or freely drifting organisms moving down-river will be carried along with the mixing water and will receive some thermal dose. The nature of the dose depends on where in the cooling sequence each organism is entrained as well as the path followed along the mixing gradient. Larger, free-swimming organisms may also receive a brief thermal dose as a result of unexpectedly encountering a shift in the current vector or local currents that exceed swimming capabilities.

Effects of Jet Entrainment on Planktonic Forms: Jet entrainment at the diffuser ports will subject fish eggs and larvae to both mechanical and thermal alterations. Mechanical alterations include shear forces and increased turbulence. No direct studies of the effects of jet entrainment or shear/turbulence effects at levels comparable to those anticipated for the diffuser

system (exit velocity of 8 to 9 ft/sec) have been performed. Morgan *et al.* (1976) conducted laboratory studies of the effects of severe shear forces on the survival of striped bass and white perch eggs and larvae. Median lethal exposures for one minute periods exceeded 400 dynes/cm^2, a value greatly in excess of that generated by a 9 ft/sec jet into standing water. Additional evidence for the insignificance of mechanical effects due to jet entrainment at the diffuser can be found in the studies of mechanically induced mortality as a consequence of passage of eggs and larvae through power plant cooling systems. Mortalities of only 5 to 25% are typically reported for plant-entrained ichthyoplankton (Ginn *et al.* 1978, Ecological Analysts, Inc. 1977, Kedl and Coutant 1976). Mortality predicted for plant passage (excluding lethal temperatures) at Quad Cities Station is less than 25% (H.E.S. 1978). Since both the time of exposure and the magnitude of the physical trauma associated with plant passage greatly exceed those experienced by an egg or larva entrained at the diffuser jets, mechanical effects can logically be discounted.

Ichthyoplankton entrained into the diffuser near-field will suffer no adverse effects from the brief exposure to elevated temperatures. Substantial numbers of fish eggs and larvae are present in Pool 14 from mid-April through late June at water temperatures ranging from 48 to about 72°F (Table 1). Eggs or larvae subjected to the worst case exposure, entrainment at the diffuser port and transport down the plume centerline, will experience a thermal dose as displayed in Figure 1. Maximum ΔT will be approximately 23°F, decaying as a consequence of entrainment mixing to about 4°F over a period of 13 to 14 seconds. This worst case situation is in no way representative of the average thermal dose for the majority of entrained organisms.

Actual thermal doses will, for the most part, be much smaller in accord with the cooling by dilution relation, which governs proportions of heated and ambient temperature waters making up successively cooler isotherms of the plume (see Carter *et al.* 1977).

The most direct evidence that thermal doses experienced as a consequence of entrainment at the Quad Cities Station diffuser will have no effect on fish eggs and larvae is provided by the studies conducted at the station to evaluate effects of (total) cooling system passage (H.E.S. 1978). In these studies, ichthyoplankton were collected from the Station discharge canal, held at discharge temperatures for 8.5 minutes, cooled to ambient river temperature plus 3.5°F and examined for survival immediately and after 24 hrs. Proportions of live and dead larvae were compared with those for samples collected from the Station intake to determine the combined effects of mechanical abrasion and thermal dose. Larvae examined included all species listed in Table 1 except walleye/sauger (tests were conducted in June following the walleye/sauger spawning period). Survival under these test circumstances and at discharge temperatures of 92°F or less ranged from 54 to 75% with no delayed mortalities in spite of the extended holding time (8.5 min) and severe mechanical and collection stress imposed. Further, similar studies conducted in 1979 (Commonwealth Edison Company 1980) have verified these observations and shown them to be conservative in that sampling procedures tended to adversely affect survival. Certainly the much smaller thermal dose (23°F to less than 4°F in 13 to 14 sec) and reduced mechanical stress associated with jet entrainment of ichthyoplankton into the near-field plume will have even less of an effect on survival.

Effects of Jet Entrainment of Juvenile and Adult Fish: Juvenile or adult fish that encounter the near-field plume will experience no physical damage as a consequence of jet entrainment. There are situations in which similar events have been shown to kill or damage fish. For example, juvenile salmon entrained into a jet (firehose) having an exit pressure of 100 psi were quickly killed (Anonymous 1957, cited in Bell *et al.* 1967). However, extensive literature reviews on the effects of fish entrainment by hydraulic turbines confirm that velocity changes of 8 to 9 ft/sec (maximum exit velocity at the diffuser ports) is far below the critical level (see reviews by Bell *et al.* 1967, Lucas 1962).

The brief thermal dose received by jet-entrained juveniles or adults will also not be sufficient to cause harm. This can be shown by calculating the length of time specific fish can tolerate an increase of 23°F above ambient river temperature following procedures and tolerance relations provided by the U.S. EPA (Brungs and Jones 1977). U.S. EPA recommends calculation of the length of time a particular species or life stage can survive a given temperature rise according to the relation:

$$\log \text{time} = a + b\ (\text{temp} + 2)$$

> where a and b are the intercept and slope respectively of the relation between test temperature and lethal temperature for a particular acclimation temperature.

Using an ambient temperature of 77°F[1] (an approximation of the mid-summer maximum or worst case for heat tolerance), a temperature rise of

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1/ This value (77°F) is slightly lower than the actual mid-summer maximum for Pool 14 (78°F). However, it is the closest temperature for which values of a and b are available in Brungs and Jones (1977).

23°F (maximum ΔT for Quad Cities Station) and values for a and b taken from Appendix B of the U.S. EPA document, we obtain the limiting exposure times given in Table 4. Since the maximum time of passage is only about 14 seconds (the calculation ignores progressive cooling by dilution), it is clear that short-term thermal exposures of this type will not harm local fishes.

Conclusions

The possible mechanisms and likelihood of harm to fishes resident to Pool 14 of the Mississippi River by heated water discharge at Quad Cities Station during open-cycle operations have been considered. Three potential means of exposure to elevated temperatures have been defined: jet entrainment of planktonic eggs and larvae, plume attraction of juvenile and adult forms and occasional long-term exposures (weeks) to low-level temperature increments of $\leq$ 3.95°F. The potential for cold-shock and gas bubble disease have also been considered.

Data on fish occurrence and distribution obtained in the Quad Cities Monitoring Program (1969-present) and special studies conducted at the Station relating to thermal effects have been evaluated as have sources from the primary scientific literature. Procedures recommended by the U.S. EPA for evaluation of thermal effects have been employed. This effort has revealed no existing or potential impacts on resident fishes associated with the thermal plume.

Table 4. Maximum acceptable exposure times (mid-summer)[1/] for juvenile and adult fish entrained at the Quad Cities Station diffusers.

Species	a [2/]	b [2/]	Minimum Survival Time min	Exceeds Maximum Potential Exposure by
Gizzard shad	47.1163	-1.3010	1.44	>5X
Northern pike	17.3066	-0.4520	1.02	>4X
Channel catfish				
Juvenile	34.5554	0.8854	1.68	>7X
Adult	46.2155	-1.2899	1.43	>5X
Bluegill	23.8733	-0.6230	1.16	>5X
Largemouth bass	26.3169	-0.6846	1.21	>5X
Emerald shiner	26.7096	-0.7337	1.20	>5X

1/ Calculated according to Brungs and Jones (1977), using an ambient temperature of 77°F (25°C).

2/ Taken from Brungs and Jones (1977), Appendix B.

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Section III

316(b) Demonstration Supplement

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Introduction

This section is an update of the Demonstration previously submitted to Region V, U.S. Environmental Protection Agency (USEPA) by Commonwealth Edison Company on April 10, 1975, under Section 316(b) of the Federal Water Pollution Control Act (FWPCA).

Results of studies conducted in 1972-1973 to evaluate the effects of entrainment on phytoplankton, zooplankton and macroinvertebrate drift were presented as part of the original 316(a) Demonstration submission in 1975. Special studies conducted during 1974 to determine ways of minimizing impingement at Quad Cities Station were also presented in the original 316(b) Demonstration.

Since submission of the original 316(b) Demonstrations, several studies have been conducted to document the effects of open cycle operation on organisms entrained in condenser cooling water. Also studies have been undertaken to evaluate methods to minimize impingement and to quantify impingement losses relative to fish population levels in Pool 14. These special studies included investigations to document the effects of open cycle operation on entrainment (phytoplankton, zooplankton and macroinvertebrate drift) during the low flow year of 1976; investigations to define more precisely the effects of condenser passage on ichthyoplankton; and a study to evaluate the effectiveness of a barrier net located at the river's edge of the intake forebay in minimizing impingement.

A. Entrainment Studies

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A. Entrainment Studies

Several reports form the basis of this summary. Entrainment studies conducted during 1972 through 1973 and 1976, are reviewed in the report entitled, "Preoperational and Operational Environmental Monitoring in the Mississippi River near Quad Cities Station, August, 1969 to December, 1978" (Hazleton Environmental Sciences, 1979a). That report also discusses ichthyoplankton impact assessments. Special ichthyoplankton studies defining the effects of entrainment are discussed in three reports, "The Survival of Ichthyoplankton at Quad Cities Station" (Hazleton Environmental Sciences, 1979b), "Intensive Ichthyoplankton Studies at Quad Cities Station, June, 1978" (Hazleton Environmental Sciences, 1979c) and "Quad Cities Station Aquatic Program, 1979 Annual Report" (Commonwealth Edison Company, 1980).

1. Phytoplankton and Zooplankton

This summary is based on Hazleton Environmental Sciences (1979a pp. 3.31 and 3.32 and 4.24 to 4.26). In 1976, as in the earlier studies effects of condenser passage on phytoplankton were evident but somewhat inconsistent. In spite of the reductions in phytoplankton abundance and chlorophyll a concentrations noted in the discharge bay, slight increases were observed at locations in the river immediately downstream of the diffuser discharge. Thus the net effect of condenser passage on phytoplankton does not constitute an adverse impact on the river.

The effect of entrainment on the total community passing the Station was assumed to be directly related to cooling water diverted through the Station. During all previous entrainment studies (1972-1973) the Station used a maximum of 9% of the river for condenser cooling. On the date of the 1976 study, however (a period of extraordinarily low flows) almost 13% of the river's flow was estimated to pass through the Station. Projected total river effects during river flows in excess of 23,000 cfs reached an estimated peak of 6% and averaged less than 1% reduction of total phytoplankton productivity during 1972-1973 (two unit open-cycle operation). Less than 1% reduction during the low flow sampling period (one unit open-cycle operation) was recorded in 1976.

Results of the zooplankton entrainment studies indicated mortalities associated with passage through the condensers never reached 100% and the percentage of the total river zooplankton killed was very small. During the 1972-1973 period, it was estimated that the maximum percentage killed for two unit open-cycle operation was 4.4%. For the low flow period in 1976 when only one unit was operating open-cycle, approximately 2.1% of the river's zooplankton community was killed.

The projections for the plankton community ignore the natural resiliency of plankton communities to reductions in numbers resulting from such occurrences as passage through a condenser cooling system. Rapid compensatory response is a result of high reproductive rates and short generation times of plankters.

2. Macroinvertebrate Drift

This summary is based on Hazleton Environmental Sciences (1979a pp. 6.123 to 6.124). Studies conducted during the low flow period in 1976, were limited to measuring macroinvertebrate drift densities at locations upstream and downstream of the diffuser pipe discharge within the area of the mixing zone. No significant changes were observed in the drift passing across the mixing zone of the diffuser pipe system in the Mississippi River. Mortalities for the macroinvertebrate drift assemblage increased about 4% after passage through the area of thermal discharge; these increases were not statistically significant and could just as easily have been a result of sampling mortality and natural variability.

3. Ichthyoplankton

This summary is based on reports by Hazleton Environmental Sciences (1979a, pp. 8.1-74 and 1979b,c) and Commonwealth Edison Company (1980, pp. 2-1 through 2-32). In the initial entrainment studies conducted in 1975 and 1976 at Quad Cities Station, it was estimated that as much as 10% of the total ichthyoplankton drift was being entrained during actual Station operation. Further most of the entrainment occurred during closed or partial closed-cycle operation (NALCO Environment Sciences, 1977, p. 479). This implies an even greater percentage would be ..t for open-cycle cooling. During 1978, a review of the methods, sample locations and assumptions used in deriving these estimates indicated that they were undoubtedly much greater than actual entrainment. The high initial estimate was due to unrepresentative, high ichthyoplankton densities at the sampling location used to estimate entrainment densities. This sampling location was situated immediately downstream of

a barge ramp, upstream of the intake, in a calm current-free area. Dye studies indicated that intake water was not withdrawn from this area as originally anticipated.

In 1978, special studies were undertaken which had as one of their objectives, estimates of entrainment based on sampling immediately in front of the intake and in the discharge bay as well as at the location used to make entrainment estimates in 1975 and 1976 (Hazleton Environmental Sciences, 1979b). Abundance at locations immediately in front of the intake and in the discharge were shown to be substantially less than at the quiescent location used for estimating entrainment in 1975 and 1976.

These studies also found that densities in the discharge canal were lower than those in front of the intake and it was suspected that dencities of ichthyoplankton at the discharge location may provide the most accurate estimate of the density of entrained ichthyoplankton. However, entrainment abundances were conservatively based on those abundances at the location in front of the intake rather than on discharge samples.

The special 1978 studies also had as an objective the evaluation of survival of entrained ichthyoplankton (Hazleton Environmental Sciences, 1979b,c). These special survival studies were conducted because previous estimates of entrainment losses assumed a 100% mortality of entrained ichthyoplankters. Recent studies at other steam electric generating stations indicated that this was not likely to be the case. Consequently, entrainment survival was documented at various Station operating power levels during open-cycle cooling. Entrainment survival of total ichthyoplankton ranged from 63 to 72% when discharge wat temperatures were below 90.5°F (32.5°C) and decreased to 40% when discharge

water temperatures ranged from 90.5 to 91.4°F (32.5 to 33°C). Lowest entrainment survival occurred when the Station was operating at full power capacity (96 to 99%) and discharge temperatures exceeded 100.2°F (37.9°C). Evaluations of river and Station operating data for 1975 through 1978, however, indicated that greater than 80% of the ichthyoplankton drift pass the Station intake prior to discharge temperatures reaching 91.4°F (33.0°C).

In light of these special studies, the ichthyoplankton abundance data were used to estimate the percentage ichthyoplankton drift past the Station lost due to entrainment from 1975 through 1978 (Hazleton Environmental Sciences, 1979a, pp. 8.57-67). Only these years were included in the analysis because the sampling design used in the river to estimate abundance was more consistent than during earlier years.

The total ichthyoplankton drift for Pool 14 in the vicinity of Quad Cities Station between 1975 and 1978, was estimated to range from 3.0×10^9 to 13.5×10^9 individuals. Freshwater drum comprised 66-98% of all fish eggs collected. Typically, freshwater drum, carp and minnows were the most abundant taxa of ichthyoplankters. Ichthyoplankters were typically present in the drift by mid to late April each year, and the greatest number of ichthyoplankters were usually found in the drift prior to mid-June.

Based on abundances at river locations either immediately adjacent to or upstream of the forebay, estimated annual total ichthyoplankton losses from 1975 through 1978, during actual Station operation would have amounted to 1.3-3.1% of the ichthyoplankton drift. Actual Station operation was based on the daily cooling cycle mode of operation which varied from closed or partial open-cycle and to a much less degree, open cycle (Hazleton Environmental Sciences, 1979a, Table 8.13).

The estimated percentage of the total river ichthyoplankton loss due to entrainment was also projected for open-cycle operation for each year 1975 through 1978, and it was estimated it would have ranged from 1.6-5.4% (Hazleton Environmental Sciences, 1979a, Table 8.14). Highest percentage of entrainment losses would have occurred during the low flow years of 1976 and 1977. Based on average weekly Station loads and ambient temperatures for the months of April through June, 1975 through 1978, the majority of entrained ichthyoplankters would survive intake entrainment since the estimated maximum discharge temperatures were below 90.5°F (32.5°C).

Two sources of variation were identified during the course of the special studies in 1978, which suggested that a potential for further improvement in the estimate of entrainment mortality may be possible. First, as mentioned earlier, larval densities measured at river locations immediately in front of the intake and used to estimate entrainment in 1978, appeared to over-estimate those actually observed within the Station discharge bay by a significant margin. Discharge densities, presumably a direct measure of numbers of larvae which had passed through the cooling system, were as much as 30% less than at the locations used to estimate entrainment abundance in the 1978 studies. While it was assumed that the extremely turbulent conditions at the sampling area in the discharge ensured thorough mixing, this assumption was not tested in 1978, and it may have been possible that spatial variation within the discharge bay was responsible for the observed differences.

Second, it was noted that a portion of the dead larvae collected from the Station discharge in the survival studies had assumed an opaque appearance associated with tissue deterioration. In the 1978 study, the

density of opaque larvae was higher in the discharge than in the intake. These density differences resulted in a decrease in survival estimates since all dead larvae were used in estimating survival. The short time required for a larvae to traverse the cooling system did not seem adequate for such degenerative changes to take place. This suggested that the fraction of dead larvae collected from the discharge which were opaque had actually been dead prior to entering the cooling system and should be excluded from estimates of Station induced mortality. However, unexplained differences between densities of dead opaque larvae collected from the discharge and from a single, mid-depth location in the intake forebay prevented such a correction for the 1978 data set. Therefore, estimates of survival in 1978, were based on the use of both transparent and opaque dead ichthyoplankton.

Studies were designed and conducted in 1979, to evaluate these sources of variation in estimates of fish egg and larvae entrainment and survival at Quad Cities Station (Commonwealth Edison Company, 1980, pp. 2-1 through 32). These included further investigations as to which location was most appropriate for estimating entrainment abundances and whether opaque larvae should be included in mortality estimates. Comparisons were made of net collections at the river location in front of the Station intake forebay and at three cross sectional transects in the discharge bay. The river location was found to be a poor basis for making estimates of entrainment in terms of species composition, abundance of various taxa and abundance of specific life stages within taxa. Egg and larval densities at the river location were consistently higher than densities in the discharge.

The single known contradictory explanation for these differences was the possible destruction of eggs or larvae during the course of passage

through the cooling system. This consideration was disregarded because of the results of the survival study. In addition to the many larvae surviving passage through the Station, careful examination of larvae collected revealed very few mechanically damaged individuals. It was concluded then that entrainment abundances were lower than what would be predicted based on larval abundances at the intake location. Densities of total larvae at the discharge bay location were about 20% lower than the river location.

With respect to the opaque larvae evaluation from the laboratory studies conducted in 1979, it was concluded that larvae killed by passage through the condensers at temperatures below 91.4°F (33°C) and collected from the discharge bay do not turn opaque in the time it takes to collect and examine the samples and thus opaque larvae can be excluded from entrainment mortality estimates (Commonwealth Edison Company, 1980). The relationship between water temperature and time to opacity for recently killed larvae (transparent dead larvae) as determined in this study showed that, at discharge temperatures of less than 91.4°F (33°C), more than 30 minutes are required for the development of opacity. The time required for a larvae to traverse the cooling system is 8.5 minutes. The study also showed that differences in the densities of live larvae and dead, opaque larvae observed between the intake forebay and the discharge bay in 1978, can be explained by spatial variability at the two locations. Thus, the true survival below the critical temperature of 91.4°F (33°C) would be greater than the 40 to 72% reported in 1978. A re-evaluation of the 1978 data suggests that the increase in survival would range from 2-12%.

It was also concluded that there were little meaningful differences between estimates of ichthyoplankters lost due to open cycle operation and the present operating mode (partial-open cycle) where the volume of river water used for make-up is increased when the return water from the spray canal exceeds 93°F (34.0°C). Small differences result between these two operating modes, even though 50 to 80% less water is withdrawn from the river during partial open-cycle operation, because it can be assumed that all ichthoplankters entrained during this operating mode would be lost as discharge temperatures would exceed 91.4°F (33°C).

Literature Cited

Commonwealth Edison Company, 1980. Quad Cities Aquatic Program, 1979 Annual Report. Chapters 1 through 5 and Appendices A, B, C, D and E.

Hazleton Environmental Sciences, 1979a. Environmental Monitoring in the Mississippi River near Quad Cities Station, August 1968 to December 1978. Chapter 1 through 8 and Appendices A, B, C and D.

____________________ 1979 b. The Survival of Entrained Ichthyoplankton at Quad Cities Station, June 1978. HES No. 550105739. 55 pp.

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B. Impingement Studies

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B. Impingement

This summary is based on Hazleton Environmental Sciences (1979a pp. 7.74 to 7.123) and Commonwealth Edison Company (1980 pp. 4-1 to 4-27). Impingement studies have been conducted at Quad Cities Station since 1973. Results considered in this summary cover the period 1973 through 1979. The total number and weight of fish estimated to be impinged at Quad Cities Station each year is shown in Figures 1 and 2.

Annual impingement estimates for the years 1977 and 1978 were substantially less than the estimates presented in the 1976 annual report (NALCO Environmental Sciences, 1977, pp. 343-351) for the period 1973 through 1976. The differences between the 1977-1978 annual estimates and those annual estimates presented in the 1976 report for the years 1973-1976, prompted a review and recalculation (Adjusted Ratio Estimator) of the original Ratio Estimators (RE) on which the years 1973-1976 annual impingement estimates were based.

The Ratio Estimator was developed for the years 1973-1976, because the mesh size (1" x 3-3/4") of the trash basket used to collect impinged fish in these years was larger than that of the traveling screens (3/8" x 3/8") and many of the smaller impinged fish were believed to be lost from the basket. Prior to initiation of impingement studies in 1973 when the Station was operating open-cycle, small mesh baskets (3/8" x 3/8") were used to collect impinged material. These baskets proved unsatisfactory because leaves and debris often plugged the small openings causing the baskets to overflow, thus, making the data unreliable. The small mesh basket was replaced

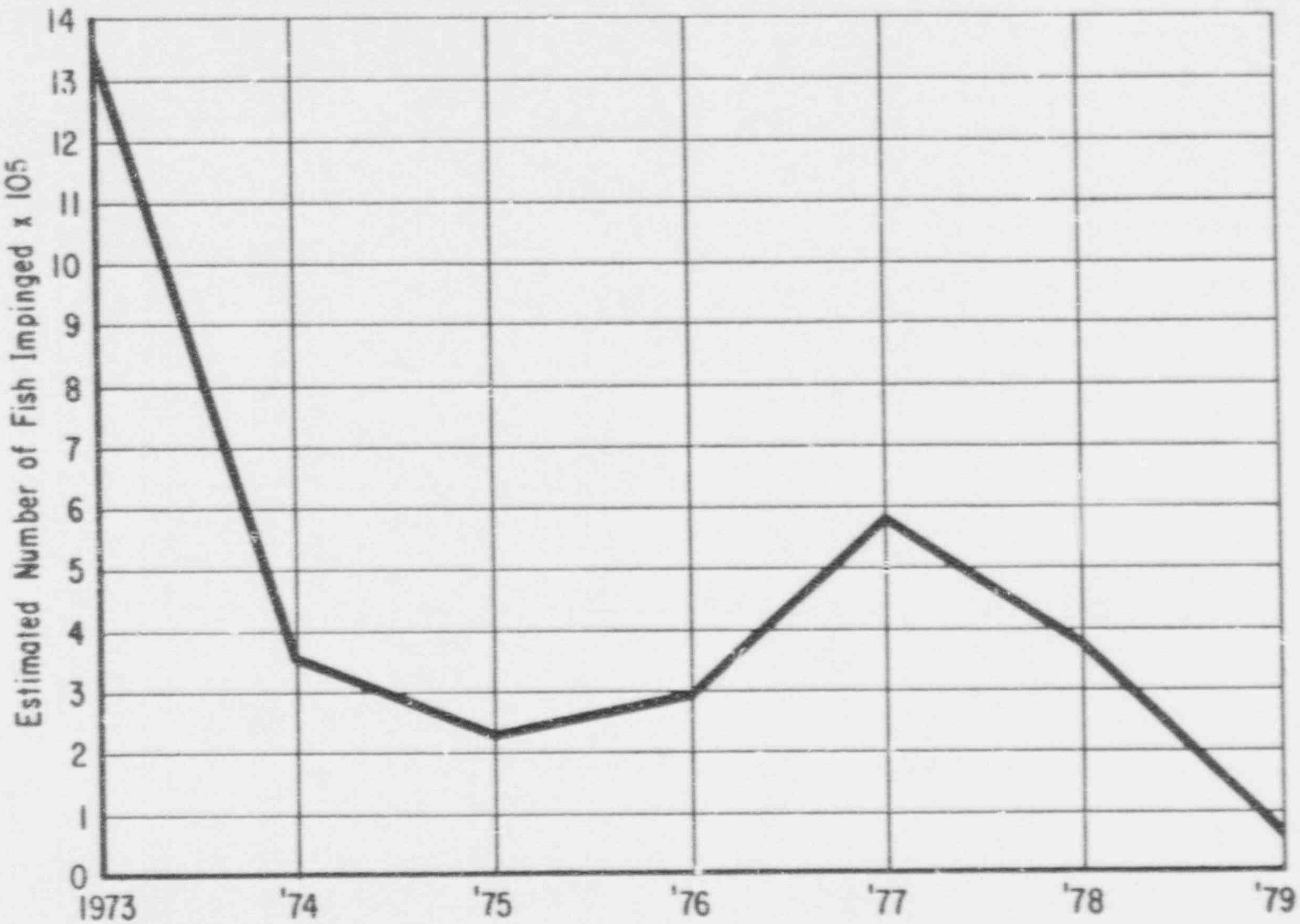

Figure 1. Estimated Number of Fish Impinged at Quad-Cities Station from 1973 through 1979.

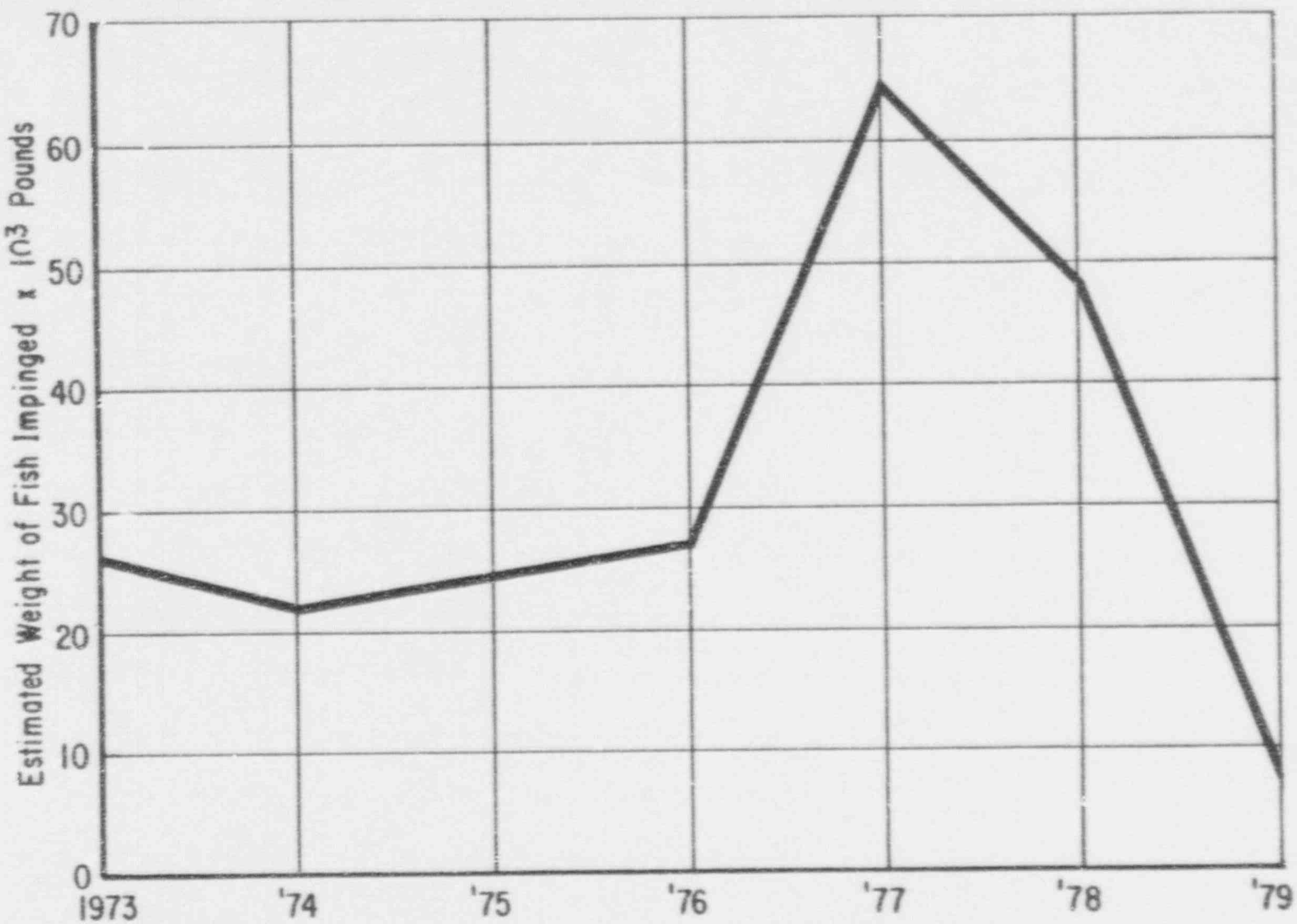

Figure 2. Estimated Weight of Fish Impinged at Quad-Cities Station from 1973 through 1979.

with the large mesh basket in 1973 and continued to be used through January, 1977 when it was again replaced with a small mesh (3/8" x 3/8") basket. The smaller mesh size basket was installed at this time because the Station was operating closed or partially closed-cycle which resulted in lower debris loading in the basket. To determine the extent that smaller fishes were passing through the larger mesh, the catches of small and large mesh baskets were compared during special studies conducted in 1973 and 1976, and a conversion factor or "Ratio Estimator" (RE) was calculated on a monthly basis. The monthly RE's were averaged and this value was multiplied by the annual estimate of impingement to correct for losses through the large mesh basket.

It was concluded after reviewing the 1977 and 1978 impingement data, when small mesh baskets were used, that the earlier monthly RE's should not be developed solely on a monthly basis, or averaged and multiplied by the actual annual impingement since impingement varies with biological changes in the fish population rather than by artificial changes based on calendar events. For example, by November, fish were large enough to be retained by the large mesh basket and it was inappropriate to correct for losses based on summer impingement. As a result, the monthly RE's were adjusted (ARE) to account for biological changes which occurred within or among calendar months. Within each year, the actual impingement catches were expanded to monthly estimates which were summed to estimate annual impingement (Hazleton Environmental Sciences, 1979a, pp. 7.74-97).

The presence of the spray canal return water in the area of the forebay probably explains differences in annual impingement numbers between

1973, when the Station was operating open-cycle and 1974-1979, when the Station generally operated closed or partial closed-cycle. During closed-cycle and partial closed-cycle, a small portion of warm water from the spray canal leaks from the intake bay into the river. This warm water appears to attract fish in the fall and winter. During the summer months, however, the warm return water from the spray canal in the intake bay probably results in fish avoidance of this area. Impingement was very high in the summer, 1973, compared to the remaining years when open-cycle was no longer used. During 1973-1976, the annual total estimated weight did not vary appreciably between open (1973) and closed or partial closed-cycle (1974-1976). In 1977 and 1978, however, much higher total annual weights of fish impinged were estimated even though total numbers remained less than 1973 levels. This was probably due to impingement of larger sized fish later in the year because of attraction to the intake forebay, and avoidance of the warm water temperatures in the forebay as smaller individuals in the summer.

During the seven years of study, seventy-five species of fish have been identified with gizzard shad and freshwater drum comprising almost 90% of the total numerical catch. Species composition during the period 1973-1979, has been similar with gizzard shad and freshwater drum, the two most abundant species and channel catfish and white bass generally among the five most abundant species each year.

Impingement Exploitation

The purpose of this section is to compare impingement losses with estimated standing stocks in Pool 14. The ratio of impingement loss (weight)

to estimated standing stock is considered for this summary to be impingement exploitation (or percent impinged) except as noted. Estimates of standing stock were derived from several sources. The standing stock of fish in Pool 14 of the Mississippi River was estimated to be 356 lbs/acre with a multiple regression analysis as developed by Jenkins and described in NALCO Environmental Sciences, 1977 (p. 371). Cove or backwater rotenone surveys were conducted near the station during 1977 (Muench, 1978) and 1979 (Commonwealth Edison Co., 1980) and yielded an estimated standing stock of 566 lbs/acre in 1977, and 648.9 lbs/acre in 1979. In addition to the studies conducted near the station in Pool 14, several other standing stock estimates have been made for the Mississippi River backwaters using the backwater or cove rotenone sampling technique. Results of the various studies including those near the station are presented in Table 1.

Standing stock estimates in most of the other studies were in general, considerably less than the Pool 14 rotenone study estimates. These lower estimates may have resulted from incomplete recovery of fish. For example, of the four surveys described by Christenson and Smith (1965), only one utilized recovery of marked fish to estimate collection efficiency (Area B in Pool 5A). In that survey, only 16 fish representing 8 species were marked and released prior to rotenone application. Because all 16 fish were recovered, it was assumed that in the remaining surveys there was complete recovery of fish, thereby depicting accurate standing stock estimates. In the rotenone surveys conducted near the Station, a much greater number of fish were marked and released prior to application of rotenone than was recorded in the Christenson and Smith surveys. Results are presented in

Table 1. Standing Crop Estimates for Rotenone Surveys in Pool 14 of the Mississippi River with Comparisons to Other Mississippi River Surveys

Data Source	Survey Method	Location (Pool Number)	Average lbs/A
Commonwealth Edison Co., (1980)	Rotenone and Mark-Recapture using Electrofishing	14	648.6
Muench, (1978)	Rotenone and Mark-Recapture using Electrofishing	14	566.0
Christenson and Smith, (1965)	Rotenone 1/	5-A	324.0 2/
UMRCC, (1948) (Oquawka-1)	Rotenone	18	390.6
UMRCC, (1948) (Oquawka-2)	Rotenone	18	694.6
UMRCC, (1947) (Savanna-1)	Rotenone	13	171.4
UMRCC, (1947) (Savanna-2)	Rotenone	13	422.8

1. Mark and recapture procedures used during 1 of 4 surveys at this location

2. Average of four surveys

Table 2. In 1977, 88 fish of 8 species were captured, marked by fin clipping and released inside the sampling area. In 1979, 278 fish of 10 species were fin clipped and released inside the sampling area. In contrast to results reported by Christiansen and Smith during both the Muench, 1977 survey and the Commonwealth Edison Company 1979 survey, recovery of marked fish was low, 25.0% and 32.4%, respectively. Consequently, actual numbers and weights of fish collected after poisoning each area were adjusted to reflect the percentage of marked fish released that were recovered, thereby resulting in much higher standing stock estimates on both a total and species basis.

Based on the various standing stock estimates in Table 1, conservative or over-estimates of impingement exploitation rates at Quad Cities Station from 1973-1979 of the Pool 14 fishery have been made using only the combined total slough-lake habitat in Pool 14 and multiplied by slough standing stock estimates. Only the slough-lake habitat standing stock estimates were used because expanding the present data base for all habitats is not appropriate given the differences that would be expected to occur between the slough-lake habitat and other habitats. Because differences in standing stock between habitats is expected, a more reliable approach would be to stratify projections by habitat type if standing stock estimates for other habitats were available. With the present data base, however, it is possible to reliably estimate standing stocks only for the slough-lake habitat in Pool 14.

The total surface area of Pool 14 is 10,410.7 acres, of which 41.0 percent or 4267.7 acres represents the slough-lake habitat (Helms,

Table 2. Results of Mark-Recapture Study Using Electroshocking to Determine Collection Efficiency of Rotenone Surveys in Pool 14, Mississippi River near Quad Cities Station

Year Sampled	Data Source	Location	Number Fish Marked and Released	Number Marked Fish Recovered	% Recovered
1977	Meunch (1978)	RM 511.5	88	22	25.0
1979	Commonwealth Edison (1980)	RM 511.8	278	90	32.4

1968). Using the average estimate of 459.7 lbs/acre presented in Table 3, the total standing stock for the slough-lake habitat in Pool 14 is estimated to be about 2.0 x 10^6 Pounds. Exploitation rates were estimated to range from 0.4 to 3.3 percent for the years 1973 through 1979. The lowest impingement exploitation rate was estimated for 1979, and attributed to placement of a barrier net in front of the intake forebay to minimize impingement (this section). However, estimated impingement exploitation rates still only range from 1.1 to 3.3 percent for 1973 through 1978.

Standing stock estimates of four of the five most abundant impinged species (gizzard shad, channel catfish, bluegill and white bass) recorded in impingement samples were estimated for the slough-lake habitat in Pool 14 (Tables 4-7). The second highest impinged species was freshwater drum, which is addressed in greater detail later in this section. Impingement exploitation was estimated for 1977 through 1979 for each species. The years 1977 through 1979 were selected for comparison because annual impingement estimates for the individual species are available for these years while they are not for the earlier years 1973 through 1976. As discussed previously, for the years 1973 through 1976, only total annual impingement (all species combined) was estimated (Hazleton Environmental Sciences, 1979a).

For the four species annual impingement exploitation rates ranged from 0.4 to 8.9 percent for gizzard shad, 0.3 to 2.4 percent for channel catfish, 0.3 to 0.4 percent for bluegill, and 1.1 to 10.9 percent for white bass (Tables 4 through 7). These estimated exploitation rates

Table 3. Impingement Exploitation Rates (Percent) at Quad Cities Station Based on Total Estimated Standing Crop Only for Slough-Lake Habitat in Pool 14 of the Mississippi River, 1973 Through 1979

	Estimated Standing Crop		Estimated Exploitation Rate (Percent)[b] Estimated Weight Impinged (lb)						
Data Source	lbs/Acre	Total (lb)[a]	1973 25,615	1974 21,833	1975 24,251	1976 27,045	1977 63,998	1978 48,245	1979 7,494
Commonwealth Edison Co., (1980)	648.6	2,768,030	0.9	0.8	0.9	1.0	2.3	1.7	0.3
Muench (1978)	566.0	2,415,518	1.1	0.9	1.0	1.1	2.6	2.0	0.3
Christenson and Smith (1965)	324.0	1,382,735	2.0	1.6	1.8	2.0	4.6	3.5	0.5
UMRCC (1947) Savanna-1	171.0	729,777	3.5	3.0	3.3	3.7	8.8	6.6	1.0
Savanna-2	423.0	1,805,237	1.4	1.2	1.3	1.5	3.5	2.7	0.4
UMRCC (1948) Oquawka - 1	390.6	1,666,964	1.5	1.3	1.5	1.6	3.8	2.9	0.4
Oquawka - 2	694.6	2,964,344	0.9	0.7	0.8	0.9	2.2	1.6	0.3
Average	459.7[c]	1,961,862	1.3	1.1	1.2	1.3	3.3	2.5	0.4

a. Total based on 4,267.7 acres slough-lake habitat in Pool 14

b. Percentage calculated by dividing estimated weight impinged by total estimated standing crop for slough-lake habitat.

c. Average of estimates of standing crop presented in various sources of data.

for all species are believed to be conservative because the standing stock estimates on which exploitation rates are based, are only for the slough-lake habitat in Pool 14. This is especially true for gizzard shad and white bass which are common to all sampling locations in Pool 14 (Commonwealth Edison Company, 1980, Tables 3-3 and 3-7). Since both of these species are common to the main channel and side channel habitats, in addition to backwater areas, standing stock estimates on an individual species basis would undoubtedly be much greater if considered on a pool wide basis.

The exploitation rate ranges discussed above will not measurably affect the Pool 14 fishery. In a review of many published commercial and sport fishery exploitation rate estimates, McFadden (1977) reports that it is not uncommon for > 25% of the exploitable age classes in a population to be removed annually for a period of time spanning decades while at the same time these fish stocks continue to operate at maximum productivity. Of particular interest are exploitation rates of freshwater drum, channel catfish and bluegill populations. McFadden cites literature indicating annual commercial and sport fishery exploitation rates ranging from 31 to 58 percent for freshwater drum, 30 percent for channel catfish, and 15 to 42% for bluegill (see Table 2, pp. 173 through 175 in McFadden, 1977).

These estimates of compensable exploitation reviewed by McFadden are based on older fish. When class 0 and I fish are considered, it is likely that for a highly fecund and short-lived fish such as the gizzard shad, that compensable exploitation rates could be even higher than 25%. Thus, it is noteworthy that impingement at Quad Cities Station consists primarily of 0 and 1+ freshwater drum and gizzard shad (Commonwealth Edison Company, 1980, pp. 4-1 through 16).

Table 4: Impingement Exploitation Rates (percent) at Quad Cities Station for Gizzard Shad based on Estimated Standing Stocks for Slough-Lake Habitat in Pool 14 of the Mssissippi River during 1977 through 1979.

Data Source	Estimated Standing Stock		Impingement Exploitation Rate (Percent)[b] Estimated Weight Impinged (lb)		
	lb/Acre	Total(lb)[a]	1977 50,276	1978 27,767	1979 2,494
Commonwealth Edison Co. (1980)	326.6	1,393,831	3.6	1.9	0.2
Muench (1978)	55.2	[illegible]45,577	21.3	11.8	1.1
Christenson and Smith (1965)	39.9	170,281	29.5	16.3	1.5
UMRCC(1947) Savanna - 1	1.2	5,121	--	--	48.7
Savanna - 2	12.4	52,919	95.0	52.5	5.2
UMRCC(1948) Oquawka - 1	81.2	346,537	14.5	8.0	0.7
Oquawka - 2	408.2	1,742,075	2.9	1.6	0.1
Average	132	563,763	8.9	4.9	0.4

a. Total based on 4,267.7 acres slough-lake habitat in Pool 14

b. Percentage calculated by dividing estimated weight impinged by the total estimated standing stock for slough-lake habitat

Table 5. Impingement Exploitation Rates (percent) at Quad Cities Station for Channel Catfish based on Estimated Standing Stocks for Slough-Lake Habitat in Pool 14 of the Mississippi River, 1977 through 1979.

Data Source	Estimated Standing Stock lb/Acre	Estimated Standing Stock Total(lb)[a]	Impingement Exploitation Rate (Percent)[b] Estimated Weight Impinged (lb) 1977 311	1978 2,683	1979 302
Commonwealth Edison Co. (1980)	3.9	16,644	1.8	16.1	1.8
Muench (1978)	13.3	56,760	0.5	4.7	0.5
Christenson and Smith (1965)	27.9	119,069	0.3	2.2	0.3
UMRCC (1947)					
Savanna - 1	16.2	69,137	0.4	[illegible]	0.4
Savanna - 2	22.8	9[illegible] 304	0.3	[illegible].8	0.3
UMRCC (1948)					
Oquawka - 1	56.9	242,832	0.1	1.1	0.1
Oquawka - 2	11.4	48,65[illegible]	0.6	5.5	0.6
Average	26.7	114,051	0.3	2.4	0.3

a. Total based on 4,267.7 acres for slough-lake habitat in Pool 14.
b. Percentage calculated by dividing estimated weight impinged by the total estimated standing stock for slough-lake habitat.

Table 6. Impingement Exploitation Rates (percent) at Quad Cities Station for Bluegill Based on Estimated Standing Stocks for Slough-Lake Habitat in Pool 14 of the Mississippi River, 1977 through 1979.

Data Source	Estimated Standing Stock		Impingement Exploitation Rate (Percent)[b] Estimated Weight Impinged (lb)		
	lb/Acre	Total(lb)[a]	1977 182	1978 158	1979 139
Commonwealth Edison Company (1980)	3.2	13,657	1.3	1.1	1.0
Muench (1978)	15.7	67,003	0.3	0.2	0.2
Christenson and Smith (1965)	8.0	34,142	0.5	0.5	0.4
UMRCC (1947)					
Savanna - 1	5.5	23,472	0.8	0.7	0.6
Savanna - 2	14.0	59,748	0.3	0.3	0.2
UMRCC (1948)					
Oquawka - 1	5.8	24,753	0.7	0.6	0.6
Oquawka - 2	20.5	87,488	0.2	0.2	0.2
Average	10.4	44,323	0.4	0.4	0.3

a. Total based on 4,267.7 acres for slough-lake habitat in Pool 14.
b. Percentage calculated by dividing estimated weight impinged by the total estimated standing stock for the slough-lake habitat.

Table 7. Impingement Exploitation Rates (percent) at Quad Cities Station for White Bass Based on Estimated Standing Stocks for Slough-Lake Habitat in Pool 14 of the Mississippi River, 1977 through 1979.

	Estimated Standing Stock		Impingement Exploitation Rate (Percent)[b] Estimated Weight Impinged (lb)		
Date Source	lb/Acre	Total (lb)[a]	1977 600	1978 1,155	1979 122
Commonwealth Edison Company (1980)	10.2	43,530	1.4	2.7	0.3
Muench (1978)	2.7	11,523	5.2	10.0	1.1
Christenson and Smith (1965)	1.5	6,402	9.4	18.0	1.9
UMRCC (1947) Savanna - 1	0.03	128	--	--	--
Savanna - 2	--	--	--	--	--
UMRCC (1948) Oquawka - 1	0.22	938	64.0	--	0.13
Oquawka - 2	2.8	11,949	5.0	9.7	1.0
Average	2.5	10,639	5.6	10.9	1.1

a. Total based on 4,267.7 acres for slough-lake habitat in Pool 14.
b. Percentage calculated by dividing estimated weight impinged by the total estimated standing stock for slough-lake habitat.

Commercial Fish Harvest

Commercial fish harvest is discussed in Hazleton Environmental Sciences (1979 pp. 7.117 to 7.124) and in Commonwealth Edison Company (1980 p. 3-49). In summary, commercial catches during years of Station operation have been well within the range of commercial harvest records for the 27 years prior to Station operation, which indicates that Station operation has not affected commercial fishing.

Freshwater Drum Life History and Population Dynamics Study

Of considerable importance to the 316(b) Demonstration is a freshwater drum (*Aplodinotus grunniens*) life history and population dynamics study which was initiated in 1978 as part of the Quad Cities Station Aquatic Program. The species was selected on the advice of the Illinois Department of Conservation to receive special attention because all of its life history stages are affected by Station operation, and it is a sport and a major commercial species. Its eggs and larvae frequently constitute a majority of the condenser cooling water entrained ichthyoplankton. With the exception of gizzard shad (*Dorosoma cepedianum*), freshwater drum impingement is numerically higher by a considerable margin than that for any other species in Pool 14. Thus, if it can be demonstrated that the combined effects of entrainment and impingement do not result in a significant population decrease and a reduction in the yield of freshwater drum to the commercial and sport fishery in Pool 14, it would be logical to assume that other species are probably not suffering adverse effects as a result of Quad Cities Station operation.

Through 1979, freshwater drum larvae studies were directed at deriving estimates of entrainment survival and percentages of annual larvae drift lost to entrainment. Other studies were conducted to estimate population size, age class distribution, total annual mortality rates and impingement and commercial fishing annual exploitation rates. Larvae studies (Hazleton Environmental Sciences, 1979c) conducted in 1978 revealed that most larvae survive entrainment for open-cycle operation if discharge temperatures do not exceed 91.4°F. The percentage of larvae drift for each year lost due to entrainment for actual operating conditions was estimated, and ranged from 1.3 to 3.1 percent for the years 1975 through 1978, and from 1.6 to 5.4 percent for the same years for the projected case of complete open-cycle operation. Studies conducted in 1979 (Commonwealth Edison Company, 1980) demonstrated that the estimates for complete open-cycle were over-estimates. This was attributed to under-estimates of survival and over-estimates of entrainment abundance in the 1978 estimate. It is likely that there is not much difference in the number of larvae lost due to entrainment between open-cycle and the present operating modes.

In the spring of 1979, a mark-recapture population estimate for fish greater than 250 mm was made for a segment of Pool 14 (Commonwealth Edison Company, 1980, pp. 5-1 through 5-25). The estimate was calculated based on the Chapman modification of the Schnabel multiple census estimate and its 95% confidence limit as described by Ricker (1975). The point estimate was 189,845 fish with a 95% confidence interval of 117,553 to 398,060 fish. This estimate, which applies only to fish with a length greater than 250 mm, was considered to be applicable only to the portion of the freshwater drum population between

RM 506.8 and RM 514.5, since recaptured fish were almost always taken near the original area of capture.

The population estimate study was expanded in 1980 to include mark and recovery areas downstream of the Station. In addition to the area sampled in 1979, the 1980 program included the area downstream of the Station between River Mile 495.0 and 506.0. The estimate for 1980 was 179,820 fish with a 95% confidence interval of 96,586 to 368,784 fish (ERT, 1981) for fish of age class 4 and older. Age class four was the first age class to be fully recruited to the fishery.

Freshwater drum impingement exploitation rates for older fish in 1979 was estimated to be less than one percent (Commonwealth Edison Company, 1980, p. 5-19). This estimate is based on fish marked and recovered from impingement collections in 1978 and 1979. As part of the 1978 fall haul seine program, 603 fish, 200 mm and larger were tagged and released. During the period December, 1978 through December, 1979, only two of the 1978 marked fish were found in impingement samples. Because approximately 40% of the total impingement was sampled during this time period, the data suggests an impingement exploitation rate of less than 1% (0.33) for fish greater than 200 mm.

Between April 16 and June 6, 1979, there were 2178 fish greater than 250 mm, total length, tagged and released in the spring study area (Commonwealth Edison Company, 1980, p. 5-19). During the interval June, 1979 through June, 1980, only three fish marked in 1979 have been impinged. Approximately 40 percent of the total impingement was again sampled during the same time period, which suggests that seven marked fish would have been impinged. For

fish greater than 250 mm, the annual impingement exploitation would be less than one percent (0.32%). This impingement exploitation estimate is only for larger fish and does not consider exploitation of small fish.

This low impingement estimate for larger fish may be due in part to placement of the 3/4 inch bar mesh barrier net at the river's edge of the forebay. The net was in place from mid-December, 1978 through mid-April, 1979, and from the end of October, 1979 through the end of March, 1980. The net was in place during the period of the year when historically, larger drum had been collected in impingement samples. Consequently, it is not known what the impingement exploitation rate would have been had the net been out of the water.

The above impingement exploitation estimate is applicable only to older fish when the barrier net was in place and it would be inappropriate to use this estimate for exploitation of younger fish. Most impingement for this species is constituted by age class 0 and I, and a different approach was used to estimate exploitation for these younger fish. Two methods were used to estimate age class 0 and I abundances for the years 1973-1980 to be used to develop exploitation estimates for those years.

For the years 1973-1976, the reciprocal of the annual survival rate (0.561, ERT, 1981) was multiplied by the estimated number of each fully recruited year class of a Pool 14 population estimate obtained in 1980, to obtain an estimate of the numbers of that year class in 1979. This procedure was followed for each preceding year for each year class until the number of each age class 0 and I of that year class was estimated. Results are presented in Table 8.

Table 8. Estimates[1/] for Age Class 0 and 1 Freshwater Drum from Backcalculation of 1980 Population Estimates.

	Year							
Age Class	1980[2/]	1979	1978	1977	1976	1975	1974	1973
0					853,726	724,229	196,100	1,805,329
1				478,940	406,292	110,012	1,045,844	
2			268,686	227,930	61,717	586,719		
3		150,733	127,869	34,623	329,149			
4	8[illegible],561	71,734	19,424	184,653				
5	40,243	10,897	103,590					
6	6,113	58,114						
7	32,602							

1/ Assumes constant survival rate of 0.561 between age classes

2/ Based on 179,820 Age 4-12 fish in 1980 which were fully recruited and vulnerable to hoop nets.

Source: ERT, 1981 Table 3-12

The second method was used to estimate the number of age 0 and 1 freshwater drum in the years 1977-80. The estimates were obtained from a linear regression (ERT, 1981) which used age class as the independent variable and age class abundances in 1980 as the dependent variable. This procedure provides an estimate of the average number of age class 0 and I's expected to be found in any year and is used to estimate impingement exploitation for recent year classes until that year class is fully recruited into the population estimate study.

Impingement exploitation ranges from 1.1 to 30.4 percent for age 0 fish and from 0.6 to 19.2 percent for age 1 fish (Table 9). These exploitation rates are, however, probably conservative or overestimates of impingement exploitation due to a variety of factors.

First, the exploitation rates were based on backcalculated population estimates that assumed a constant survival rate between age classes. This assumption is known to be invalid since survival rates are lower for younger fish. Second, the 1980 population estimate on which the backcalculations for year class 1973-1976 are based, is believed to be an underestimate. This underestimate was probably a result of inadequate sampling in certain (downstream of the station) designated sampling areas of the 1980 program (ERT, 1981). An underestimated population and overestimated survival rate would result in an overestimate of impingement exploitation since both parameters lead to smaller estimates of age class 0 and I's. This is particularly evident in the high exploitation rate estimated for age 0 (30.8%) and age 1 (19.2%) freshwater drum impinged during 1974 and 1975 respectively (Table 9). It should also be noted that the age 0 fish in 1974 and age 1 fish in 1975 belong

Table 9. Impingement Exploitation Estimates for Age Class 0 and 1 Freshwater Drum at Quad-Cities Station from 1973 through 1980.

	Year							
	1980	1979	1978	1977	1976	1975	1974	1973
Age class 0 estimates[1/]	648,000	648,000	648,000	648,000	853,726	724,229	196,100	1,864,250
Estimated age class 0 impingement[2/]	6,827	11,048	23,380	28,540	24,453	8,928	60,373	118,849
Age class 0 impingement exploitation rate (%)[3/]	1.1	1.7	3.6	4.4	2.9	1.2	30.8	6.4
Age class 1 estimate[1/]	382,000	382,000	382,000	478,940	406,292	110,012	1,045,844	--
Estimated age class 1 impingement[4/]	10,922	4,819	35.089	21,077	2,378	21,160	48,287	19,688
Age class I impingement exploitation rate (%)[3/]	2.9	1.3	9.2	4.4	0.6	19.2	4.6	--

[1/] Estimate based on population estimate of 179,820 Age 4-12 freshwater drum in 1980. Age 0 fish (1977-1980) and age 1 fish (1978-1980) were estimates of those age classes in any given year derived from linear regression (ERT, 1981).

[2/] Estimated assumes all freshwater drum impinged from July through December each year are age class 0 fish.

[3/] Impingement exploitation rate estimated by dividing age class impingement estimate by age class population estimate for each respective year.

[4/] Estimate assumes all freshwater drum impinged from January through June each year are age class I fish.

Source: ERT, 1981 Table 3-13

to the same year class. Estimated exploitation rates for other years (age 0 = 1.1 - 6.4% and age 1 = 0.6 - 9.2%) are lower than the above 1974 age 0 and 1975 age 1 estimates which further suggest that they are unrealistic.

Barrier Net Studies

In 1979, the estimated impingement both for numbers and weights was the lowest recorded for the seven years of monitoring. This low estimate is attributable to the placement of a barrier net in front of the forebay. The placement of the barrier net was initiated at the suggestion of the USEPA to evaluate its effectiveness in reducing impingement for the months during which impingement has been shown to be greatest for closed-cycle or partial closed-cycle cooling. Results of the barrier net study during 1978-1979 indicated that impingement was reduced by 85 to 98% when the Station operated closed-cycle. A 48 to 78% reduction was measured during varying conditions of partial closed-cycle operation (Commonwealth Edison Company, 1980, Section IV). It is expected, however, that this lower percentage for partially closed-cycle can be improved.

It is obvious from the results of the barrier net study that placement of this type of gear works fairly well during closed-cycle operation at Quad Cities Station. However, it is also evident that the net could be effective in reducing impingement of river fish during open-cycle operation through the judicious operation of the circulating water pumps, and the return of condenser cooling water back to the forebay by means of the de-icing line, to reduce velocities at the river's edge of the forebay.

During the summer months, it is expected that impingement can be minimized during open-cycle cooling by returning condenser cooling water from the discharge bay to the intake forebay via the icemelt line located on the floor of the forebay. The summer months have historically been the time when impingement of smaller individuals has been the greatest. Up to 200,000 gpm can be diverted back to the forebay through the icemelt line. By diverting condenser cooling water back to the forebay it is expected that temperatures will increase enough in the forebay to cause smaller individuals to avoid the intake during this period of the year. The extent of the avoidance can only be documented through open-cycle operation.

During the winter months, impingement can be minimized during open-cycle operation by installing the barrier net at the river's edge of the forebay in conjunction with reducing the number of circulating water pumps and by diverting condenser discharge back to the intake forebay by means of the de-icing line. As mentioned earlier, larger sized fish have been impinged during closed-cycle operation for this period of the year because of attraction to the intake forebay. During closed-cycle operation, the net has been shown to be effective in reducing impingement. By reducing the number of operating circulating water pumps, in addition to diverting condenser discharge back to the forebay, intake velocities at the river's edge during open-cycle operation would correspondingly be reduced about 50% to about 0.5 fps. Low velocities in this area are necessary to ensure that the net rests on the floor of the forebay.

Finally, an added benefit to operating the Station in this manner is expected to be the absence of the thermal "leak" that occurs during closed

and partial closed-cycle operation. It is expected that the absence of warm water outside the forebay will result in reduced impingement. As mentioned previously, this warm water appears to attract fish in the fall and winter. A testing period during open-cycle operation is the only method by which these hypotheses may be tested, but sufficient information is already available to document that impingement would be reduced compared to open-cycle operation without the net or use of the de-icing line. The extent of the reduction cannot be quantified without operational data.

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