**AN EVALUATION OF ENVIRONMENTAL DATA
RELATING TO SELECTED NUCLEAR POWER
PLANT SITES**

THE QUAD-CITIES NUCLEAR POWER STATION SITE

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August 1976

MASTER

DIVISION OF ENVIRONMENTAL IMPACT STUDIES

ARGONNE NATIONAL LABORATORY

Argonne, Illinois

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by

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Preface

The Office of Regulatory Research, U. S. Nuclear Regulatory Commission, is supporting a program at the Argonne National Laboratory for the evaluation of the data collected by field studies at a number of operating nuclear power plants. The objective is to analyze data from both a disciplinary and a statistical standpoint. Each of the plants chosen is required, by the terms of the licenses granted, to conduct certain monitoring programs. Some plants are running additional programs to serve their own interests. Do such programs meet the interests of ecologists concerned with the protection of biota? What is the precision and accuracy of the results? What decisions are made on the basis of the field data and how valid are such decisions? Answers to such questions would be of great value in establishing the most cost-effective programs for future plants and redesigning the programs for existing plants.

Through the cooperation of the companies operating the plants, the staff is obtaining the data from a number of installations. As the results are compiled the Laboratory plans to prepare an informal report such as this to present the analysis pertaining to each plant chosen. A summary and inter-comparisons of data, together with the Laboratory's recommendations, will then be presented in one or more reports to the NRC.

This, the second of the informal reports, pertains to the Quad-Cities Nuclear Power Station. Similar reports pertaining to the sites of the Zion, Prairie Island, Three Mile Island, Duane Arnold, and Nine Mile Point plants are envisaged.

Reports previously issued in this series:

ANL/EIS-1 *The Kewaunee Nuclear Power Plant Site.*

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AN EVALUATION OF ENVIRONMENTAL DATA RELATING
TO SELECTED NUCLEAR POWER PLANT SITES

THE QUAD-CITIES NUCLEAR POWER STATION SITE

Abstract

Environmental monitoring data for the years 1972 through 1975 pertaining to the Quad-Cities Station, which began commercial operation Feb. 18, 1973, were analyzed by the most practical qualitative and quantitative methods. Four different cooling methods that were used are described.

The results showed no significant immediate deleterious effects or violations of state water quality standards, thus confirming preoperational predictions. Although the plant has not operated long enough to reveal long-term deleterious effects, the present indications do not lead to a concerned prediction that any are developing.

The data utilized, the methods of analysis, and the results obtained are presented in detail, along with recommendations for improving monitoring techniques.

THE PLANT

The Quad-Cities Nuclear Power Station is a facility of the Commonwealth Edison Company and the Iowa-Illinois Gas and Electric Company, located in Rock Island County on the east bank of the Mississippi River (Pool 14), about three miles north of Cordova, Illinois and about 20 miles northeast of the Quad-Cities/Bettendorf area. The Quad-Cities are Davenport, Iowa, and Rock Island, Moline, and East Moline, Illinois (see Fig. 1).¹ The site, which contains two 809-Mwe (net) boiling water reactors, consists of approximately 560 acres of flat land with a grade level about 9 ft above maximum recorded flood stage. The surrounding land areas are primarily used for agriculture, with an industrial park directly north of the station.

The Mississippi River flow is controlled below flood stage throughout its length by a series of locks and dams, so that its channels and levels are usable for transportation by water. In addition, a series of wing dams that were installed previously for navigational purposes have modified the natural flow patterns in the river.

Fig. 1. Location of the Quad-Cities Nuclear Power Station.
The circle represents the 50-mile radius.

OPERATING HISTORY

Quad-Cities Unit 1 attained initial criticality on October 18, 1971, but did not start commercial operation until February 18, 1973. Unit 2 attained initial criticality on April 26, 1972, and started commercial power production on March 10, 1973. Since the plant began commercial operation, daily power generation levels have been reported to the U. S. Nuclear Regulatory Commission (NRC), formerly the Atomic Energy Commission. The data for years 1974 and 1975 (obtained from the NRC gray book) for each unit are plotted in Figures 2 and 3. It is evident that the daily power generation fluctuates over the full range from zero output to the maximum level of 809 MWe (net) for each unit.

This operating characteristic influences the environmental measurements and the determination of changes in the biota, water chemistry, and thermal regime in the vicinity of the station.

PART I. HYDROTHERMAL ASSESSMENT

CHARACTERISTICS OF THE OUTFALL

The original operating plan for the Quad-Cities Station called for once-through cooling with the cooling water containing the waste heat being returned to the Mississippi River via a surface shoreline discharge system. The 2270 cfs of cooling water, which is raised 23°F in the condensers, was to have been guided from the shoreline to the higher velocity main-stream portion of the river by a wing dam extending 1200 feet from the east bank and inclined about 70° from the downstream shore.

After this system was proposed, the Iowa Institute of Hydraulic Research (IIHR) at the University of Iowa² was engaged to determine whether the dilution required to meet the thermal water quality standards (see Appendix) could be obtained. Hydraulic modeling studies clearly indicated that it would not, and that the thermal water-quality standards would surely be violated. IIHR was then commissioned to design a system that would meet such standards. Additional studies showed that for a once-through cooling system, the standards could be met by installing a submerged multiport diffuser.

A two-line diffuser system was designed and tested by means of more laboratory model studies and installed in the river during the spring and summer of 1972.

When Commonwealth Edison applied for a permit for initial operation of the plant at up to 50% full power, the installation of the diffuser was not complete, so the Illinois Pollution Control Commission granted temporary permission to use a side-jet discharge which was the initially constructed channel with most of the open end at the shoreline closed off. This system was used only during the period April through July 1972, at which time the diffusers became operational.

Following public hearings in Illinois and Iowa, permits to operate the plant at full power were granted. These permits stipulated that the applicant would build a spray cooling canal to replace the diffuser system as a means of dissipating heat from the condensers. This stipulation resulted from the

Fig. 2.. Daily Power Generation by Quad-Cities Unit 1.

Fig. 3. Daily Power Generation by Quad-Cities Unit 2.

settlement of a suit against the applicant by the State of Illinois, the Izaak Walton League, and the UAW. They did provide, however, that the diffuser system could be used until the spray canal became operational. As a result, the plant was operated with both units on the diffuser system from August 1972 until May 1, 1974. From that date until October 1975, it was operated with one unit on the diffuser and one on the spray canal, and since October 1975 both units have been on the spray canal.

Figure 4 shows the cooling system as it now exists. Note the separate diffuser for the cooling canal blowdown.

Although the spray canal is in operation, the diffuser is being kept on standby. During the period that it was used, nearly two years' experience in operating and monitoring the system was obtained. Should the diffuser system ever be used again, the experience gained will enable a still better monitoring system to be organized. This account pertains then only to the diffuser system, not the spray canal currently in use.

THERMAL REQUIREMENTS

The Quad-Cities discharge must satisfy both the Iowa and the Illinois water quality standards. The relevant portion of these are listed in the Appendix.

In addition, temperature limitations and monitoring requirements were set forth in the Environmental Technical Specifications 1.2.³

Heated effluent from the plant shall meet the following restrictions beyond a mixing zone 600 feet downstream of the diffuser pipes:

- A. *The normal daily and seasonal temperature fluctuations that existed before the addition of heated effluent shall be maintained.*
- B. *The maximum temperature rise at any time (or place) above natural, ambient temperatures shall not exceed 5°F.*
- C. *The rate of change of temperature due to heated effluent from the diffuser pipes shall not exceed 2°F per hour (during controlled changes in operation of the plant).*

The temperature monitoring requirements are:

Four temperature sensors will be located downstream of the diffuser pipes, one temperature sensor will be located in the discharge bay, and two temperature sensors will be located in the intake area to record ambient data. (See Fig. 4).

In addition, four continuous recording thermometers will be placed in downstream island areas. Two will be placed in the island area below the side jet discharge and two others in the Steamboat Slough area; one recording thermometer in each area will be considered as the minimum necessary to adequately monitor the downstream island areas. These continuous recorders will monitor the rate of change of river temperature due to Quad Cities Station cooling water effluent.

Monthly thermal mapping surveys will be performed downstream of the diffuser pipes. Each of these surveys shall be conducted at the highest

Fig. 4. Location of Stations for Monitoring Temperature and Dissolved Oxygen.

practicable power level. Power level and river flow shall be recorded during the thermal mapping surveys. The thermal survey maps will be included as part of the monitoring program report.

DIFFUSER DESIGN

The Iowa Institute of Hydraulic Research designed the Quad-Cities diffuser to meet the following specifications:

- (1) The head required at the entrance of the diffuser pipes does not exceed 3.7 feet which is the available head with the existing pumping facilities.
- (2) The jet velocity is sufficiently high (about 10 fps was judged to be adequate) to ensure complete mixing of the condenser-water discharge with the river flow within 600 ft downstream of the diffuser.
- (3) The system has sufficient built-in flexibility to enable modifying the distribution of condenser-water discharge across the river, if required for any reason in the future.

The diffuser consists of two 16-foot-diameter pipes, one for each unit, as shown in Figure 5. The pipes are buried in the river bed, one extending almost all the way across the river, the second terminating 500 feet from the west bank.

Each pipe has 20 ports of 36-inch diameter spaced at 19-foot 8-inch intervals in the deep portion of the river and 14 ports of 24-inch diameter spaced at 78-foot 8-inch intervals in the shallow region of the river. The first 18 ports (nine on each pipe) from the Illinois shore are closed by removable flanges, but nozzles can be installed if it proves desirable for any reason to release some effluent near the east shore. The port spacings and diameters were selected on the basis of data from river velocity distribution measurements made in the river by the USGS and data from the tests in the three-dimensional model. The objective was to distribute the effluent across the river in proportion to the local river flow per unit width. It will be noted that most of the condenser water is to be released in the deep portion of the river away from the Illinois shore. In this region the river flow per unit width is much greater because of the greater depths and higher velocities and because plant withdrawal also tends to diminish locally the river flow near the Illinois shore.

The heated effluent is discharged from the diffuser in the downstream direction at an angle of 20° with respect to the river bottom. The exit jet velocity is approximately 10 fps.

DIFFUSER MODEL STUDIES

In designing the diffuser, it was necessary to know the effects of the discharge-port geometry on flow patterns, temperature distributions, and river bed scour in the vicinity of the diffuser pipes. In order to simulate jet diffusion and buoyant spread, an undistorted hydraulic model was required. Thus, a two-dimensional undistorted model, which represented a longitudinal "slice" along the river and through the diffuser pipe was set up in a flume, 30 feet

Fig. 5. Quad-Cities Multiport Diffuser Pipe.

long, 2 feet wide, and 1.5 feet deep. The tests in the sectional model demonstrated that the ports inclined at an angle of 20° from the horizontal produced no river bed scour or significant surface disturbances. Virtually complete mixing of the jet efflux with the ambient flow was achieved within a very short distance in all the tests, regardless of port spacings and diameters.

Tests were also conducted in the distorted river model with a simulated diffuser system to determine how the discharge of heated effluent should be distributed across the river to obtain a uniform lateral distribution of temperature downstream of the diffuser. These tests indicated that no condenser water should be discharged within about 800 feet of the east bank and about 120 feet of the west bank.

A description of these hydraulic modeling techniques can be found in Reference 2, but some of the results are discussed here.

Figure 6 shows results of the undistorted two-dimensional model tests in which three ports were set up in a 30-foot long, 2-foot wide, and 1.5-foot deep glass walled flume. The upper figure shows temperature rise distributions measured in a vertical plane passing longitudinally through the center jet. The two figures below represent vertical sections through the river at distances of 47.2 feet and 109 feet downstream from the diffuser. The river flow modeled (11,000 cfs) was approximately equal to the lowest daily flow on the Mississippi River since construction of the navigation dams.

It is evident that at the second cross section, 109 feet downstream from the diffuser, the heated effluent is completely mixed with the ambient flow; the difference between the largest and smallest temperature rise is only 0.3°F , where the average temperature rise is approximately 5°F . At the cross section 47.2 feet downstream from the diffuser, the variation is, of course, much larger.

Additional diffuser tests in the distorted river-model indicated that for effective operation, the condenser-water discharge across the river should be in direct proportion to the local river flow per unit width. Figure 7 shows the estimated effluent discharge distribution across the river at the location of the diffuser pipe. Also included are the river flow distributions 200 ft upstream and 500 ft downstream from the diffuser pipe, averaged for surveys from February 20, 1973 to August 30, 1973.

Tests were conducted to determine the predicted temperature rises, 600 feet downstream from the diffuser for four different river flows:

- (a) 11,000 cfs - minimum river flow
- (b) 13,500 cfs - 7-day, 10-year recurrence interval flow
- (c) 20,000 cfs
- (d) 30,000 cfs - average river flow

Figure 8 shows the results for the case of minimum river flow (case a above).

The general conclusion of Jain et al.² is that for all discharges investigated, virtually complete mixing will be achieved within 600 feet from the diffuser system.

4.9	5.0	5.0	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
4.9	5.0	5.0	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
4.7	5.2	5.1	4.6	4.6	4.8	4.7	4.7	4.9	5.0	5.0	
4.6	5.2	5.0	4.6	4.8	5.2	5.0	5.1	5.2	5.3	5.1	
4.3	4.4	4.6	4.2	4.1	4.6	4.5	4.6	4.8	4.8	4.9	
3.7	3.4	3.2	3.0	3.2	3.4	3.9	4.3	4.7	4.7	4.8	

X = 47.2'

4.7	4.6	4.6	4.7	4.7	4.8	4.8	4.8	4.8	4.7	4.8	
4.7	4.6	4.6	4.7	4.7	4.8	4.8	4.8	4.8	4.7	4.8	
4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.8	4.7	4.7	4.8	
4.8	4.8	4.6	4.6	4.6	4.6	4.5	4.6	4.6	4.8	4.8	
4.7	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.7	4.7	
4.6	4.6	4.6	4.6	4.6	4.6	4.5	4.6	4.6	4.6	4.6	

X = 109'

NOTE: Thermal Wedge Extends to 300 ft Upstream of the Diffuser

INSTITUTE OF HYDRAULIC RESEARCH at the UNIVERSITY OF IOWA	ISOTHERMS (T-Tr) °F	RIVER DISCHARGE 11,000 cfs	PLANT DISCHARGE 2,270 cfs	PLANT TEMP RISE 23° F	RUN NO. 11
	JET VELOCITY 100 fps	PORT SPACING 19'-8"	CHK'D SCL	DATE APR 86	DATE APR 86

Fig. 6. Longitudinal and Cross-Sectional Temperature-Rise Distribution (Depth - 25 ft).

Fig. 7. Average Normalized Transverse Distributions of River Discharge 200 ft Upstream and 500 ft Downstream from Diffuser Pipe and Diffuser-Pipe Normalized Discharge Distribution at the Pipe.

Fig. 8. Cross-Sectional Temperature-Rise Distribution
 ($Q_R = 11,000$ cfs).

Finally, single-port model studies were performed in order to determine detailed measurements of temperature and velocity distribution in the higher temperature regions close to the diffuser pipe. These studies permit the evaluation of the diffuser performance with respect to the zone of passage requirements of the water quality standards.

OBSERVED EFFECTS

IIHR Temperature Surveys

Since May of 1972, IIHR, under a contract with the Commonwealth Edison Company, has conducted temperature surveys in the Mississippi River near the vicinity of the Quad-Cities Plant to determine temperature distributions in the reach downstream from where the condenser cooling water is returned to the river. The purposes of the investigation were: (1) to verify the predictions of the IIHR laboratory model tests for both the interim side-jet and diffuser-pipe discharge systems, and (2) to determine whether the diffuser pipe system was performing as designed and to make recommendations for readjusting the cross-channel distribution of the cooling water discharge if it were not.

IIHR not only took an enormous amount of data, but also did an outstanding job of analyzing and interpreting the results. Data presentation and interpretation were reported in a group of limited distribution reports.⁴⁻⁷ In addition, a more detailed analysis can be found in A. D. Parr's Ph.D thesis.⁸ Accordingly, only a brief summary of the work is given here.

Background data for the days on which boat surveys were made are listed in Tables 1 and 2. All surveys were 500 feet downstream from the centerline between the two diffusers except those on 11/9/72 and 1/16/73 when additional data were taken 300 feet downstream. Also, the data taken on 3/14/74, 4/15/74, 10/2/74, and 11/11/74 were at a distance of 150 feet from the diffusers.

Table 1 gives the background data obtained during operation with both diffuser pipes. Table 2 gives the background data during the period when only one diffuser pipe was used.

Flow data were provided either by the USGS or obtained by measurement by IIHR. The USGS data included the river flow rate at the gaging station at Clinton, Iowa (14 miles upstream from the station), and the inflow from the Wapsipinicon River, whose confluence with the Mississippi is approximately 1500 feet upstream from the diffuser pipes. The IIHR-measured flow rates agreed well with the USGS values except during the winter days when the river was partially covered with ice. For these days, IIHR data were about 20% lower than the USGS data and the former values were assumed to be correct.

Under normal full load operation, the plant discharges the heated effluent at the rate of 2270 cfs with a temperature increase of 12.8°C (23°F). When the plant is operating at partial load, the effluent discharge is maintained at 2270 cfs, so the temperature rise is proportionally less. This flow, however, is not measured other than by noting the number of pumps in operation (6 pumps corresponds to 2270 cfs), which is not very accurate.

Table 1. Background River Flow and Plant Effluent Data

Date	River Discharge Q_R (cfs)	Average Ambient Temperature T_a (°C)	Plant Intake Temperature T_I (°C)	Plant Effluent Temperature T_E (°C)	Percent of Full Plant Load (P)	No. of Pumps Running	Estimated Plant Effluent Discharge Q_E (cfs)	Estimated Mixed Temperature Rise ΔT_m (°C)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
11-02-72	70,700	8.0	8.1	23.4	90	6	1,710	0.37
11-09-72	73,600	6.7	6.4	20.4	95	6	1,970	0.37
11-28-72	56,500	1.4	1.1	16.1	90	6	1,740	0.45
1-16-73	38,000	0.5	0-4.4*	22.9	90	6	1,140	0.67
2-20-73	39,300	0.4	0.2	16.7	92	6	1,620	0.67
7-23-73	34,600	23.6	23.5	35.2	94	6	2,330	0.78
7-26-73	33,700	25.5	25.5	37.6	94	6	2,250	0.81
7-31-73	36,900	25.4	25.2	32.7	46	6	1,785	0.35
8-17-73	41,800	26.1	25.6	37.8	94	6	2,230	0.62
8-30-73	43,000	26.7	26.0	37.8	93	6	2,290	0.59
9-12-73	37,100	21.7	21.4	31.7	85.5	6	2,410	0.65
10-08-73	47,500	17.1	18.0	28.8	85.0	6	2,280	0.56
10-31-73	58,800	10.9	10.9	21.6	77.8	6	2,110	0.38
11-14-73	39,100	4.6	4.7	16.4	79.4	6	1,970	0.60
12-03-73	51,100	4.6	4.9	18.8	89.0	6	1,860	0.52
1-16-74	31,400	0.1	0.01	10.0	47.5	6	1,380	0.43
1-21-74	41,900	0.2	0.04	11.5	82.5	6	2,090	0.57
3-14-74	82,700	3.1	3.7	16.4	91.9	6	2,095	0.34

* Ice melting unit in operation.

Table 2. Background River Flow and Plant Effluent Data when Operating
with Spray Canal and/or One Diffuser Pipe Only

Date	Diffuser Pipe	River Discharge	Average Ambient Temp. $\bar{T}_a$ (°C)	Plant Intake Temperature		Plant Effluent Temp. T_E (°C)	Percent of Full Plant Load (P)	Number of Pumps Running		Estimated Plant Effluent Discharge Q_E (cfs)	Estimated Mixed Temperature Rise ΔT_m (°C)
				T_{aI} (°C)	Est. T_I (°C)			Lift	CW		
(1)	(2)	(3)	(4)	(5a)	(5b)	(6)	(7)	(8a)	(8b)	(9)	(10)
4-15-74	Long	103,000	8.6	8.9	8.9	20.8	46.9	0	3	1150	0.14
7-23-74	Short	22,200	26.8	26.4	27.4	33.3	40.2	2	6	1160	0.34
7-25-74	Short	37,100	26.4	26.1	31.2	40.4	65.2	3	6	850	0.32
8-22-74	Short	32,000	25.2	25.0	30.4	43.0	91.0	3	6	880	0.49
9-10-74	Short	27,000	21.7	21.6	30.0	42.4	79.0	3	5	650	0.50
10-02-74	Short	26,700	13.3	13.3	22.4	35.6	81.0	3	5	580	0.48
11-11-74	Short	37,600	9.0	8.9	22.2	34.3	79.0	3	5	690	0.46
1-08-75	Short	25,300	0.3	0.3	0.3	7.9	46.0	0	6	1750	0.53

It has been observed that often the temperature rise does not correspond to that calculated from the equation

$$\Delta T_E = T_E - T_I = 12.8 \times P/100 \quad (1)$$

where ΔT_E = temperature rise across the condenser (12.8°C under full load)

T_E = plant effluent temperature, °C

T_I = plant intake temperature, °C

P = percentage of full load.

At times, ΔT_E is as much as 50% larger than expected. In order to explain this discrepancy, it has been assumed that the higher temperatures are attributable to reduced plant effluent discharge, Q_E , due to partial blockage in the circulating water system as a result of growth of slime deposits. The assumed value of Q_E can then be calculated from:

$$Q_E = \frac{12.8 \times 2270 \times P/100}{\Delta T_E} \quad (2)$$

When the spray canal is in operation, the estimation of Q_E is more involved and less reliable.

The plant intake temperature T_I and plant effluent temperature T_E listed in the table were measured continuously by Industrial BIO-TEST Laboratories and are found in the semiannual reports of the Quad-Cities Nuclear Station. These data, as well as the number of pumps operating and the percentage of full plant load were supplied to IIHR by the technical staff of the station for days on which surveys were conducted. The average ambient temperatures $\bar{T}_a$ are weighted averages (with respect to river flow per unit width) of sets of temperature readings taken at the upstream cross section both before and after the downstream data were obtained.

The estimated mixed temperature rise ΔT_m is given by the relationship

$$\Delta T_m = (Q_E/Q_R) \Delta T_E \quad (3)$$

and represents the temperature of the heated discharge and river water when completely mixed with each other.

Seven single-port surveys were conducted by IIHR. The background data for these surveys are given in Table 3.

Data Acquisition

In order to determine whether temperature standards are being met, one must know the temperature increase above ambient. As mentioned previously, the maximum temperature rise allowable outside the mixing zone is 5°F. The Illinois standards require that no single mixing zone exceed the area of a circle with a radius of 600 feet (about 26 acres). At Quad Cities, the river width is approximately 2000 feet, and the corresponding mixing zone thus extends downstream about 500 feet. It is assumed that the mixing zone extends all the way across the river even though there is no discharge near the Illinois shore.

Table 3. Background Data for Single-Port Prototype Studies in 1973 and 1974

Date	River Discharge Q_R (cfs)	Distance from Illinois Shore z (ft)	Outlet Diameter of Port D (ft)	Distance Downstream from Port x (ft)	Percent of Full Plant Load P (%)	Local Ambient Temp. T_a (°F)	Plant Effluent Temp. T_E (°F)	Estimated Discharge from Single Port Q_j (cfs)	Estimated Velocity from Single Port U_j (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

For this reason, the temperature surveys for evaluating the overall performance of the diffuser pipe system were made at cross sections located for the most part 500 feet downstream from the centerline between the two diffuser pipes. Two surveys were taken 300 feet downstream and four 150 feet downstream.

The temperatures were measured by IIHR using a YSI thermistor probe attached to a weighted cable operated from a boat. Details of the equipment and time averaging of the temperature fluctuations can be found in the references.

The distribution of ambient temperatures at a cross section 200 feet or 1000 feet upstream from the diffuser pipes was determined in the same way, except that the temperature was measured at fewer points. The ambient temperatures were measured both before and after the downstream surveys on all but two days.

The water quality standards also require that any mixing zone shall not contain more than 25% of the cross-sectional area or volume of flow of a stream. Since the mixing zone is delimited by the 5°F excess isotherm, temperature and velocity measurements must be made close to the ports in order to observe these higher excess temperatures.

As shown in Table 3, these surveys were taken between 15 feet and 95 feet downstream of a given port. Ambient temperature and velocity were measured upstream from the ports both before and after the downstream measurements.

Temperature Data

Diffuser Survey

Figure 9 is a typical example of a temperature survey; it was taken on July 26, 1973. The locations of the decimal points of the downstream temperature readings correspond to the probe positions in the river cross section where the readings were taken except for the surface readings, where the probe was located six inches beneath the water surface, and the bottom readings, where the probe was located ten inches above the bottom. The times at which temperature measurements at each cross section were started and completed are shown also. This information proved to be useful in accounting for the variation of ambient temperature with respect to time (see Fig. 10).

All of the temperature data in Figure 9 are time-averaged values--mostly ten-second averages. However, at points where significant fluctuation on the meter dial was observed, a sequence of several ten-second averages was taken, in which case the average of these averages is the reported temperature. At some points in the 500-ft section, differences in the ten-second averages of as much as ± 0.2 – 0.3°C were observed. At other points the readings were very steady. The fluctuations are indicative of zones where turbulent mixing is still occurring. No systematic study of either the locations of these mixing zones, or of the statistical properties of the fluctuations was attempted.

Figure 10 shows the transverse distribution of depth-averaged temperature $\bar{T}_d$ for November 28, 1972. The abscissa is the fractional distance across the river.

Fig. 9. Observed Temperatures in °C 200 ft Upstream and 500 ft Downstream from the Diffuser Pipe on December 3, 1973.

Fig. 10. Transverse Distribution of Depth-Averaged Temperature 500 ft Downstream and Ambient Temperature 1000 ft Upstream from the Diffuser Pipe on November 28, 1972.

Figure 11 shows the normalized transverse distribution of depth-averaged excess temperature $(\bar{T}^d - T_a)/\Delta T_m$. The variable ambient temperature distribution pattern has been subtracted, leaving only the transverse distribution of the excess temperature. If there were no heat transfer to the atmosphere and the heated effluent were completely mixed with the river water, the difference $\bar{T}^d - T_a$ would be equal to ΔT_m all the way across the channel, and $(\bar{T}^d - T_a)/\Delta T_m$ would have the uniformly-distributed value of one. The amount by which the curves deviate from this value is a measure of the non-uniformity of excess heat dilution. In view of the short distance from the diffuser pipes to the two cross sections, it is safe to neglect the heat loss. If the excess heat is not uniformly distributed, the average value of $(\bar{T}^d - T_a)/\Delta T_m$ across the channel should equal one only if the discharge per unit width of the ambient flow q_a is uniformly distributed. In the present case, as shown in Figure 7, the ambient flow is weighted heavily toward the Iowa shore, and the total heat balance has to be stated in terms of the heat flux distribution as

$$Q_E \Delta T_E = Q_R \Delta T_m = \int_0^W d \overline{u(T - T_a)^d} dz \quad (4)$$

where d is the local depth, W is the river width, and d , u , T , and T_a are all functions of distance z across the river, measured from the Illinois shore.

The multi peaked nature of these distributions is due to the differences in the transverse distribution patterns of the ambient flow per unit width and the effluent discharge per unit width. This is explained in detail in the references.

Figure 12 shows the observed excess temperatures for October 31 and November 14, 1973. These were determined by subtracting the time-averaged upstream ambient temperature at the same value of z/W from the measured downstream temperature. Temperature rises near the Illinois shore are almost always extremely small since there is no discharge in the first 840 feet. The same is true very close to the Iowa shore (within about 100 ft) for the same reason, although it is not as evident.

The highest excess temperatures are usually found near the surface in the shallower region of the river. The heated effluent from these smaller ports has less ambient flow available for dilution and rises to the surface due to buoyancy. In the winter, the largest temperature excesses are usually found near the river bottom, due to the sinking plume phenomenon. This occurs when the ambient river temperature falls below 4°C, the temperature corresponding to maximum water density. The warmer water in this case is more dense than the ambient and tends to remain at the river bottom. As will be discussed later, the higher excess temperatures in the shallow regions can be eliminated.

Tables 4 and 5 include data relevant to points where the maximum temperature rises occur, which implies that minimum dilutions were obtained. Again, Table 4 refers to data taken when both diffusers were operating and Table 5 to data when only one diffuser pipe was used.

The largest temperature rise observed was 3.8°F, so no violation of the 5°F limit has been recorded. However, there is a tendency for the temperature rise to increase with decreasing river flow, and all the surveys listed in Table 3 were made at times when the river flow exceeded the average value.

Fig. 11. Transverse Distribution of Normalized Depth-Averaged Excess Temperature 500 ft Downstream from the Diffuser Pipe. $Q_R > 40,000$ cfs.

Fig. 12. Observed Excess Temperatures in °F 500 ft Downstream from the Diffuser Pipe on October 31 and November 14, 1973.

Table 4. Performance Characteristics of Diffuser Pipe 500 ft
Downstream at Points where Minimum Dilution was Obtained

Date	Distance from Illinois Shore	Maximum Local Normalized Excess Temp. $\frac{(T-T_a)_{\max}}{\Delta T_m}$	Maximum Local Excess Temp. $(T-T_a)_{\max}$ (°F)	Dilution at Point of Least Mixing $\frac{\Delta T_E}{(T-T_a)_{\max}}$	Maximum Possible Dilution $\frac{Q_R}{Q_E} = \frac{\Delta T_E}{\Delta T_m}$
(1)	(2)	(3)	(4)	(5)	(6)
11-02-72	1610	1.95	1.3	21.3	41.3
11-09-72	1675	1.50	1.0	24.7	37.4
11-28-72	1610	2.47	2.0	13.3	32.5
1-16-73	1640	2.07	2.5	16.2	33.3
2-20-73	1810	2.23	2.7	10.8	24.3
7-23-73	945	2.71	3.8	5.5	14.8
7-26-73	855	1.86	2.7	8.1	15.0
7-31-73	1420	2.20	1.4	9.4	20.7
8-17-73	2060	2.05	2.3	9.2	18.7
8-30-73	1015	2.73	2.9	6.9	18.8
9-12-73	700	2.22	2.6	6.9	15.4
10-08-73	930	2.58	2.6	8.1	20.8
10-31-73	955	2.03	1.4	13.8	27.9
11-14-73	1400	1.67	1.8	11.8	19.8
12-03-73	905	2.26	2.1	12.2	27.5
1-16-74	910	2.71	2.1	8.5	22.8
1-21-74	1045, 1820	1.66	1.7	12.0	20.0
3-14-74*	1310	3.62	2.2	10.9	39.5

*150 ft downstream from diffuser pipe.

Table 5. Performance Characteristics of Diffuser Pipe at Points where Minimum Dilution was Obtained when Operating with Spray Canal and/or One Diffuser Pipe Only

Date	Downstream Distance (ft)	Distance from Illinois Shore (ft)	Maximum Local Excess Temperature $(T-T_a)_{\max}$ (°F)	Maximum Local Normalized Excess Temperature $\frac{(T-T_a)_{\max}}{\Delta T_m}$	Dilution at Point of Least Mixing $\frac{\Delta T_E}{(T-T_a)_{\max}}$	Maximum Possible Dilution $\frac{Q_R}{Q_E} = \frac{\Delta T_E}{\Delta T_m}$	Estimated Proportion of Waste Heat to Diffuser Pipe*
4-15-74	150	1740	1.4	5.72	15.7	89.6	1.00
7-23-74	500	920	2.1	3.45	5.57	19.1	0.65
7-25-74	500	1495	1.8	3.12	14.0	43.6	0.63
8-22-74	500	1475	2.8	3.17	11.4	36.4	0.59
9-10-74	500	1475	3.2	3.57	11.6	41.5	0.59
10-02-74	150	950	4.2	4.82	9.56	46.0	0.55
11-11-74	150	1475	2.8	3.35	16.3	54.5	0.76
1-08-75	500	1345	1.9	2.01	7.20	14.5	1.00

* Estimated proportion of waste heat to diffuser pipe = $\frac{Q_E \Delta T_E}{(2270)(12.8)P/100}$

The graph shown in Figure 13 was plotted with a view toward estimating the river flow Q_R at which the maximum temperature rise at full plant load in the 500-foot downstream cross section would reach 5°F. The denominator P in the ordinate is the percent of maximum plant load, which ranges from zero at no load to 100 at full load. Different symbols are used to denote sections of the diffuser pipes that are responsible for the hot spots. For comparison, data from the laboratory model study,⁷ and the perfect mixing curve representing the equation

$$\frac{(T - T_a)_{max}}{P/100} = \frac{\Delta T_m}{P/100} = \frac{Q_E \Delta T_E}{P Q_R / 100}$$

where $Q_E = 2270$ cfs and $\Delta T_E = 23^\circ\text{F}$, are shown also. Considering all of the points representing the field temperature surveys, the uppermost envelope curve, labeled A, indicates that a temperature rise of 5°F in the 500-ft-downstream cross section would not be exceeded at full plant load so long as the river flow is greater than about 25,000 cfs. Except for several of the points associated with the small ports, which account for only ten percent of the total diffuser pipe discharge, the field data group fairly closely around curve B. The laboratory model data on curve B indicate that the mixing performance of the diffuser pipe should approach the perfect mixing curve more closely as the river flow decreases below 30,000 cfs. However, curve B lies above the laboratory data since distorted models tend to increase the relative effect of transverse turbulent mixing, yielding results that are too optimistic.⁸ According to curve B a 5°F temperature rise would not be exceeded at river flows down to about 15,000 cfs. Because river flows have remained high throughout the observation period there has been no opportunity to verify that this trend actually exists in the field.

Single-Port Survey

Figure 14 is a typical example of a single-port survey. The solid dot between each pair of numbers represents the location of the midpoint between the thermistor probe and the current meter. The number above the dot is the excess temperature in °F, obtained by subtracting the upstream ambient temperature from the measured downstream temperature. The number below the dot is the measured velocity in feet per second.

Three adjacent 5°F isotherms are shown in the figure. The percentage of the zone of passage with respect to area, ZPA, is just the percentage of the area between vertical lines halfway between adjacent ports and outside the 5°F isotherm. This area is listed in column (3a) in Table 6 along with the value predicted by the laboratory model, column (3b). In all cases, the zone of passage is greater than 75%, as required by the water quality standards. It can be seen that the model and the prototype results agree very well.

The zone-of-passage with respect to discharge, ZPD, is calculated from the relationship

$$\text{ZPD} = 100\{1 - A_5 \bar{U}_5 / (Q_a + Q_j)\} \quad (5)$$

Fig. 13. Maximum Excess Temperature 500 ft Downstream from Diffuser Pipe for Full Plant Load Versus River Discharge.

Fig. 14. Excess Temperature in °F and Velocity in ft/sec Measured 15 ft Downstream from a Main Channel Diffuser-Pipe Port on October 30, 1974.

Table 6. Comparison of Model and Prototype Results for Single-Port Surveys

Date of Prototype Survey	Distance Downstream from port (ft)	Zone of Passage (Area) (%)		Zone of Passage (Discharge) (%)		Minimum Dilution ^a (%)	
		P (3a)	M (3b)	P (4a)	M (4b)	P (5a)	M (5b)
11-16-73	35	99.2	96.5	98.3	93.1	4.7	4.1
	65	100	100	100	100	7.0	7.1
3-12-74	15	97.3	94.5	96.5	94.4	3.1	2.3
	45	99.7	96.3	99.6	96.2	4.3	3.9
		--	100	100	100	--	5.4
3-13-74	35	100	100	100	100	5.3	5.9
	65	100	100	100	100	13.7	10.5
	99	100	100	100	100	16.6	14.9
7-24-74	15	100	96.5	100	89.2	3.10	2.3
	47	100	100	100	100	6.33	5.1
	75	100	100	100	100	8.00	7.0
10-01-74	15	89.5	92.9	86.2	88.4	2.62	2.3
	45	94.4	93.6	91.9	92.7	5.79	5.9
	75	100	100	100	100	9.70	11.4
10-25-74	15	86.1	88.7	81.2	83.7	2.7	2.3
	45	86.7	89.5	81.5	86.9	5.7	7.2
	75	97.5	93.8	97.0	92.8	8.5	8.6
10-30-74	15	87.1	88.7 ^b	76.2	83.7 ^b	2.5	2.3 ^b
	45	87.2	89.5 ^b	85.3	86.9 ^b	5.8	7.2 ^b
	75	98.6	93.8 ^b	98.5	92.8 ^b	8.9	8.6 ^b

$$^a \text{Minimum dilution} = \frac{T_E - T_a}{T_{\max} - T_a}$$

^bUsed 10-25-74 results.

where A_5 = area enclosed by the 5°F isotherm

$\bar{U}_5$ = estimated average velocity within the 5°F isotherm

Q_a = ambient discharge for local increment of river width equal to 1 port spacing

Q_j = estimated discharge from a single port

The ZPD is listed in column (4a) of Table 6 and the values determined from the laboratory model are found in column (4b). In all cases, the ZPD is greater than 75%. The model and the prototype values again agree quite well, though not as well as the ZPA.

Since the agreement with the model and the prototype are quite good, it is reasonable to use the model results to predict the zones-of-passage. Since ZPD is always less the ZPA, this is the quantity to be used for monitoring purposes. The method of calculating ZPD for the entire river is given by Parr⁸ and will not be discussed. The results of the minimum ZPD with respect to the total river discharge are shown in Figure 15. This graph shows that the water quality standard with respect to zone-of-passage will be satisfied as long as the river flow is greater than 15,300 cfs.

Utility Monitoring

As mentioned previously, the utility has four continuous temperature monitoring stations in the Mississippi River, 600 feet downstream from the diffuser pipe, and one upstream from the intake. The sensors are located approximately two to three feet above the river bottom. Temperatures in the intake were recorded from a sensor suspended from the floating boom and is located two feet above the bottom of the intake bay. A sensor is also located in the discharge bay near the diffuser inlets. These locations are shown in Figure 4.

Hourly temperature values from each of these sensors are listed in the appendix to each semiannual report. Table 7 is an example of the listing for April 9, 1974. In the main body of the semiannual report, the minimum, maximum, and mean temperatures for each day are listed for the upstream, intake, discharge and average of the four downstream sensors. An example of this listing is shown in Table 8.

ADEQUACIES AND DEFICIENCIES OF THE MONITORING PROGRAM

IIHR Monitoring Program

Cross-sectional surveys were performed over a wide range of ambient flow and plant operating conditions. Unfortunately, the surveys covering the period when both diffuser pipes were used always occurred when the river flows (31,400 cfs to 73,600 cfs) were greater than average. The largest excess temperature observed 500 feet downstream from the diffuser pipe was 3.8°F and thus the diffuser pipe system was found to be operating in compliance with the 26-acre mixing zone limitation.

Figure 13 was plotted so that one can estimate the river flow Q_R at which maximum temperature rise at full plant load would exceed 5°F in the 500-foot

Fig. 15. Minimum Zone-of-Passage with Respect to Total River Discharge.

Table 7. Daily Water Temperature Data (°F), Quad-Cities Station,
9 April 1974

Time	Upstream	Intake	Discharge	Downstream Sensors			
				A	B	C	D
0100	42.0	42.0	51.2	43.0	43.0	43.2	43.7
0200	42.0	42.2	51.2	42.8	43.0	43.1	43.9
0300	42.4	42.5	51.3	43.0	43.1	43.3	44.0
0400	42.6	42.6	51.3	43.6	43.4	43.3	44.0
0500	42.7	42.7	51.5	43.4	43.1	43.4	43.9
0600	42.8	42.8	51.5	43.3	43.1	43.4	43.9
0700	42.9	42.9	51.6	43.5	43.0	43.5	44.0
0800	42.9	43.0	51.8	43.4	43.2	43.3	44.1
0900	43.0	43.0	52.3	43.5	43.2	43.2	44.1
1000	43.0	43.0	52.1	43.5	43.3	43.2	44.2
1100	43.0	43.0	52.1	43.4	43.6	43.2	44.3
1200	43.0	43.1	52.1	43.4	43.5	43.1	44.4
1300	43.2	43.3	52.4	43.4	43.5	43.3	44.3
1400	43.4	43.4	52.6	43.5	43.6	43.5	44.3
1500	43.5	43.5	52.9	43.4	43.4	43.2	44.5
1600	43.7	44.1	53.1	43.3	43.2	43.2	44.8
1700	43.6	43.9	53.0	43.5	43.6	43.5	44.5
1800	43.6	43.9	52.9	43.6	43.8	43.9	44.6
1900	43.4	43.5	52.7	43.9	44.0	44.5	44.6
2000	43.2	43.3	52.5	43.8	44.0	44.2	44.4
2100	43.1	43.2	52.4	43.4	43.8	44.0	44.4
2200	43.0	43.1	52.3	43.4	43.6	44.1	44.2
2300	43.0	43.0	52.2	43.4	43.7	43.9	44.2
2400	42.9	42.9	52.1	43.3	43.7	43.9	44.2

Table 8. Summary of Daily Minimum, Maximum and Mean Water Temperatures (°F) at the Quad-Cities Station for October 1974

Day	Upstream			Intake			Discharge			Downstream		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
1	56.4	58.5	57.3	56.4	58.5	57.3	95.3	96.7	96.0	56.5	59.3	58.0
2	55.2	56.6	55.8	55.2	56.6	55.9	91.5	99.5	96.1	54.9	57.9	56.7
3	54.3	55.9	54.9	54.1	55.6	54.8	87.3	98.8	96.4	53.7	56.9	55.6
4	54.3	56.1	55.1	54.3	56.1	55.1	77.1	84.0	79.0	54.3	56.5	55.4
5	55.4	56.1	55.6	55.5	56.1	55.7	75.9	78.5	77.3	55.0	57.0	55.8
6	55.6	56.4	56.0	55.6	56.5	56.0	74.5	78.0	76.9	55.4	56.9	56.0
7	55.2	56.6	55.8	55.2	56.7	55.8	65.2	74.0	70.0	55.3	57.0	56.1
8	54.2	55.7	55.1	54.3	55.8	55.1	69.0	78.1	74.0	54.5	56.8	55.6
9	54.7	55.7	55.3	54.8	55.7	55.4	72.8	74.9	73.7	55.1	56.6	55.7
10	54.6	56.1	55.5	54.6	56.1	55.5	66.1	74.6	71.1	55.0	57.0	56.0
11	55.5	57.0	56.2	55.5	57.0	56.2	65.2	68.5	66.8	55.4	57.5	56.5
12	56.4	57.0	56.6	56.5	57.0	56.6	66.0	68.0	67.2	56.5	58.1	56.9
13	55.5	56.4	55.8	55.5	56.4	55.8	58.9	72.6	66.9	55.4	57.2	56.3
14	54.6	55.6	55.2	54.6	55.5	55.2	54.9	58.0	55.5	54.5	56.4	55.3
15	53.9	54.6	54.4	54.0	54.6	54.4	56.5	67.1	63.5	54.2	55.7	54.7
16	53.0	54.5	53.9	53.1	54.5	54.0	65.0	66.7	66.0	53.4	54.9	54.2
17	53.4	54.5	54.0	53.5	54.5	54.0	56.1	76.5	66.7	53.4	54.7	54.2
18	53.2	54.0	53.6	53.2	54.0	53.6	70.7	96.0	81.7	53.2	54.8	54.1
19	51.6	53.1	52.5	51.6	53.0	52.5	92.0	98.6	96.3	52.9	54.4	53.6
20	50.5	51.4	50.9	50.6	51.4	51.0	90.2	96.4	93.8	52.3	53.7	52.8
21	49.5	50.6	49.9	49.5	51.5	50.3	94.0	111.0	102.2	49.3	52.5	50.6
22	49.6	50.5	50.1	49.5	50.5	50.2	91.5	97.4	93.9	49.3	52.8	50.8
23	50.5	52.1	51.2	50.7	52.1	51.2	96.3	103.5	100.2	50.5	53.0	51.5
24	52.1	53.0	52.5	52.0	53.0	52.5	102.0	105.0	103.5	52.0	53.9	53.0
25	53.1	54.1	53.5	53.1	54.1	53.6	101.3	105.9	104.5	53.2	54.6	53.9
26	52.5	54.0	53.3	52.6	54.0	53.5	101.0	106.5	103.8	53.5	55.0	54.2
27	53.5	54.2	53.8	53.5	54.2	53.8	101.4	105.9	103.9	53.6	54.8	54.3
28	54.0	55.0	54.5	54.0	55.0	54.5	101.5	107.2	105.8	51.1	56.5	54.9
29	54.9	55.9	55.3	54.9	55.9	55.3	102.7	107.5	105.5	55.0	57.7	56.2
30	55.5	56.1	55.7	55.6	56.1	55.8	106.1	107.5	106.8	56.2	58.0	56.8
31	56.0	57.8	57.0	56.1	57.8	57.0	103.9	106.9	105.2	56.4	58.6	57.4

cross section. Thus, IIHR has provided a method for determining when a violation might occur.

The one deficiency of the IIHR surveys was the failure to measure two parameters, the intake water temperature T_I and the discharge water temperature T_E independently of the data provided by the station technical staff. These are necessary to calculate the plant effluent discharge rate Q_E . It must be emphasized, however, that this deficiency does not invalidate any of the results presented by IIHR.

Continuous temperature recording instrumentation such as that used by the utility can give erroneous readings for two reasons:

- (1) system malfunctions
- (2) changes in calibration.

System malfunctions are easiest to detect, but erroneous measurements may be made over long periods of time if the data is not reviewed frequently. Baschiere⁹ has stated, in a paper on cooling lake monitoring, "A monitoring system as large as the one at Dresden and continuously exposed to the environment requires daily observation, preventive maintenance, and calibration. For the data collected to be as accurate and inclusive as possible, rigorous maintenance procedures must be followed and records kept."

Preoperational data¹⁰ indicate that the temperature difference between intake and discharge recorded by continuous monitors can be up to about 4°F with the plant not operating. Pritchard¹¹ has observed outlet temperatures 1 to 2°F lower than inlet temperature at the Zion Nuclear Power Station on Lake Michigan with no heat being rejected.

Furthermore, at the Quad-Cities Station two intake monitors are provided, one near the surface at the entrance to the intake channel and one two feet above the bottom of the intake bay (location not specified).¹² Temperature differences as much as 16.7°C have been observed between these two sensors during periods of recirculating water flow for de-icing purposes. However, no mention is made of temperature differences at other times. Normal stratification could produce temperature gradients, but no record of this is contained in any of the annual reports. Since IIHR finds good agreement between their average ambient river temperature and the listed plant intake temperature (Tables 1 and 2), this indicates that possibly only the intake sensor near the surface at the entrance to the intake channel was used in the comparison. Thus, the actual water temperature entering the condensers could be somewhat different.

Similarly, the discharge temperature is measured in the discharge canal near the entrance to the diffuser pipes, and it is not evident that there is no temperature difference between the condenser outlet and the diffuser inlet, although it would be expected to be small.

Rather than deduce the value of the plant flow rate, this parameter should be measured. One method is the use of dye techniques, as was done at Zion.¹¹ Another method is the installation of a permanent flow-measuring device, such as a Venturi meter or a Parshall flume.¹³ This would remove some of the uncertainty in the value of Q_E used in all calculations.

Utility Monitoring Program

The four downstream temperature sensors are not able to detect most violations of the water quality standards if they were to occur. First, they are about 100 feet downstream from the end of the mixing zone. Second, the largest temperature rises above ambient observed by IIHR usually occurred near the surface in the shallow portion of the river and would not be recorded by the four sensors.

CRITIQUE, CONCLUSIONS AND RECOMMENDATIONS

IIHR Monitoring Program

Since the station is now operating on a closed-cycle spray canal cooling system, it is not known if and when the diffuser system might ever be used since it is merely a backup system at present. Therefore, the following recommendations made by IIHR are relevant only if the diffuser system is again used. In our evaluation, these recommendations are found to be adequate should the diffuser system be used again.

- (1) Surveys should be made for lower-than-normal river flows to verify the trend that the prototype data and model data tend to merge in one curve (Fig. 13).
- (2) The small ports (those that discharge into the shallow portion of the river) should be closed off. Maximum excess temperatures were often ascribed to these small ports, which account for only about ten percent of the total effluent discharge.

One can estimate the maximum temperature rise with the small ports closed by the equation⁶

$$(T - T_a)_{\max, \text{est.}} = 1.11 \frac{(T - T_a)_{\max, L}}{P/100} \quad (6)$$

where $(T - T_a)_{\max, L}$ = maximum observed temperature rise attributable to effluent discharge from a large port

P = percentage of full plant load

Figure 16 shows a plot similar to Figure 13 with the estimate given by Equation 6. The field data tend to approach more closely the model data when the effects of the small port are removed. This curve indicates that water quality standards will most likely be satisfied down to flows of about 15,000 cfs.

Also, from Figure 15, it is evident that water quality standards with respect to zone-of-passage will be satisfied down to flows of about 15,300 cfs.

The following monitoring program is proposed (by IIHR):⁷

- a. Provided ambient river temperature, as estimated by the continuously-monitored plant intake temperature (or upstream river monitor temperature), is 5°F or more below the limiting temperatures for the month listed in the water quality standards, temperature surveys at the 500-foot-downstream cross section should be required only when the river flow is less than the minimum value for which compliance, as shown in Figure 13 (or Fig. 16 if the small ports are closed) has been verified by temperature surveys in

Fig. 16. Estimated Maximum Excess Temperature at Full Plant Load when Effluent Is Discharged Only through Large Ports.

the field. In other words, evidence that the river flow exceeds this minimum value should be accepted as proof of compliance. At present this minimum river flow is about 30,000 cfs. As new verification data for lower river flows are obtained, the 30,000 cfs figure can be revised downward.

b. If ambient temperatures are within $5^{\circ}F$ of the limiting temperatures for each month, the curve A on Figure 13 (or the curve through the data in Fig. 14) should be used as a provisional monitoring curve. For example, suppose that the ambient temperature during September were to reach $82^{\circ}F$, which is just $3^{\circ}F$ below the maximum temperature of $85^{\circ}F$ allowed outside of the mixing zone for that month. If the river discharge were $Q_R = 35,000$ cfs, then curve A on Figure 13 would indicate compliance provided that the plant load is less than or equal to $P = 75$. That is,

$$\frac{(T - T_a)_{max}}{P/100} = 4^{\circ}F \quad (T - T_a)_{max} \leq 3^{\circ}F$$

for $P \leq 75$. For any larger value of P , compliance should have to be demonstrated by actual temperature measurements.

c. Temperature surveys showing the distribution of temperature rises at the 500-ft-downstream cross section, or river flow and plant load data indicating compliance as stipulated in items a and b above, should be accepted as evidence of compliance in lieu of actual determination of the 5°F temperature-rise isotherm.

Utility Monitoring Program

In addition to endorsing the above, we recommend that the present location of the four downstream temperature monitors be moved upstream 100 feet (500 feet downstream from the diffuser pipe). The exact position (distance from the Illinois shore) should be recorded. Correlations between this data and any future surveys should be noted.

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12. "Determination of Thermal Effects in this Mississippi River near Quad-Cities Station, August 1972 through January 1973," Semiannual Report to Commonwealth Edison Company by Industrial BIO-TEST Laboratories, Inc., March 15, 1973.
13. W. W. Sayre, private communication.

PART II. WATER QUALITY ASSESSMENT

PREDICTED CHEMICAL IMPACTS

Under the present operating system using closed-cycle cooling (i.e., spray channel), the intake and discharge of the Quad-Cities Station constitute only a very small fraction ($\sim 0.2\%$) of the average Mississippi River flow at Clinton. Consequently it would be exceedingly difficult to detect any plant-induced changes beyond the immediate discharge vicinity. This is particularly true in view of the normal water quality fluctuations of the river. Islands, sloughs, and the discharge of the Wapsipinicon River all contribute to water quality heterogeneities in the neighborhood of the Quad-Cities Station.

Closed-cycle cooling minimizes the total water discharge; however, evaporation of water increases the dissolved solids concentration to twice that of the ambient river. The only planned additions of chemicals are sodium hypochlorite as a biocide and wastes from demineralizer regeneration. The biocide added to prevent fouling is expected to be the principal chemical of concern.

Indirect chemical effects are possible as a result of large temperature increases in the cooling water; however, dissolved oxygen is the only obvious or likely substance to be affected. The solubility of oxygen decreases and the rates of oxygen consumption and production (photosynthesis) reactions increase as temperature increases. Again, however, the rapid dilution by the diffusers make it difficult to trace or model the effects at any distance from the discharge.

Once-through (open-cycle) cooling was used until May 1974. A combined cycle (53% spray channel cooling, 47% open cycle) was used until October 1975 and total closed cycle thereafter. While temperature effects were considerably different under the older system, major chemical considerations were nearly the same.

Table 9 shows the principal waste streams bearing chemicals from the station. The last two columns show the average concentration of chemicals when the cooling water system is operated in the closed-cycle mode (100 cfs) and in the open-cycle (once-through) mode (2270 cfs). Because of the intermittent addition of chemicals by batch treatments, the open-cycle (once-through) case has peak concentrations higher than average. Such peak concentrations do not occur when batch treatment discharges are made to the circulating water system in the closed-cycle mode. The discharge from the diffuser pipe and from the spray canal will result in further dilution after mixing and the increments shown in the last two columns will be undetectable beyond the discharge plume.

Not listed in the table is the effluent resulting from the addition of sodium hypochlorite to cooling-water streams to minimize fouling.

Sodium hypochlorite solution is injected into the cooling water flow just ahead of the condensers. The condenser of each turbine is divided in half so that each half can be chlorinated separately. There are two condensers (two generating units) for a total of four separately treatable units. Only one unit is treated at a time so that the chlorinated discharge is diluted by the

Table 9. Principal Chemical Additions to Liquid Discharges
(All Additions other than for Chlorination)

Chemical Effluent	Expected Average Daily Addition, lb	Expected Average Discharge Volume, gal	Average Flow Dura- tion	Average Discharge Frequency	Yearly Average Concentration in Discharge, mg/liter		Peak Con- centration in 2270 cfs outfall, mg/liter
					in 100-cfs outfall	in 2270-cfs outfall	
Well-water minerals and sodium sulfate from demineralizer regeneration.	390	5700 (batch)	2.5 hr	1 per day	0.72	0.03	~ 0.3
Dissolved and sus- pended solids in filter backwash from demineralizer.	34	6000 (batch)	30 min	3 per day	0.063	0.0027	~ 0.04
Sodium sulfite and phosphate in heating boiler blowdown.	2	560 (batch)	5.6 hr	1 per week	0.0037	1.8×10^{-4}	~ 0.005
Sodium sulfate in radwaste plant discharge.	1.8	20,000 (batch)	8.3 hr	50 per month	0.0033	1.6×10^{-4}	~ 3×10^{-4}
Dissolved solids in sewage treatment plant discharge.	49	Con- tinuous	Con- tinuous	10,000 gal/day	0.091	0.004	~ 0.008

discharge from the other three halves. Each unit is scheduled to be chlorinated three times per day in three 30-minute periods. A dosage necessary to give a 0.3 to 0.7 mg/l of free residual chlorine at the central water box was specified, the amount of sodium hypochlorite to be determined by automatic monitors in the central water box. With this system a maximum residual chlorine concentration of 0.25 mg/l at the discharge bay was predicted. The technical specifications required that residual chlorine be ≤ 0.1 mg/l at the discharge bay.

After plant operation began, a large number of violations of the 0.1-mg/l specification occurred, and in November 1973, the utility proposed modifications to the specifications, which were accepted by NRC in 1974. Under the changed specifications, chlorine dosages are determined by analyses of the chlorine demand of the river water. The allowable residual chlorine is to depend on the water discharge rate of the plant (number of circulating pumps operating) and can range from 1.5 mg/l at minimum flow to 0.5 mg/l at maximum flow. The analytical determinations of total residual chlorine are to be made on samples from the discharge bay. If the conditions are met, the impacts are considered to be negligible.

While no chemical effects were predicted, the station operators were required to monitor 30 water quality parameters at upstream and downstream points and at the intake and discharge locations. Other than an increase in concentration due to evaporation in closed-cycle cooling, no prediction was made for changes of any of the 30 water quality parameters. Although no dissolved oxygen changes were predicted, an extensive oxygen monitoring program was instituted.

OBSERVED IMPACTS

Chlorine

Total residual chlorine (from sodium hypochlorite treatment) was measured before, during, and after treatment until the level became undetectable. Measurements were usually made in the intake, discharge bay, and at a point 600 feet downstream from the diffuser. After the institution of closed-cycle cooling, measurements were also made in the spray canal. In addition, residual chlorine was measured at various stream points as part of the general water-quality surveillance program; however, chlorine was never detected in any of these measurements. In the 3-1/2 years of plant operation, residual chlorine was detected in the river on only one occasion. This occurred in July 1972 when an interim side jet discharge for cooling water was in operation. Residual chlorine has never been detected in river points since operation of the diffuser pipes.

Chlorine was often detectable in the discharge bay during and shortly after chlorination, the level roughly following the bell-shaped curve described by Draley.¹ The maximum levels range from < 0.01 mg/l to 2.10 mg/l and maximum values were reached 5 to 10 minutes after chlorination ceased. In general, levels dropped to the detection limit, 0.01 mg/l, within half an hour after chlorination ceased.

The results are summarized in Tables 10 and 11, which give frequencies of occurrence and percentages of the total times measured that the maximum residual

Table 10. Maximum Total Residual Chlorine in Discharge
(Automatic Dosage) up to January 1, 1974

Range of Values, mg/l	Frequency	% Frequency
≤ 0.01	24	48
0.01 - 0.1	6	12
0.11 - 0.2	7	14
0.21 - 0.3	3	6
0.31 - 0.4	5	1
0.41 - 0.6	3	6
0.61 - 0.8	1	2
0.81 - 1.2	<u>1</u>	2
	50	

Table 11. Maximum Total Residual Chlorine in Discharge
(Dosage According to Chlorine Demand)
after January 1, 1974

Range of Values, mg/l	Frequency	% Frequency
< 0.01	22	34
0.01 - 0.1	18	28
0.11 - 0.2	5	8
0.21 - 0.3	4	6
0.31 - 0.4	4	6
0.41 - 0.6	5	8
0.61 - 0.8	2	3
0.81 - 1.2	3	5
2.1	<u>1</u>	2
	64	

chlorine in any chlorinated period reached the given value. Table 10 is for the period before January 1, 1974, when the chlorine dosages were determined automatically, and Table 11 is for after January 1, 1974, when the dosages were determined by prior analyses of the chlorine demand. As can be seen, for most of the time for either system, the residual chlorine was well within the original limitation of 0.25 mg/l and was always within the limitation based on the number of pumps operating. High results occurred sporadically and could not be correlated with any available information on chlorine demand, dosage rate, or level of plant operation.

From April 1975 to January 1976 (the end of available data) no residual chlorine values greater than 0.2 mg/l occurred. No information was available as to whether these improved results were coincidence or due to experience and increased skill in operating the system. As mentioned earlier, residual chlorine has never been detected in the river since diffuser operation began in 1972.

General Chemicals

The largest addition of any foreign material to the Quad-Cities condenser discharge is the sodium hypochlorite added as a biocide. In 1974, 940 tons were added and the amount totaled 753 tons in 1975. The material is largely transformed to sodium chloride in the discharge and should be detectable either as chloride (which was not analyzed for in 1974 and 1975) or as an increment of the total dissolved solids (TDS). Based on the average discharge of the plant, the sodium chloride should add about 0.4 mg/l of TDS, which would be analytically undetectable. The chlorination is periodic, however, and for open-cycle cooling, the discharge of chloride would take place over three hours. This would give a 3-mg/l increment of TDS, which might be detectable if the sample for analysis were taken during the discharge period. Sodium chloride concentrations could be higher during closed-cycle operation. However, volumes would be much lower and discharge times longer.

The results of the TDS measurements are shown in Table 12 which gives the dates and results for upstream, downstream, intake and discharge points. Also given are averages and the standard deviation of the values for intake and discharge. The values given are averages of two analyses of each sample. A measure of the precision is the root mean square difference of the two analyses for each of the samples. It was computed to be 13 mg/l for TDS. The difference in averages between intake and discharge samples was 2 mg/l. A comparison with the measurement error (13 mg/l) and the variation in the environment (standard deviation of 50 mg/l) shows that the difference between intake and discharge measurements is not found.

Several other water quality parameters were examined. Since corrosion products may enter the water body, copper, iron and ammonia were chosen for evaluation. The results are shown in Tables 13, 14, and 15, respectively. Shown are dates and averages of duplicate analyses on samples for the upstream, downstream, intake and discharge points. Also given are overall averages for each location and the standard deviations for the intake and discharge and the root mean square deviations of the duplicate analyses for the intake.

For copper, the difference in averages between intake and discharges (0.0020) is both larger than the root mean square difference (0.0015) and the

Table 12. Total Dissolved Solids (mg/liter)

Date	Upstream	Downstream 600 Feet	Downstream 2 Miles	Intake	Discharge
August 1972	198	204	201	202	196
September 1972	192	217	199	189	199
October 1972	231	216	233	235	235
November 1972	182	196	184	175	173
December 1972	265	261	266	267	267
January 1973	207		205	188	187
February 1973	242		201	219	222
March 1973	166		159	168	166
April 1973	112		91	89	90
May 1973	95		103	99	104
June 1973	232		226	229	226
July 1973	251		182	243	247
August 1973	200		195	193	203
September 1973	<u>179</u>		<u>194</u>	<u>196</u>	<u>201</u>
Average	196		188	185	187
			50	50	50
			RMS	13	

standard deviation for the intake (0.0016). Consequently there is an approximately 70% chance of true increase in copper due to plant operation. Since the maximum concentration observed was 0.012 mg/l, while the EPA maximum limitation for copper is 1.0 mg/l, the observed change in copper concentration is well below the level of concern.

Iron shows only very slight differences between intake and discharge. The difference is both smaller than the measurement repeatability and the normal background fluctuation and can be considered negligible.

Ammonia is slightly lower in the discharge as expected, but the difference is very small (0.02 mg/l). However, of the fourteen intake-discharge pairs, in only one is the concentration in the discharge larger, in seven it is smaller and in six equal. Consequently, the difference is not random, although it is still of no significance.

An inspection of the other water chemistry characteristics showed that no alteration in the concentrations has occurred that can be assigned to the

Table 13. Copper (mg/liter)

Date	Sampling Location				
	U/S (5)	D/S 600 ft (8)	D/S 2 mi (13)	Intake (6)	Discharge (7)
Aug 1972	0.0043	0.0034	0.0041	0.0036	0.012
Sep	0.0076	0.0043	0.0037	0.0041	0.0051
Oct	0.0047	0.0034	0.0034	0.0040	0.0052
Nov	0.0046	0.0041	0.0037	0.0041	0.0059
Dec	0.0032	0.0020	0.0026	0.0017	0.0026
Jan 1973	0.0038		0.0037	0.0039	0.0074
Feb	0.0033		0.011	0.0034	0.0046
Mar	0.0039		0.0047	0.0054	0.011
Apr	0.0042		0.0038	0.0051	0.0062
May	0.0027		0.0040	0.0069	0.0048
Jun	0.0052		0.0028	0.0036	0.0053
Jul	0.0055		0.0037	0.0022	0.0042
Aug	0.0039		0.0032	0.0031	0.0028
Sep	0.0063		0.0038	0.0049	0.0067
Av.	0.0045		0.0041	0.0040	0.0060
			SD	0.0016	0.0027
			RMS	0.0015	

plant. Since there was no anticipated causal relationship to plant operations, a detailed analysis was not warranted.

Oxygen

Extensive measurements of dissolved oxygen levels were made as a part of the thermal modeling program. A summary of this data is contained in Table 16, which reports monthly average oxygen levels for the intake and discharge or upstream point and 600 feet and 2 miles downstream. The difference between intake and discharge averages (0.38 mg/l) is well within the fluctuations of different points on the river or time variations at one point, although one pair of the average intake-discharge values differed by 2 mg/l.

While average values indicated only a minor effect, a more detailed investigation was made to determine instantaneous effects, particularly under conditions of very low intake oxygen or very large intake-discharge temperature differences. Plots were made (points are day-average values for every fifth day) of the dissolved oxygen as a function of discharge temperature (Fig. 17) and of the change of dissolved oxygen as a function of intake-discharge temperature difference (Fig. 18). Examining the dissolved oxygen-temperature plot, it is seen that the values of dissolved oxygen cluster in a

Table 14. Total Iron (mg/liter)

Date	Sampling Location				
	U/S (5)	D/S 600 ft (8)	D/S 2 mi (13)	Intake (6)	Discharge (7)
Aug 1972	2.1	2.1	2.1	2.1	2.1
Sep	2.6	2.6	2.3	2.5	2.6
Oct	1.3	1.3	1.2	1.3	1.2
Nov	3.5	3.9	3.4	3.5	3.8
Dec	0.57	0.47	0.48	0.43	0.44
Jan 1973	2.9		2.8	2.9	3.0
Feb	0.66		0.67	0.67	0.67
Mar	2.1		2.2	2.2	2.2
Apr	1.6		1.4	1.3	1.4
May	2.5		2.6	2.6	2.6
Jun	2.4		2.6	2.6	2.6
Jul	1.1		0.79	0.89	0.79
Aug	1.3		1.1	1.3	1.3
Sep	<u>1.1</u>		<u>0.97</u>	<u>1.1</u>	<u>1.2</u>
Av.	1.84		1.75	1.8	1.85
			SD	0.9	1.0
			RMS	0.2	

Table 15. Ammonia, mg/liter - N

Date	Sampling Location				
	U/S (5)	D/S 600 ft (8)	D/S 2 mi (13)	Intake (6)	Discharge (7)
Aug 1972	0.17	0.10	0.10	0.15	0.14
Sep	0.08	0.05	0.04	0.06	0.06
Oct	0.05	0.04	0.03	0.05	0.05
Nov	0.12	0.10	0.09	0.11	0.11
Dec	0.06	0.06	0.06	0.06	0.07
Jan 1973	0.43	0.27	0.39	0.43	0.41
Feb	0.47	0.46	0.40	0.44	0.42
Mar	0.35	0.35	0.32	0.35	0.32
Apr	0.07	0.05	0.05	0.06	0.06
May	0.09	0.05	0.05	0.08	0.08
Jun	0.13	0.10	0.08	0.11	0.11
Jul	0.31	0.10	0.10	0.23	0.18
Aug	0.25		0.09	0.28	0.18
Sep	<u>0.22</u>		<u>0.08</u>	<u>0.20</u>	<u>0.15</u>
Av.	0.20	0.14	0.13	0.19	0.17
			SD	0.14	0.13
			RMS	0.03	

Table 16. Dissolved Oxygen (mg/liter)

Date	Sampling Location				
	U/S (5)	D/S 600 ft (8)	D/S 2 mi (13)	Intake (6)	Discharge (7)
Aug 1972	6.6	6.9	6.8	6.6	6.9
Sep	8.3	7.8	8.2	8.3	7.8
Oct	9.9	9.9	9.9	10.0	10.5
Nov	12.0	11.5	11.9	12.0	11.9
Dec	14.2	14.1	14.5	13.6	11.6
Jan 1973	12.3	12.2	12.2	11.2	9.6
Feb	12.3	12.1	12.2	12.8	11.7
Mar	12.3	12.3	11.9	11.1	10.9
Apr	11.2	12.0	11.2	11.1	10.9
May	9.7	8.9	9.9	9.8	9.7
Jun	7.1	6.5	7.0	6.8	6.9
Jul	6.3	6.6	6.6	6.4	6.5
Aug	7.3		6.7	6.8	6.4
Sep	7.2		7.4	7.2	7.4
Av.	9.76	10.0	9.74	9.55	9.17

broad band around the equilibrium curve with high values of supersaturation at low temperatures and some highly deficient values above 90°F. Examining the difference plot (Fig. 18) it is seen that for temperature changes less than 30°F the oxygen losses are generally less than 1 mg/l and oxygen is often gained rather than lost. Above 30°F, which occurs only with closed-cycle cooling, there appears to be a sharp increase in oxygen loss with increase in temperatures, with a maximum loss reported of 7.6 mg/l at $\Delta T = 55^\circ\text{F}$. In all cases, however, where there was a large (> 4 mg/l) loss of oxygen, the initial values of dissolved oxygen were large (i.e. > 12 mg/l) so that the final river water was not highly deficient in oxygen.

The effects of plant operation on dissolved oxygen during periods of very low ambient oxygen levels were particularly examined. Of 744 hourly measurements when either the intake dissolved oxygen was below 5.8 mg/l or the discharge below 6 mg/l, 567 (76%) measurements showed the discharge higher in oxygen than the intake, 74 (10%) were equal, and in 71 (9.5%) the decrease was 0.3 mg/l or less. Of the 32 decreases larger than 0.3 mg/l, 27 appeared questionable because of anomalous jumps in the recorded oxygen values. In any case the larger decreases were again associated with larger initial values of oxygen and were not associated with the lowest discharge values. Initial values of oxygen below 5 mg/l were generally associated with substantial increases and a maximum decrease of 0.2 mg/l.

The larger decreases in oxygen were associated with the higher temperatures of closed-cycle cooling. Since closed- or partially closed-cycle cooling

Fig. 17. Dissolved Oxygen as Function of Discharge Temperatures.

Fig. 13. Dissolved Oxygen Change as Function of Discharge Temperature Change.

is also associated with lower discharge volumes, the effects are rapidly diluted out in the stream and would be undetectable at short distances beyond the diffuser.

ADEQUACIES AND DEFICIENCIES OF THE MONITORING PROGRAM

The potentially significant chemical impact is that of the chlorine biocide. The monitoring program appears adequate and should be continued. The low residual chlorine levels observed in the last measurement periods may represent improved skill and knowledge, both in control and analysis, obtained by plant operators.

The general chemical monitoring program has been dropped in recent semi-annual reports. With regard to station influences on Mississippi River chemistry, the earlier reports have indicated little if any influence. On the basis of the amounts of chemicals added and the normal fluctuations of river chemistry, it is very unlikely that any changes could have been detected at downstream points. A general background knowledge of river chemistry would be of interest but could probably be obtained from other and public sources.

As a precautionary measure and for reference purposes, intake and discharge monitoring should be continued on a selective basis. This should be done as a comparison of intake and discharge characteristics measured at times reflecting the average travel time of the water through the plant. Probably pH and conductivity, which would reflect abnormal chemical conditions, should be monitored on a continuous basis with potential corrosion products such as iron and copper on a periodic and probably monthly basis. During closed-cycle operation, particularly during periods of high plant loads and high river and air temperatures, parameters such as total dissolved solids and total suspended solids should be determined. Discharge water chemistry during these stress periods could differ significantly from ambient and it should be known to what degree.

Dissolved oxygen levels have varied little with plant operations and temperature increases across the intake and discharge should be a sufficient indicator of a potential effect.

Reference for Part II

1. J. E. Draley, "Chlorination Experiments of the John E. Amos Plant of the Appalachian Power Co.," Report ANL/ES-23, Argonne National Laboratory, Argonne, Ill., June 1973.

APPENDIX

WATER QUALITY STANDARDS

Since the Mississippi River at the Quad-Cities site forms the border between Illinois and Iowa, the water quality standards of each state must be satisfied by the station discharge. Only thermal standards are included below.

A. Illinois Water Pollution Control Rules¹

PART II: WATER QUALITY STANDARDS

This part of the rules and regulations concerning water pollution describes the water quality standards that must be met to maintain the specified beneficial uses. References to STORET numbers identify the specific parameter as defined in the STORET system handbook published by the Federal Environmental Protection Agency.

201 *Mixing Zones*

(a) In the application of any of the rules and regulations in this Chapter whenever a water quality standard is more restrictive than its corresponding effluent standard then an opportunity shall be allowed for the mixture of an effluent with its receiving waters. Water quality standards must be met at every point outside of the mixing zone. The size of the mixing zone cannot be uniformly prescribed. The governing principle is that the proportion of any body of water or segment thereof within mixing zones must be quite small if the water quality standards are to have any meaning. This principle shall be on a case-by-case basis to ensure that neither any individual source nor the aggregate of sources shall cause excessive zones to exceed the standards. The water quality standards must be met in the bulk of the body of water, and no body of water may be used totally as a mixing zone for a single outfall or combination of outfalls. Moreover, except as otherwise provided in this Chapter, no single mixing zone shall exceed the area of a circle with a radius of 600 feet. Single sources of effluents which have more than one outfall shall be limited to a total mixing area no larger than that allowable if a single outfall were used.

In determining the size of the mixing zone for any discharge, the following must be considered:

1. The character of the body of water,
2. the present and anticipated future use of body of water,
3. the present and anticipated water quality of the body of water,

4. the effect of the discharge on the present and anticipated future water quality,
5. the dilution ratio, and
6. the nature of the contaminant.

(b) In addition to the above, the mixing zone shall be so designed as to assure a reasonable zone of passage for aquatic life in which the water quality standards are met. The mixing zone shall not intersect any area of any such waters in such a manner that the maintenance of aquatic life in the body of water as a whole would be adversely affected, nor shall any mixing zone contain more than 25% of the cross-sectional area or volume of flow of a stream except for those streams where the dilution ratio is less than 3:1.

202 *Stream Flows*

Except as otherwise provided in this Chapter with respect to temperature, the water quality standards in this Part shall apply at all times except during periods when flows are less than the average minimum seven day low flow which occurs once in ten years.

203 *General Standards*

The General Standards listed below will protect the State's water for aquatic life, agricultural use, primary and secondary contact use, and most industrial uses, and ensure the aesthetic quality of the State's aquatic environment. Except as otherwise provided in this Chapter, all waters of the State shall meet the following standards:

- (1) There shall be no abnormal temperature changes that may adversely affect aquatic life unless caused by natural conditions.
- (2) The normal daily and seasonal temperature fluctuations that existed before the addition of heat due to other than natural causes shall be maintained.
- (3) The maximum temperature rise above natural temperatures shall not exceed 5 degrees F.
- (4) In addition, the water temperature at representative locations in the main river shall not exceed the maximum limits in the following table during more than one percent of the hours* in the 12-month period ending with any month. Moreover, at no time shall the water temperature at such locations exceed the maximum limits in the following table by more than 3 degrees F.*

Main river temperatures are temperatures of those portions of the river essentially similar to and following the same thermal regime as the temperature of the main flow of the river.

*With respect to the lower Des Plaines River from the I-55 Bridge to its confluence with the Kankakee River four percent of the hours by more than 5 degrees F.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mississippi River (Wisc. Border to Iowa Border) (°F).....	45°	45°	57°	68°	78°	85°	86°	86°	85°	75°	65°	52°
Mississippi River (Iowa Border to Alton Lock and Dam) (°F).....	45°	45°	57°	68°	78°	86°	88°	88°	86°	75°	65°	52°
Mississippi River (South of Alton Lock and Dam) (°F).....	50°	50°	60°	70°	80°	87°	89°	89°	87°	78°	70°	57°

(5) The owner or operator of a source of heated effluent which discharges 0.5 billion British thermal units per hour or more shall demonstrate in a hearing before this Board not less than 5 nor more than 6 years after the effective date of these regulations or, in the case of new sources, after the commencement of operation, that discharges from that source have not caused and cannot be reasonably expected to cause significant ecological damage to the receiving waters. If such proof is not made to the satisfaction of the Board appropriate corrective measures shall be ordered to be taken within a reasonable time as determined by the Board.

(6) Permits for heated effluent discharges, whether issued by the Board or the Environmental Protection Agency, shall be subject to revision in the event that reasonable future development creates a need for reallocation of the assimilative capacity of the receiving stream as defined in the regulation above.

(7) The owner or operator of a source of heated effluent shall maintain such records and conduct such studies of the effluents from such source and of their effects as may be required by the Environmental Protection Agency or in any permit granted under the Environmental Protection Act.

(8) Appropriate corrective measures will be required if, upon complaint filed in accordance with Board rules, it is found at any time that any heated effluent causes significant ecological damage to the receiving stream.

B. Iowa Water Quality Standards²

16.2(4) *Mixing Zone in the Receiving Water*

The area of diffusion of an effluent in the receiving water is a mixing zone and the Water Quality Standards shall be applied beyond the mixing zone.

The mixing zone shall be a specified linear distance, volume, or area which is determined on a case-by-case basis using the following criteria:

(a) The mixing zone shall be as small as practicable and shall not be of such size or shape as to cause or contribute to the impairment of water uses.

(b) The mixing zone shall contain not more than twenty-five (25) percent of the cross-sectional area or volume of flow in the receiving body of water.

(c) The mixing zone shall be designed to allow an adequate passageway at all times for the movement or drift of aquatic life.

(d) Where there are two or more mixing zones in close proximity, they shall be so defined that a continuous passageway for aquatic life is available.

(e) The mixing zone shall not intersect any area of any waters in such a manner that the maintenance of aquatic life in the body of water as a whole would be adversely affected.

16.3(455B) *Surface Water Quality Criteria.*

16.3(1) *General Water Quality Criteria.*

The following criteria are applicable to all surface waters including those which have been designated as Class A, B, or C Waters, at all places and at all times.

(f) Temperature

(1) No heat shall be added to interior streams that would cause an increase of more than 5 degrees Fahrenheit. The rate of temperature change shall not exceed 2 degrees Fahrenheit per hour. In no case shall heat be added in excess of that amount that would raise the stream temperature above 90 degrees Fahrenheit.

(2) No heat shall be added to streams designated as cold water fisheries that would cause an increase of more than 3 degrees Fahrenheit. The rate of temperature change shall not exceed 2 degrees Fahrenheit per hour. In no case shall heat be added in excess of that amount that would raise the stream temperature above 68 degrees Fahrenheit.

(3) No heat shall be added to lakes and reservoirs that would cause an increase of more than 3 degrees Fahrenheit. The rate of temperature change shall not exceed 2 degrees Fahrenheit per hour. In no case shall heat be added in excess of that amount that would raise the temperature of the lake or reservoirs above 90 degrees Fahrenheit.

(4) No heat shall be added to the Missouri River that would cause an increase of more than 5 degrees Fahrenheit per hour. In no case shall heat be added that would raise the stream temperature above 90 degrees Fahrenheit.

(5) No heat shall be added to the Mississippi River that would cause an increase of more than 5 degrees Fahrenheit. The rate of temperature change shall not exceed 2 degrees Fahrenheit per hour. In addition, the water temperature at representative locations in the Mississippi River shall not exceed the maximum limits in the below table during more than one percent of the hours in the 12 month period ending with any month. Moreover, at no time shall the water temperature at such locations exceed the maximum limits in the below table by more than 3 degrees Fahrenheit.

Zone II -- Iowa-Minnesota State line to the Northern Illinois border
(Mile Point 1534.6)

Zone III -- Northern Illinois border (Mile Point 1534.6) to Iowa-Missouri State line.

<u>Month</u>	<u>Zone II</u>	<u>Zone III</u>
January	40°F	45°F
February	40°F	45°F
March	54°F	57°F
April	65°F	68°F
May	75°F	78°F
June	84°F	85°F
July	84°F	86°F
August	84°F	86°F
September	82°F	85°F
October	73°F	75°F
November	58°F	65°F
December	48°F	52°F

16.3(4) *Class C Waters*

Waters which are designated as Class C Waters are to be protected as a raw water.

References for the Appendix

1. Illinois Water Pollution Control Rules (Illinois Pollution Control Board Rules and Regulations, Chapter 3, Water Pollution; Adopted March 7, 1972; Amended June 28, 1973; July 19, 1973; January 31, 1974; March 6, 1975, Effective March 20, 1975; August 14, 1975).
2. Iowa Water Quality Standards (Iowa Department Rules, Environmental Quality--Water, Title II, Water Quality, Chapter 16, Surface Water Quality Standards, Adopted February 12, 1974).