University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 191

MISSISSIPPI RIVER ICE COVER BETWEEN DAM NO. 3 AND LAKE PEPIN

by

H. Stefan

Prepared for

NORTHERN STATES POWER COMPANY
Minneapolis, Minnesota

June, 1980

ABSTRACT

The suppression of ice covers on the Mississippi River between Lock and Dam No. 3 (near Red Wing, Minnesota) and Lake Pepin by the cooling water effluent from the Prairie Island Nuclear Power Generating Plant was investigated. The winter river temperature regime below Dam No. 3 was analyzed by equilibrium temperature and non-equilibrium temperature methods with very similar results. The length of the open water reach below Dam No. 3 was predicted. The total river reach from Dam No. 3 to Lake Pepin is 11 miles long.

River ice covers during past winters (1972/73 through 1979/80) were documented by interpretation of LANDSAT imagery and by two aerial surveys.

Predictions were made for the hypothetical case that the Prairie Island Plant would operated in a once-through cooling mode resulting in a maximum heat rejection of $8.34*10^9$ BTU's per hour.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND NOTATIONS

A = river cross-section (ft^2)

A_s = open water surface area (ft^2)

B = river surface width (ft)

E = equilibrium temperature (^oF)

h = river depth (ft)

H_p = heat rejection rate by power plant (BTU hr^{-1})

K = bulk coefficient of surface heat transfer (BTU ft^{-2} $^oF^{-1}$ day^{-1})

Q = river flow rate (cfs)

Q_M = river flow in mainstem (cfs)

Q_W = river flow in Wisconsin channel (cfs)

T = water temperature (well-mixed in cross-section) (^oF)

T_i = water temperature at branch point (River Mile 793.5)

T_o = water temperature at $x = 0$ (Dam No. 3)(^oF)

T_F = water temperature at freezing (^oC)

T_M = water temperature at end of mainstem (River Mile 785.5) (^oC)

T_W = water temperature at end of Wisconsin channel (^oC)

T_R = river temperature above plant intake (^oF)

V = average flow velocity (ft/sec)

x = distance along the river in flow direction (ft)

X_M = length of open water reach along mainstem of river

X_W = length of open water reach along Wisconsin channel

α = time constant (hrs^{-1})

ρc = specific heat of water per unit volume (BTU ft^{-3} $^oF^{-1}$)

ACKNOWLEDGEMENTS

This study was conducted under contract between the St. Anthony Falls Hydraulic Laboratory, University of Minnesota,and Northern States Power Company.

Mike Riley assisted in the LANDSAT image interpretation and Alexander Demetracopoulos assisted in the computations and table preparations.

Editorial assistance and typing for this manuscript were provided by Pat Swanson.

MISSISSIPPI RIVER WINTER TEMPERATURE REGIME AND ICE COVER BELOW DAM NO. 3

I. INTRODUCTION AND OBJECTIVE

The Mississippi River below Lock and Dam No. 3 near Red Wing, Minnesota, is a popular fishing area. Open water very early in the spring attracts fishermen from both Minnesota and Wisconsin.

The Prairie Island Nuclear Power Generating Plant, owned and operated by Northern States Power Company, is located on the Mississippi River just upstream from Dam No. 3. The plant withdraws cooling water from the Mississippi River. The plant is also equipped with four large cooling towers and can alternatively be operated in a closed cycle mode or in a once-through mode.

A study was made with the following objectives:

(a) To provide an evaluation of the extent in the past of ice covers between Dam No. 3 and Lake Pepin.

(b) To determine how the ice-coverage would change for full heat discharge from the plant (approximately $8.34 * 10^9$ BTU per hour).

The historic evaluation was based on LANDSAT images. Predictions were made by a one-dimensional steady-state water temperature analysis.

II. RECORD OF ICE COVERAGE

The most coherent documentation of the ice cover conditions was found in LANDSAT satellite images obtained by NASA, and made available through the U. S. Geological Survey, EROS Data Center. Black and white film positive reproductions of the Band 6 images were used to identify ice coverage. Open water is clearly visible in Band 6. The information was transferred to maps and compiled for the winter months (November through March) beginning in 1972. Examples are given in Figs. 1 and 2. A total of 25 maps from November 29, 1972, through March 28, 1976, have been prepared.

The ice coverage varied considerably from one picture to the next and sometimes from one day to another. The navigable river mainstem and its major side-arm, the Wisconsin channel, usually froze over last and opened first. The mean depth of the mainstem was determined at 10.7 ft and that of the Wisconsin channel was determined at 5.8 ft. The two channels carried virtually all of the river flow. A hydraulic analysis using the geometrical and roughness characteristics of the two channels showed that after the branching point and under winter flow (7,400 cfs to 14,300 cfs) the mainstem carried approximately 70 per cent of the total flow and the Wisconsin channel the remaining 30 per cent.

The shallow backwaters (lakes) were usually ice covered 2 to 6 weeks before the river mainstem and the Wisconsin channel. Table 1 gives dates of open water conditions separately for the mainstem, the backwater lakes, and Lake Pepin.

The lengths of the open water reach and the total open water surface area in the two main channels were measured and tabulated. They were highly variable in time. Monthly mean values are given in Table 2.

The formation of an ice cover downstream from Dam No. 3 is a function of the river temperature regime at Dam No. 3, the river flow downstream from Dam No. 3, and the daily weather regime. The release water temperature at Dam No. 3 is influenced by heat rejection from the Prairie Island Plant and the residual of other natural and unnatural heat inputs. A quantitative relationship will be developed in the next section.

The spatial resolution of the LANDSAT image interpretation is on the order of 200 ft. More detailed information can be obtained from aerial photography. A check with three different suppliers of such information

TABLE 1

Ice Cover on Mississippi River Between Lock & Dam No. 3
and Lake Pepin as Visible on LANDSAT Images, Band 6

Main Channel

Winter	Clear of Ice Up To	Clear of Ice After
1972-73	November 29	February 26
1973-74	December 12	February 22
1974-75	December 7	March 15
1975-76	December 1	March 10
1976-77	November 17	February 15
1977-78	November 12	March 26
1978-79	December 21	March 12

Lakes

Winter	All Lakes Clear of Ice Up To	All Lakes Completely Ice Covered After	All Lakes Ice Covered Up To	All Lakes Clear of Ice After
1972-73	--	December 16	February 26	March 17
1973-74	November 6	December 29	February 22	March 12
1974-75	December 7	January 30	February 8	--
1975-76	November 22	January 7	February 2	March 28
1976-77	--	December 23	February 15	April 9
1977-78	November 12	January 4	February 28	April 22
1978-79	November 16	December 21	March 12	--

Lake Pepin

Winter	Lake Clear Up To	Lake Clear After
1972-73	November 29	March 17
1973-74	December 12	March 12
1974-75	December 7	April 11
1975-76	November 23	March 28
1976-77	November 17	April 9
1977-78	November 12	April 22
1978-79	November 16	--

TABLE 2

Mean Lengths and Surface Areas of
Open Water Below Dam No. 3*
as Visible on LANDSAT Images, Band 6

Month	Mainstem Mean * Length (mi)	Mainstem Mean ** Surface Area (%)	Wisc. Channel Mean ** Length (mi)	Wisc. Channel Mean ** Surface Area (%)	No. of Images
November	11.5	100	6.5	100	17
December	6.2	54	1.6	25	8
January	1.6	14	0	0	13
February	7.1	61	0.5	8	9
March	11.5	100	5.9	95	11
April	11.5	100	6.5	100	10

*Includes all open water in navigation channel even if interrupted by ice.

**Winters of 1972/73 through 1978/79. Heat rejection from plant began in 1974.

revealed that the coverage of the area of interest did not include any winter photographs. The companies contacted were:

(a) Chicago Aerial Surveys, 2140 Wolf Road, Des Plaines, Ill. 60018. Tel. (312) 298-1480.

(b) Mark Hurd, Aerial Surveys, Inc., 345 Pennsylvania Ave., South, Minneapolis, Minn. Tel.(612) 545-2583.

(c) U. S. Geological Survey, EROS Data Center, Sioux Falls, S. D. Tel. (605) 594-6511.

Information was received indicating that the U. S. Army Corps of Engineers may have obtained aerial surveys of ice flows. The information could not be located.

Aerial photographs made on March 1, 1975, by the author are shown in Figs. 3 through 7. Figure 3 shows Pool No. 3 upstream from Dam No. 3 in the vicinity of the Prairie Island Power Plant. The mainstem of the river is mostly open with a thin ice cover. Figure 4 shows the cooling water discharge from the plant. The cooling towers are also in operation. Figure 5 is a view towards the northwest showing the river reach immediately below Dam No. 3. Note that the river mainstem is open water while the backwaters are ice covered.

Figure 6 is a view of the Mississippi Delta towards Lake Pepin. The Wisconsin channel and the mainstem can be clearly seen. However, because of sunlight reflections, ice covers and open water cannot be clearly distinguished. Figure 7 shows the Mississippi River plume in Lake Pepin as delineated by the ice contour.

A second set of aerial photographs was made on February 2, 1980. (See Appendix G.)

III. ANALYSIS OF WATER TEMPERATURE AND ICE COVERAGE FOR FULL HEAT REJECTION FROM THE PRAIRIE ISLAND PLANT

A steady-state analysis using average and extreme values for river flow and weather parameters was made to determine the length of the open water reach in each month.

Steady-state Water Temperature Analysis by the Equilibrium Temperature Method

In this analysis the one-dimensional river temperature equation for an artificially heated stream

$$\frac{T - E}{T_o - E} = e^{-\alpha t} \tag{1}$$

is solved, where

$$\alpha = \frac{K}{\rho c h} \tag{2}$$

$$t = x/V \tag{3}$$

$$V = Q/A = Q/Bh \tag{4}$$

$$A_s = xB \tag{5}$$

(The List of Symbols and Notations appears on page vii of this report.) Combining Eqs. (1) through (5) gives

$$\frac{T - E}{T_o - E} = \exp\left(-\frac{KA_s}{\rho c Q}\right) \tag{6}$$

Application of Eq. (6) begins at Dam No. 3 where the water temperature is T_o and requires values for the river flow rate Q, the river surface area A_s, the upstream river water temperature T_o, the equilibrium temperature E, and the bulk surface heat exchange coefficient K. The temperature T_o is found from the natural river temperature T_R augmented by the plant ΔT_p.

$$T_o = T_R + \Delta T_p, \tag{7}$$

$$\Delta T_p = \frac{H_p}{\rho c Q} \tag{8}$$

The equilibrium temperature E and the bulk coefficient of surface heat transfer K are calculated from semi-empirical equations given in Appendix A. Two alternative sets of equations to compute K and E were used with very similar results.

The river configuration below Dam No. 3 to which Eq. 6 must be applied is schematically shown in Fig. 8; for the upstream reach, Eq. 6 is applied as given. For the two downstream reaches T_o is replaced by T_i; Q and A_s are the values specified for the mainstem (subscript M) or the Wisconsin channel (W). For the downstream reaches the x-coordinate is measured from the branching point.

The division of the total river flow Q_T between the mainstem flow Q_M and the Wisconsin channel flow Q_W was determined separately by a hydraulic analysis described in Appendix B. It was found that during typical winter flow rates (Q = 7,000 to 9,000 cfs) the division is roughly in proportions of $Q_T:Q_M:Q_W$ = 1:0.7:0.3. More detailed information on the variation of river stage with flow and of Q_W/Q_T with flow is given in Fig. 9.

A summary of the river flow is given in Table 3. The main parameters of the river geometry are shown in Table 4. A short computer program listed in Appendix C was written to solve Eq. 6 for x such that $T=0^oC$. It is thus assumed that the leading edge of the ice is found where the river water temperature reaches the freezing temperature. The program also incorporates the relationships for K and E in Appendix A. It also applies the two-step procedure of solving Eq. 6 successively for the upstream reach and the main channel and the Wisconsin channel, successively. The flow division is computed according to Fig. 9.

Verification of Analysis

To verify the method of analysis, predictions of open water lengths for all observed (LANDSAT images) dates were made. To do this, weather conditions between Dam No. 3 and Lake Pepin were approximated by weather data recorded at the Minneapolis/St. Paul Internationl Airport, the closest weather station with a continuous and reliable record.

LANDSAT images are taken at approximately 10:30 a.m. on the day of record. The conditions seen by the satellite are those produced by the

TABLE 3

Daily Mississippi River Flow at Prescott, Wisconsin

November 1966 to March 1978

Month	Minimum Flow	Average Lowest Flow**	Median Flow	Maximum Flow*
	(cfs)	(cfs)	(cfs)	(cfs)
November	3,010 (1976)	11,600	14,300	58,800 (1968)
December	3,050 (1976)	7,480	10,600	30,300 (1971)
January	3,110 (1977)	7,457	8,850	15,300 (1978)
February	3,560 (1977)	7,562	8,600	14,000 (1969)
March	4,120 (1977)	8,275	13,000	78,000 (1973)

* of record.

** lowest flow in month (averaged annually).

TABLE 4

Summary of River Geometry

	Length	Ave. Width	Total Surface Area	Average Depth at 10,000 cfs
	(mi)	(ft)	(mi^2)	(ft)
Upstream Mainstem (River mile 793.5-797.0)	3	800	0.461	11.7
Downstream Mainstem (River mile 785.5-793.5)	8	730	1.106	11.7
Wisconsin (North) Channel	6.8	620	.798	6.8

weather and flow preceding the time of observation. Because weather parameters are continuously changing, the question arises as to how far back from the time of observation the weather will be of influence for a quasi-steady state analysis. Ice covers on rivers are known to change rapidly with weather. It was therefore decided to use the average weather over an 18-hour period preceding the observation. Three-hour data for air temperature, dew point, and wind velocity were averaged. Solar radiation could be neglected because the 18-hour time period covered one night (4:30 p.m. to 10:30 a.m.) and there was very little radiation on the following morning. River flow at Dam No. 3 and water temperature were extracted from U.S. Geological Survey records (Climatological Data for Minnesota).

Observed and predicted open water lengths are given in Appendix D, Table D-1. The agreement in most cases is very good, but there are some instances where the differences between predictions and observations are quite large.

Three possible main causes of differences were recognized:

(a) satellite image misinterpretation,

(b) application of steady-state analysis to highly transient conditions, and

(c) inaccurate information on upstream water temperatures at Dam No. 3.

These points are further discussed in Appendix E.

Prediction of Future Open Water Lengths

A future plant heat rejection rate of $8.34*10^9$ BTU per hour is used in Eq. 8.

Numerical computations were carried out for the flow conditions given in Table 3. The minimum flow is the lowest daily value observed in a given month from 1966 through 1978. To obtain the average minimum flow the lowest value in every year was averaged over 12 years of record.

The weather parameters applied were daily values averaged over a month or extreme values for any given day combined in such a way that they would give a low K and a high E or vice versa. Tables 5 and 6 summarize the data. Computed E and K values with an assumed water temperature of $32^{o}F$ are given in Appendix A, Table A-1.

The river geometry used for the analysis is given in Table 4. The total river reach investigated is 11 miles long. The upstream river water temperature measured at Dam No. 3 is summarized in Table 7.

TABLE 7

Summary of River Water Temperature T_o at Dam No. 3 (^{o}C) *)

	Nov	Dec	Jan	Feb	Mar
Mean (1969/70 to 1973/74)	4.7	0.6	0.3	0.55	2.1
High (1969/70 to 1973/74)	9.2	1.8	0.7	1.2	4.4
Low (1969/70 to 1973/74)	1.3	0.1	0.0	0.0	0.7
Mean (1974/75 to 1977/78)	6.3	1.5	1.1	1.7	3.1
High (1974/75 to 1977/78	12.1	2.0	2.1	3.1	6.5
Low (1974/75 to 1977/78)	1.7	0.8	0.6	1.0	1.3

*)SOURCE: U.S. Geological Survey, "Water Resources Data for Minnesota," Water Years 1969-1978.

The subdivision of Table 7 into 2 periods is made because heat rejection from the Prairie Island Plant began in 1974.

TABLE 5

Daily Weather Input Data for

Mean Rates of Surface Heat Loss

Minneapolis/St. Paul

	Nov	Dec	Jan	Feb	Mar
AIR TEMP[1] (^{o}F)	31.2	18.1	12.4	15.7	27.4
WIND VELOCITY[1] (mph)	11.1	10.4	10.5	10.7	11.3
DEWPOINT[2] (^{o}F)	24.1	9.4	2.3	9.7	20.3
SOLAR RAD.[3] (cal $cm^{-2}day^{-1}$)	135	113	155	243	318
MINIMUM SUNSHINE RAD.[3] (cal $cm^{-2}day^{-1}$)	1.0	13.0	10.0	7.0	22.0

SOURCES:

1) NOAA, Environmental Data Service, "Climate of Minnesota," June 1972.
2) NOAA, Environmental Data Service, "Local Climatological Data Sheets," Minneapolis/St. Paul, 1968-1978.
3) D. G. Baker and J. W. Enz, "Climate of Minnesota, Part XI - The Availability and Dependability of Solar Radiation at St. Paul, Minnesota," Technical Bulletin 315, Agricultural Experiment Station, University of Minnesota, 1979.

TABLE 6

Daily Weather Input Data for
High Rates of Surface Heat Loss

	Nov	Dec	Jan	Feb	Mar
LOW AIR TEMP.[1] (^{o}F)	13.6	-5.6	-13.9	-5.7	13.3
HIGH WIND[3] (mph)	18.3	16.7	18.3	18.9	17.9
LOW DEWPOINT[1] (^{o}F)	3.2	-16.4	-25.2	-18.6	-1.3
LOW SOLAR RAD.[5] (cal $cm^{-2}day^{-1}$)	1.0	13.0	10.0	7.0	22.0

Daily Weather Input Data for
Low Rates of Surface Heat Loss (or Gains)

	Nov	Dec	Jan	Feb	Mar
HIGH AIR TEMP.[2] (^{o}F)	51.7	36.0	31.4	34.6	49.3
LOW WIND[4] (mph)	4.6	3.9	4.6	4.0	4.6
HIGH DEWPOINT[2] (^{o}F)	42.9	31.5	27.7	28.9	38.9
HIGH SOLAR RAD.[6] (cal $cm^{-2}day^{-1}$)	281.0	273.0	312.0	417.0	598.0

---

1) Lowest daily temperature in a month averaged from 1968 to 1978.
2) Highest daily temperature in a month averaged from 1968 to 1978.
3) Highest average daily wind in a month averaged from 1968 to 1978.
4) Lowest average daily wind in a month averaged from 1968 to 1978.
5) Minimum daily solar radiation from 1963 to 1977.
6) Maximum daily solar radiation from 1963 to 1977.

Equation 6 was applied with the data from Tables 3, 4, 5, 6, 7, and 8 in the following combinations:

TABLE 8. Flow and Weather Conditions

Median Daily Flow	Mean K, mean E, mean T_R	Case 1
	High K, low E, low T_R	Case 2
	Low K, high E, high T_R	Case 3
Annual Minimum Flow	Mean K, mean E, mean T_R	Case 4
	High K, low E, low T_R	Case 5
	Low K, high E, high T_R	Case 6

Input parameters and results of the six case studies are shown in Table 9. The river water temperatures predicted by the quasi-steady state analysis at the end of the mainstem T_M and at the end of the Wisconsin channel T_W before entering Lake Pepin are given. T_M and T_W are found by a two-step procedure by solving Eq. 6 first for $T=T_i$ and then by using $T_o=T_i$ for the lower segments (Fig. 8). The upstream river temperature T_R before addition of the Prairie Island heat load and after addition $T_o = T_R + \Delta T$ are shown among the input parameters.

Two heat rejection ratios, PHRR and THRR, are also given. The plant heat rejection ratio PHRR is defined as the ratio of the heat dissipated to the atmosphere between Dam No. 3 and Lake Pepin and the heat rejection rate H_p from the plant.

$$PHRR = \frac{(T_o - T_W)Q_W + (T_o - T_M)Q_M}{H_p/\rho c} \qquad (9)$$

for $T_W \geq 0$, $T_M \geq 0$.

The total heat rejection ratio THRR takes into consideration that even without the heat input from the plant the water temperature at Dam No. 3 may be above freezing and the river may be in a natural cooling regime unrelated to the Prairie Island Plant.

$$THRR = \frac{(T_o - T_W)Q_W + (T_o - T_M)Q_M}{(T_o - T_F)Q_T} \qquad (10)$$

for $T_W \geq 0$, $T_M \geq 0$.

If either of the predicted water temperatures T_M or T_W becomes less than $T_F = 0^oC$, the lower portion of the channel to which it pertains is ice-covered. The open water reach is then calculated from Eq. 6 by substituting $T = T_F = 0^oC$, $T_o = T_i$ and solving for A_s . The results are reported as open water reaches X_M and X_W , where X is defined by Eq. 5 and calculated separately for each channel segment separately.

To assist in the interpretation of the results, the predicted open water reaches have been plotted in Figs. 10 through 14. The results of the analysis show that under mean monthly weather and flow conditions the river mainstem will remain completely open and the Wisconsin channel will remain open over a length of 6 miles. Some of the backwater lakes will also remain open. Under extreme cold conditions which would occur on about one day in every month, the lower portions of the main channel and the Wisconsin channel will freeze over. On the mean coldest day of January, 4.1 miles of open water below the dam would be found. Open water reaches for other months are given at the bottom of Table 9, Case 2. Predictions in Table 9 include the effects of a waste heat rejection of $8.34*10^9$ BTU/hr. For comparison,predictions without any waste heat load are shown in Appendix I.

If the flow is at the annual minimum rather than the median value, the open water lengths will not change much. The reason, of course, is that the river flows in the winter do not vary a great deal (Table 3).

The above analysis adds the plant heat rejection to the river flow at Dam No. 3 and ignores Pool 3. An analysis of the thermal plume downstream from the planned new cooling water outfall was made by Northern States Power Company. It was reported (personal communication) that the total heat dissipation from the surface of Pool No. 3 to the atmosphere resulted in a river water temperature change downstream from Dam No. 3 of no more than 0.05^oF. It was assumed in NSP's computations that the thermal plume in Pool No. 3 would become fully mixed with the river through Dam No. 3. A temperature of 0.05^oF is less than the accuracy with which existing river water temperatures have ever been reported, and the cooling effect of the pool was therefore ignored for the ice cover prediction.

TABLE 9

Steady-State Water Temperature and Ice Cover Predictions

Case 1: Median Flow and Mean Weather*

Parameters	Nov	Dec	Jan	Feb	Mar
Q_T (cfs) **	14,300	10,600	8,850	8,600	13,000
Q_M (cfs) ***	9,810	7,420	6,301	6,175	8,957
Q_W (cfs) ***	4,490	3,180	2,549	2,425	4,043
K(BTU $ft^{-2} day^{-1} {}^oF^{-1}$) †	93.6	100.7	104.6	103.7	100.4
E (^{o}C) †	-1.43	-10.26	-13.47	-7.59	0
T_R (^{o}C) ††	4.7	0.6	0.3	0.55	2.1
T_o (^{o}C)	6.14	2.54	2.63	2.95	3.69
T_i (^{o}C)	6.02	2.25	2.18	2.65	3.62
T_M (^{o}C)	5.62	1.32	.76	1.71	3.40
T_W (^{o}C)	5.41	0.72	-0.26	0.99	3.27
PHRR	.407	.722	.897	.601	.208
THRR	.095	.551	.794	.489	.090
X_M (mi)	11.0	11.0	11.0	11.0	11.0
(%)	100	100	100	100	100
X_W (mi)	6.8	6.8	6.0	6.8	6.8
(%)	100	100	88	100	100

* Table 8

** Table 3

*** Fig. 9

† Table A-1

†† Table 7

TABLE 9 (Cont'd)

Steady-State Water Temperature and Ice Cover Predictions

Case 2: Median Flow and High Rate of Surface Heat Loss*

Parameters	Nov	Dec	Jan	Feb	Mar
Q_T (cfs)	14,300	10,600	8,850	8,600	13,000
Q_M (cfs)	9,810	7,420	6,301	6,175	8,957
Q_W (cfs)	4,490	3,180	2,549	2,425	4,043
K (BTU $ft^{-2}day^{-1}{}^{o}F^{-1}$)	150.8	157.8	179.6	174.1	149.8
E (^{o}C)	-15.99	-26.72	-31.66	-28.03	-18.2
T_R (^{o}C)	1.3	0.1	0	0	0.7
T_o (^{o}C)	2.74	2.04	2.33	2.40	2.29
T_i (^{o}C)	2.27	1.04	.72	.97	1.73
T_M (^{o}C)	0.73	-2.14	-4.15	-3.34	-0.09
T_W (^{o}C)	-0.09	-4.10	-7.45	-6.47	-1.10
PHRR	1.56	1.05	1.00	1.00	1.44
THRR	.817	1.00	1.00	1.00	1.00
X_M (mi)	11.0	5.5	4.1	4.7	10.6
(%)	100	50	37	43	96
X_W (mi)	6.5	1.3	0.5	0.8	4.0
(%)	96	19	7	12	59

* Table 8.

TABLE 9 (Cont'd)

Steady-State Water Temperature and Ice Cover Predictions

Case 3: Median Flow and Low Rate of Surface Heat Loss (Gain)*

Parameters	Nov	Dec	Jan	Feb	Mar
Q_T (cfs)	14,300	10,600	8,850	8,600	13,000
Q_M (cfs)	9,810	7,420	6,301	6,175	8,957
Q_W (cfs)	4,490	3,180	2,549	2,425	4,043
K (BTU $ft^{-2}day^{-1}{}^{o}F^{-1}$)	46.79	40.31	53.21	40.64	45.97
E (^{o}C)	18.36	13.60	9.62	19.30	30.48
T_R (^{o}C)	9.2	1.8	0.7	1.2	4.4
T_o (^{o}C)	10.64	3.74	3.03	3.60	5.99
T_i (^{o}C)	10.70	3.83	3.12	3.78	6.20
T_M (^{o}C)	10.91	4.13	3.43	4.35	6.90
T_W	11.02	4.33	3.66	4.82	7.31
PHRR	-0.211	-0.232	-0.200	-0.368	-0.653
THRR	-0.029	-0.120	-0.154	-0.245	-0.173
X_M (mi)	11.0	11.0	11.0	11.0	11.0
(%)	100	100	100	100	100
X_W (mi)	6.8	6.8	6.8	6.8	6.8
(%)	100	100	100	100	100

* Table 8.

TABLE 9 (Cont'd)

Steady-State Water Temperature and Ice Cover Predictions

Case 4: Annual Minimum Flow and Mean Weather*

Parameter	Nov	Dec	Jan	Feb	Mar
Q_T (cfs)	11,600	7,480	7,457	7,562	8,275
Q_M (cfs)	8,062	5,423	5,406	5,475	5,925
Q_W (cfs)	3,538	2,057	2,051	2,087	2,350
K (BTU $ft^{-2} day^{-1} {}^oF^{-1}$)	93.6	100.7	104.6	103.7	100.4
E (^oC)	-1.43	-10.26	-13.47	-7.59	0
T_R (^oC)	4.7	0.6	0.3	0.55	2.1
T_o (^oC)	6.48	3.36	3.07	3.28	4.59
T_i (^oC)	6.33	2.93	2.53	2.93	4.46
T_M (^oC)	5.83	1.60	0.86	1.85	4.05
T_W (^oC)	5.53	0.52	-0.51	0.98	3.74
PHRR	.417	.745	.883	.612	.252
THRR	.114	.612	.797	.509	.137
X_M (mi)	11.0	11.0	11.0	11.0	11.0
(%)	100	100	100	100	100
X_W (mi)	6.8	6.8	5.56	6.8	6.8
(%)	100	100	82	100	100

* Table 8.

TABLE 9 (Cont'd)

Steady-State Water Temperature and Ice Cover Predictions

Case 5: Annual Minimum Flow and High Rate of Surface Heat Loss*

Parameter	Nov	Dec	Jan	Feb	Mar
Q_T (cfs)	11,600	7,480	7,460	7,560	8,270
Q_M (cfs)	8,062	5,423	5,407	5,475	5,923
Q_W (cfs)	3,538	2,057	2,053	2,085	2,347
K (BTU $ft^{-2} day^{-1} {}^{o}F^{-1}$)	150.8	157.8	179.6	174.1	149.8
E (^{o}C)	-15.99	-26.72	-31.66	-28.03	-18.2
T_R (^{o}C)	1.3	0.1	0	0	0.7
T_o (^{o}C)	3.08	2.86	2.77	2.73	3.19
T_i (^{o}C)	2.50	1.41	.85	1.09	2.29
T_M (^{o}C)	0.63	-2.90	-4.77	-3.75	-0.47
T_W (^{o}C)	-0.48	-6.22	-9.01	-7.39	-2.45
PHRR	1.484	1.036	1.000	1.000	1.000
THRR	.858	1.000	1.000	1.000	1.000
X_M (mi)	11.0	5.47	4.12	4.68	9.55
(%)	100	50	37	43	87
X_W (mi)	5.62	1.10	0.50	0.75	3.06
(%)	83	16	7	11	45

* Table 8.

TABLE 9 (Cont'd)

Steady-State Water Temperature and Ice Cover Predictions

Case 6: Annual Minimum Flow and Low Rate of Surface Heat Loss (Gain)*

Parameter	Nov	Dec	Jan	Feb	Mar
Q_T (cfs)	11,600	7,480	7,460	7,560	8,270
Q_M (cfs)	8,062	5,423	5,407	5,475	5,923
Q_W (cfs)	3,538	2,057	2,053	2,085	2,347
K (BUT $ft^{-2} day^{-1} {}^oF^{-1}$)	46.79	40.31	53.21	40.64	45.97
E (^oC)	18.36	13.6	9.62	19.30	30.48
T_R (^oC)	9.2	1.8	0.7	1.2	4.4
T_o (^oC)	10.98	4.56	3.47	3.93	6.89
T_i (^oC)	11.05	4.68	3.57	4.13	7.20
T_M (^oC)	11.24	5.05	3.90	4.76	8.21
T_W (^oC)	11.44	5.37	4.18	5.30	9.01
PHRR	-0.200	-0.209	-0.183	-0.359	-0.621
THRR	-0.032	-0.127	-0.146	-0.249	-0.225
X_M (mi)	11.0	11.0	11.0	11.0	11.0
(%)	100	100	100	100	100
X_W (mi)	6.8	6.8	6.8	6.8	6.8
(%)	100	100	100	100	100

* Table 8.

IV. RIVER ACCESSIBILITY BY BOAT IN WINTER

The records analyzed show that in the winter and under present average conditions the mainstem of the Mississippi River below Dam No. 3 is partially open (not ice-covered). The average length of the open water reach in December, January, and February is 6.2 mi, 1.6 mi, and 7.1 mi, respectively. The open water reach in the Wisconsin channel from its branching point on is 1.6 miles in December and 0.5 miles in February. In January, the Wisconsin channel is completely frozen over. (All mileage figures are for average conditions.)

The backwater lakes in the Lake Pepin Delta are ice-covered much longer than the river mainstem. (See Table 1.)

The current open water conditions below Dam No. 3 are attributed to residual heat carried by the river entering Pool No. 3 and by the current heat rejection from the Prairie Island Plant which started to operate in the Fall of 1973.

The above information can be related to the accessibility of the river below Dam No. 3 in the winter. Figure 15 shows four major access points for boats. They are at the following approximate distances below Dam No. 3:

1. Everts Resort (Trenton), 2.4 mi
2. Island Campground, 0.9 mi from branch point
3. Red Wing Yacht Club, 5.3 mi
4. Edgewater Landing, 5.8 mi
5. Colville Park in Red Wing, 7.8 mi

River accessibility from these points by boat as seen on Landsat images is given in Table 10.

The future accessibility of the river reach in the event that the Prairie Island Plant were to release a full heat load of $8.34 * 10^9$ BTU per hour was derived from the results of the steady-state water temperature analysis presented in Section III. The results are presented in Table 11. For comparison with Table 10, percentages of time are estimated from the six case studies. These are approximate time percentages based on

TABLE 10

Historical Accessibility of Tailwater below Dam No. 3
by Boat (Open Water) as Interpreted from Landsat Scenes

Month/Year	Total No. of Used Landsat Scenes	No. of Observations with Open Water Access	Per cent of Observations with Open Water Access
Access from Evert's Resort (Point 1)			
November/1972-78	17	17	100
December/1972-78	8	7	87
January/1973-79	13	2	15
February/1973-79	9	6	66
March/1973-79	11	11	100
April/1973-79	10	10	100
Access from Red Wing Yacht Club (Point 3)			
November/1972-78	17	17	100
December/1972-78	8	4	50
January/1973-79	13	1	7
February/1973-79	9	6	66
March/1973-79	11	11	100
April/1973-79	10	10	100
Access from Hwy 63 to Mainstem (Point 4)			
November/1972-78	17	17	100
December/1972-78	8	4	50
January/1973-79	13	1	7
February/1973-79	9	6	66
March/1973-79	11	11	100
April/1973-79	10	10	100
Access from Hwy 63 to Wisconsin Channel (Point 2)			
November/1972-78	17	17	100
December/1972-78	8	2	25
January/1973-79	13	0	0
February/1973-79	9	1	11
March/1973-79	11	11	100
April/1973-79	10	10	100

TABLE 11

Future Accessibility of Tailwater Below Dam No. 3 by Boat (Open Water)

Case: Month	1	2	3	4	5	6	Per cent of Time
Access from Evert's Resort (Point 1)							
November	yes	yes	yes	yes	yes	yes	100
December	yes	yes	yes	yes	yes	yes	100
January	yes	yes	yes	yes	yes	yes	97
February	yes	yes	yes	yes	yes	yes	100
March	yes	yes	yes	yes	yes	yes	100
April	yes	yes	yes	yes	yes	yes	100
Access from Red Wing Yacht Club (Point 3)							
November	yes	yes	yes	yes	yes	yes	100
December	yes	yes	yes	yes	yes	yes	100
January	yes	no	yes	yes	no	yes	50-97
February	yes	no	yes	yes	no	yes	50-97
March	yes	yes	yes	yes	yes	yes	100
April	yes	yes	yes	yes	yes	yes	100
Access from Edgewater Landing (Point 4)							
November	yes	yes	yes	yes	yes	yes	100
December	yes	no	yes	yes	no	yes	50-97
January	yes	no	yes	yes	no	yes	50-97
February	yes	no	yes	yes	no	yes	50-97
March	yes	yes	yes	yes	yes	yes	100
April	yes	yes	yes	yes	yes	yes	100
Access from Island Campground (Point 2)							
November	yes	yes	yes	yes	yes	yes	100
December	yes	yes	yes	yes	yes	yes	100
January	yes	no	yes	yes	no	yes	50-97
February	yes	no	yes	yes	no	yes	50-97
March	yes	yes	yes	yes	yes	yes	100
April	yes	yes	yes	yes	yes	yes	100

Case 1: Median flow and mean weather.
Case 2: Median flow and high rate of surface heat loss.
Case 3: Median flow and low rate of surface heat loss (gain).
Case 4: Annual minimum flow and mean weather.
Case 5: Annual minimum flow and high rate of surface heat loss.
Case 6: Median flow and low rate of surface heat loss (gain).

the assumptions: (a) that median flow and mean weather occur 50 per cent of the time; (b) that high rates of surface heat exchange occur no more than one day in every month (3 per cent probability of occurrence); and (c) that the percentages cannot be lower than those listed under historical conditions in Table 10. For those cases where a range (e.g. 50-97 per cent) is listed, more accurate values can be provided by additional statistical analysis of winter weather parameters and frequencies of occurrence of K and E values.

V. SUMMARY

1. Ground observations and LANDSAT images show that the Mississippi River below Dam No. 3 is frequently without ice cover even in midwinter. The current open water conditions below Dam No. 3 can be attributed to residual heat carried by the river entering Pool No. 3 and by the current heat rejection from the Prairie Island Plant (operating since fall of 1973).

2. The mean open water lengths in the river mainstem beginning at Dam No. 3 were determined from 68 LANDSAT images as follows:

November	11.5 miles
December	6.2 miles
January	1.6 miles
February	7.1 miles
March	11.5 miles

The nearest public boat access at Everts' Resort is at 2.4 miles below Dam No. 3.

3. Open water access from Everts Resort was identified in the following percentage of observations.

November	100%
December	87%
January	15%
February	66%
March	100%

4. The Wisconsin channel is completely frozen over in January and partially open at its upstream end in December and February.

5. The backwaters in the Lake Pepin Delta are ice-covered longer than the river mainstem. (See Table 1.)

6. An analysis of the winter water temperature regime below Dam No. 3 for a waste heat rejection of $8.34 \cdot 10^9$ BTU hr^{-1} from the Prairie Island Plant (once-through cooling mode) shows that for mean monthly weather and flow conditions the open water reach in the mainstem below Dam No. 3 would extend to Lake Pepin. Accessibility to the open water from Everts Resort would increase from the values given under Point 3 above to about 100 per cent.

7. A major portion of the $8.34*10^9$ BTU hr^{-1} of waste heat will be transferred through the water surface to the atmosphere between Dam No. 3 and Lake Pepin. Heat rejection ratios are given in Table 9. Residual heat will enter into Lake Pepin.

8. Under extremely cold weather the Mississippi River below Red Wing will be frozen over even if $8.34*10^9$ BTU hr^{-1} is rejected from the Prairie Island Plant.

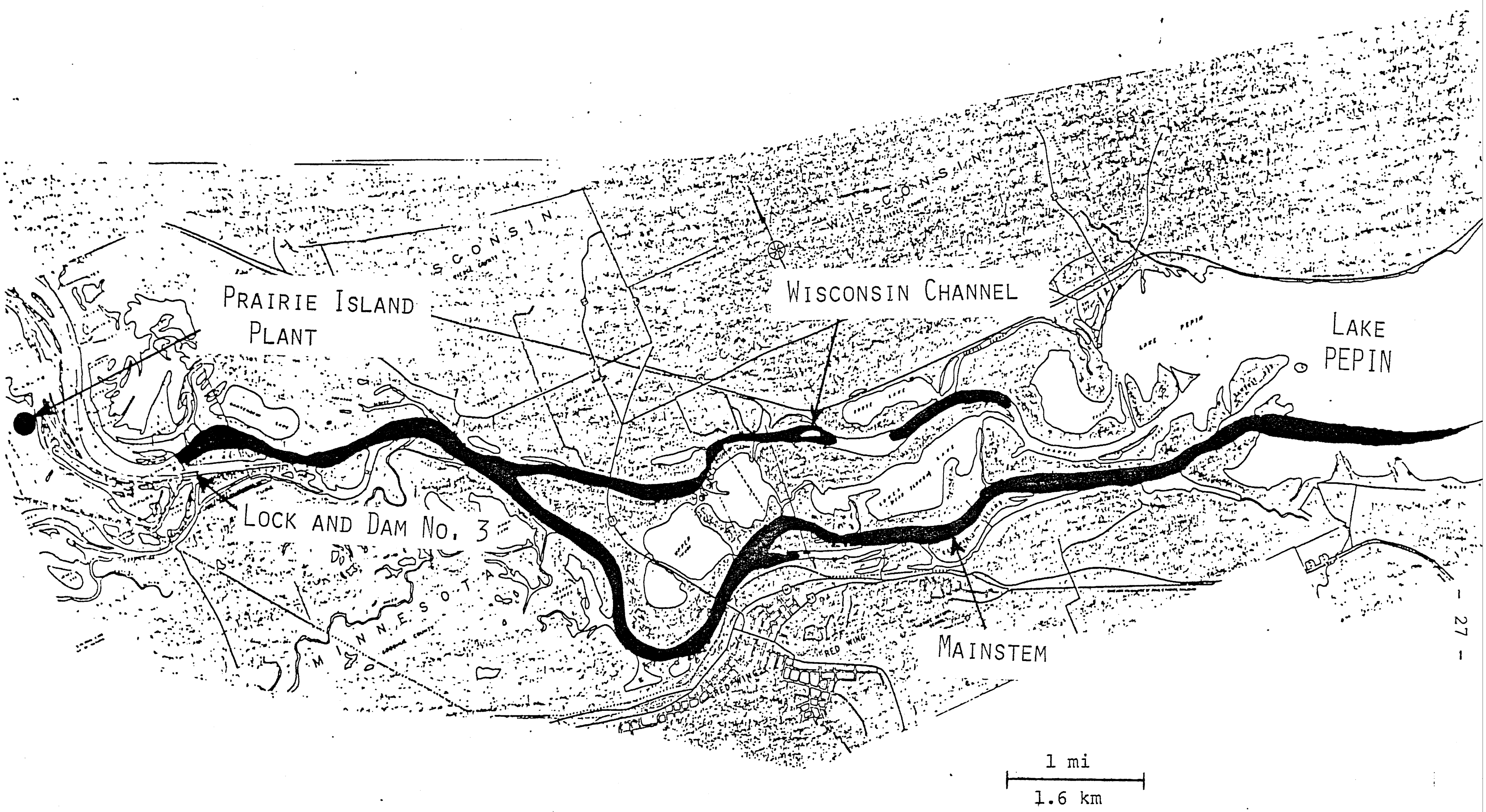
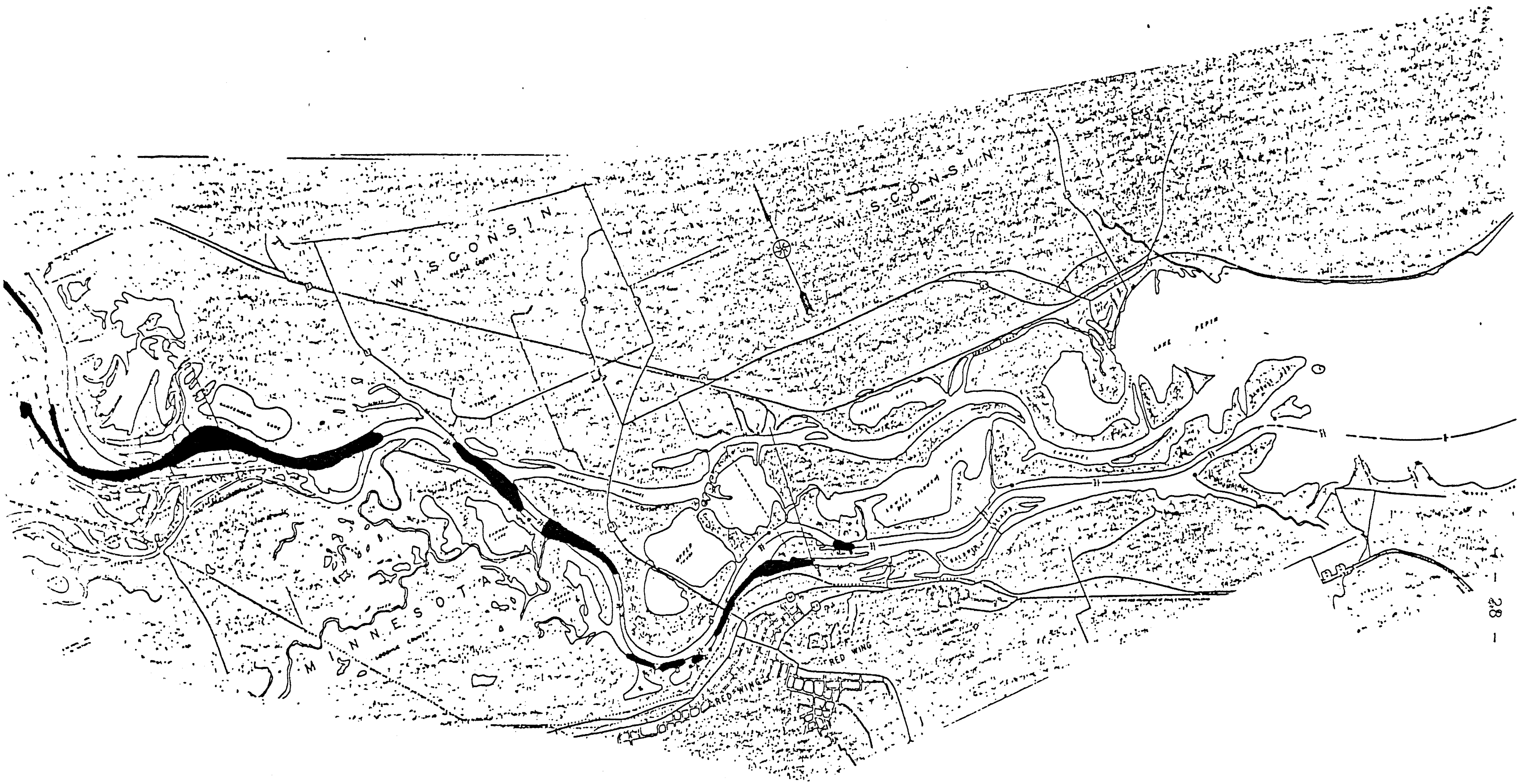


Fig. 1. Open Water Below Dam No. 3 on February 8, 1973.



February 8, 1975

Length Open	
Main stem	5.0 mi
Wisc. chan.	0 mi
Surface Area Open	
Main stem	34 %
Wisc. chan.	0 %

Fig. 2. Open Water Below Dam No. 3 on February 8, 1975.

Fig. 3. Aerial View of Pool No. 3 Upstream from Dam No. 3 in the Vicinity of Prairie Island Power Plant (March 1, 1975). Stream plumes are from cooling towers; view is looking downstream in direction of river flow.

Fig. 4. Aerial View Showing Cooling Water Discharge from the Prairie Island Nuclear Plant.

(March 1, 1975)

Fig. 5. Aerial View Towards the Northwest Showing the River Reach Immediately Below Dam No. 3.

(March 1, 1975)

Fig. 6. Aerial View of the Mississippi Delta Towards Lake Pepin.

(March 1, 1975)

Fig. 7. Aerial View of the Mississippi River Plume in Lake Pepin as Delineated by the Ice Contour.

(March 1, 1975)

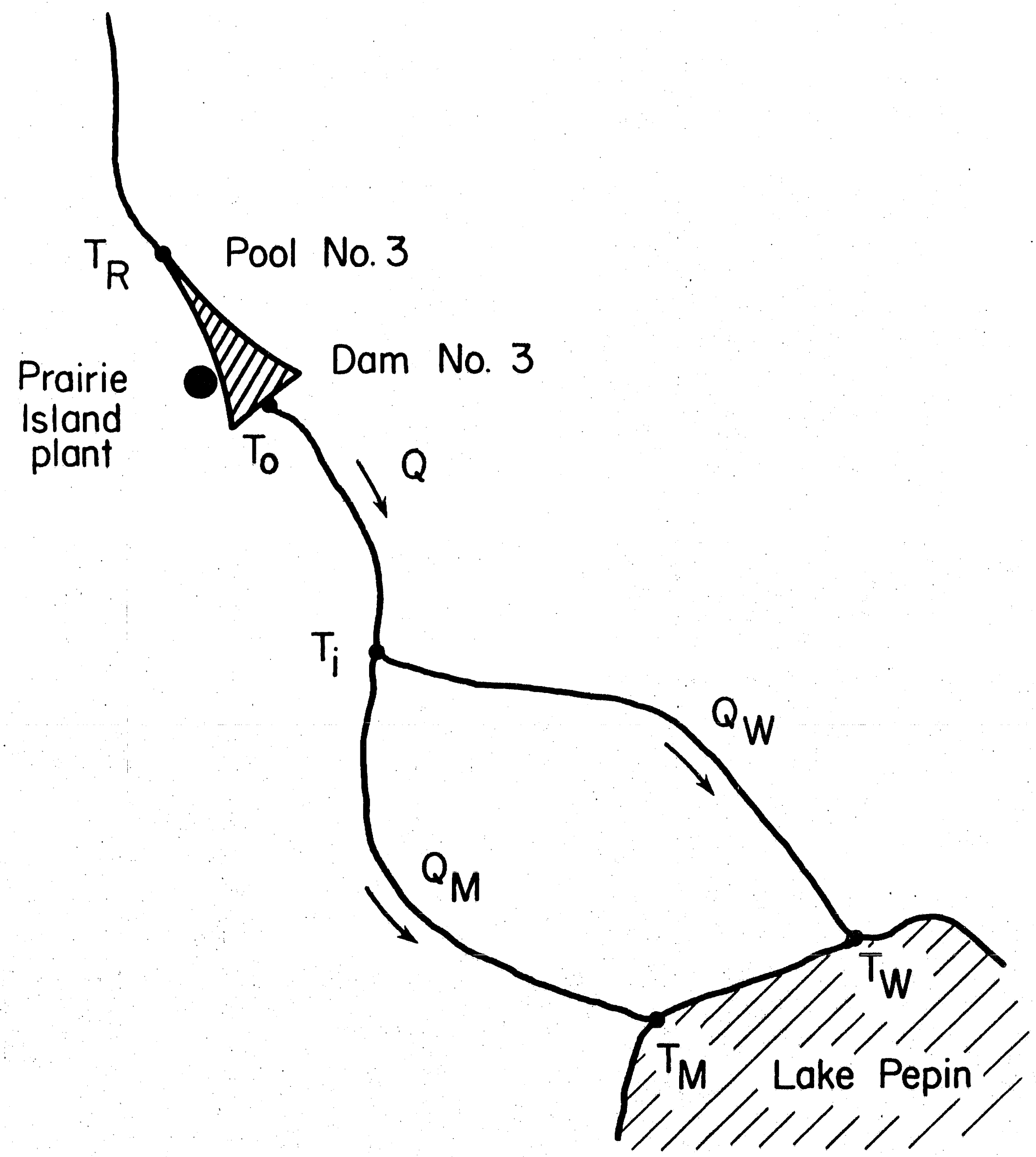


Fig. 8. Schematic of Mississippi River System for Water Temperature Analysis.

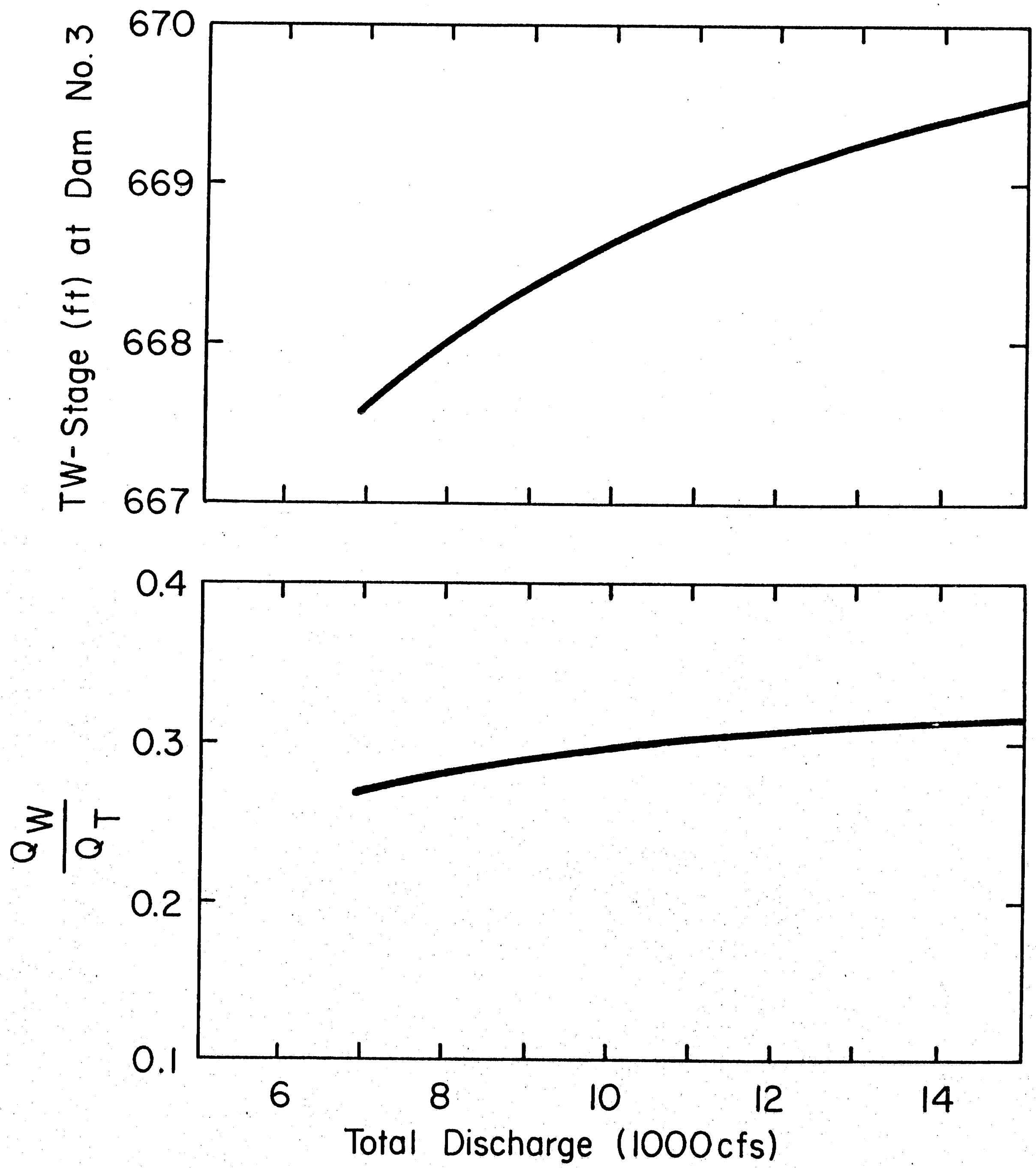


Fig. 9. Tailwater Stage-Discharge Relationship at Dam No. 3 (top). Wisconsin Channel Flow, Q_W/Q_T, versus Total River Flow Q_T (bottom).

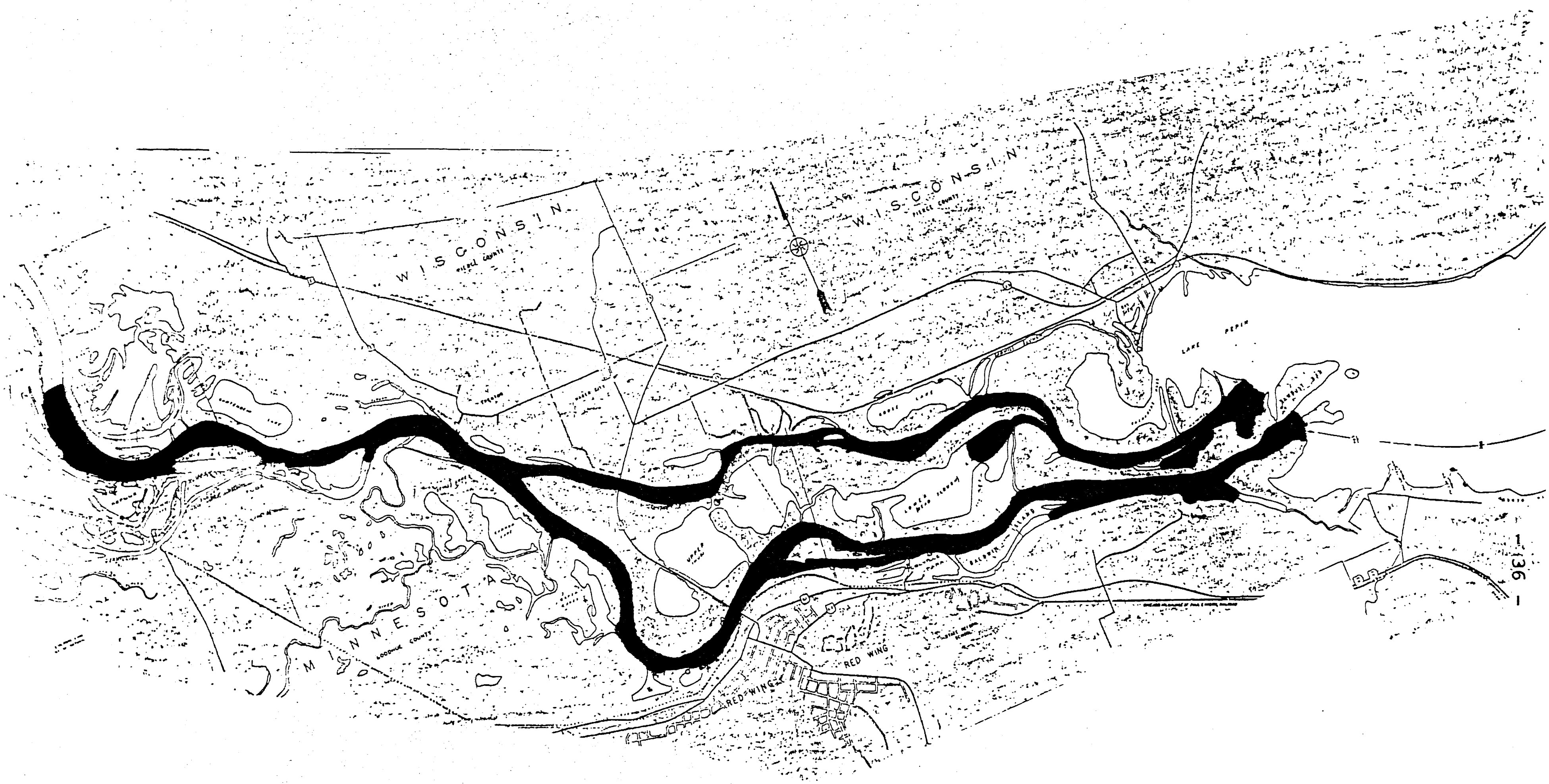


Fig. 10. Predicted Open Water. Median or Annual Minimum Flow. Mean Weather. February and December. (Lake Pepin not completed)

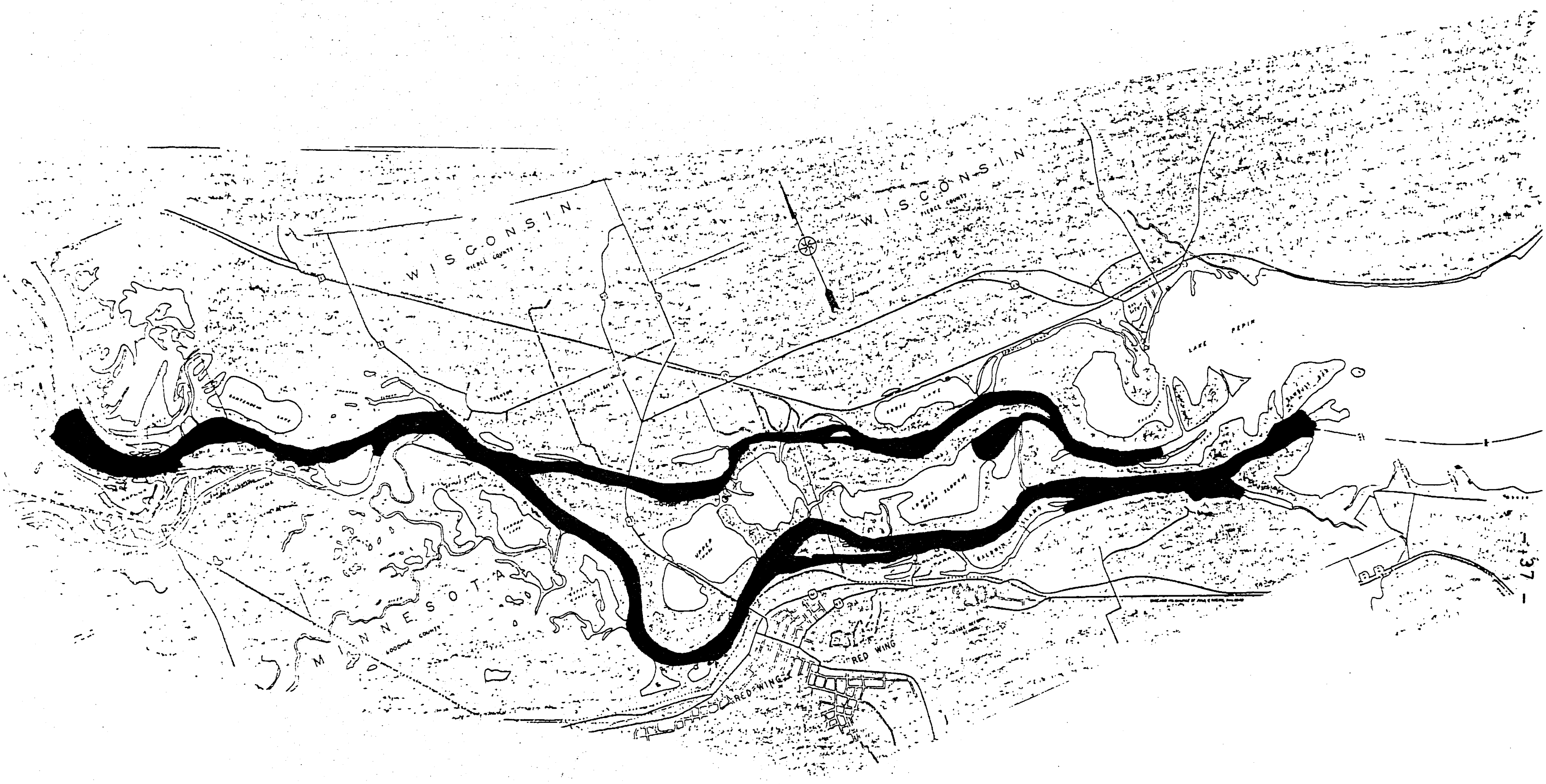


Fig. 11. Predicted Open Water. Median or Annual Minimum Flow. Mean Weather. January. (Lake Pepin not completed)

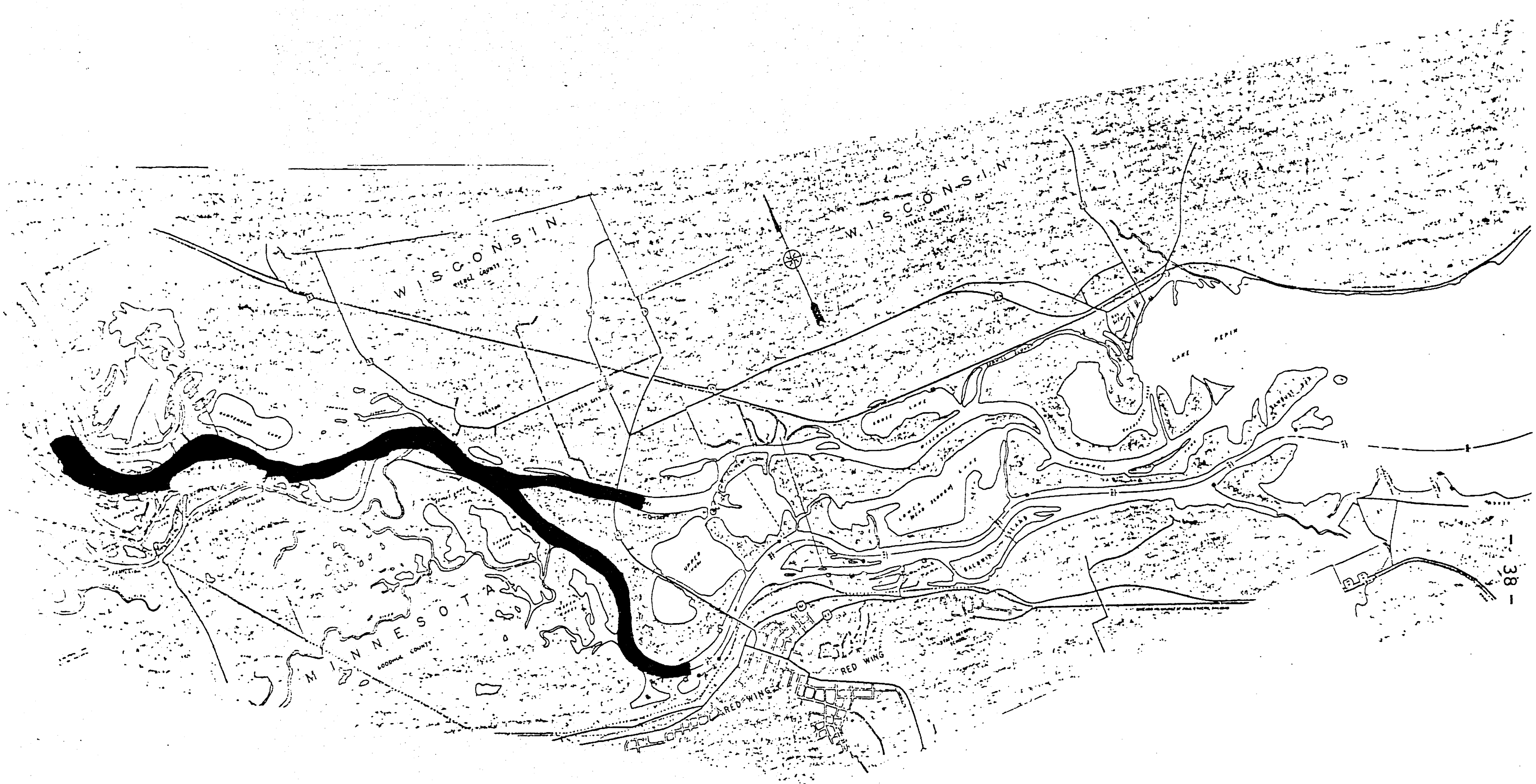


Fig. 12. Predicted Open Water. Median or Annual Minimum Flow. Annual Highest Daily Rate of Surface Heat Loss in December.

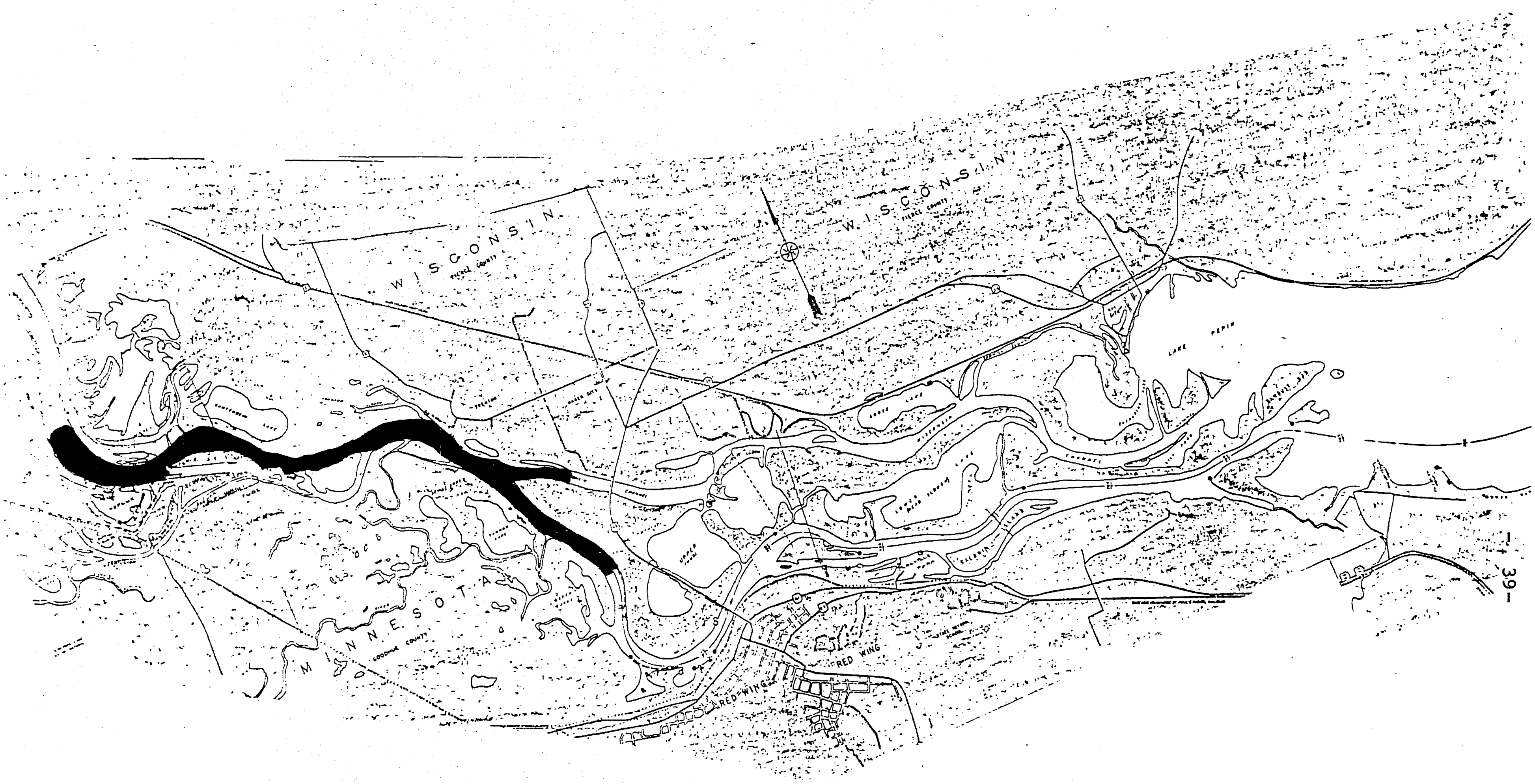


Fig. 13. Predicted Open Water. Median or Annual Minimum Flow. Annual Highest Daily Rate of Surface Heat Loss in January.

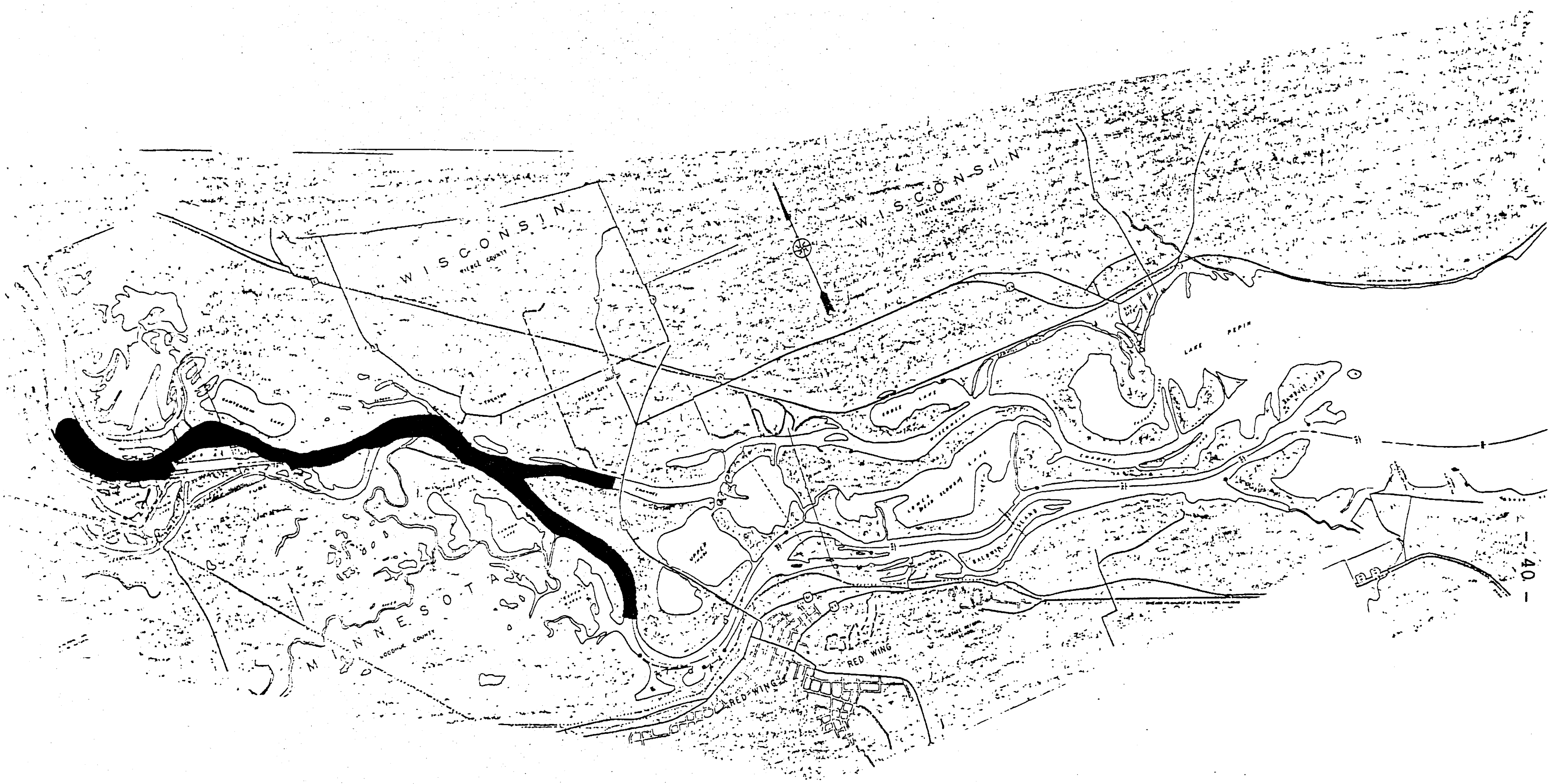


Fig. 14. Predicted Open Water. Median or Annual Minimum Flow. Annual Highest Daily Rate of Surface Heat Loss in February.

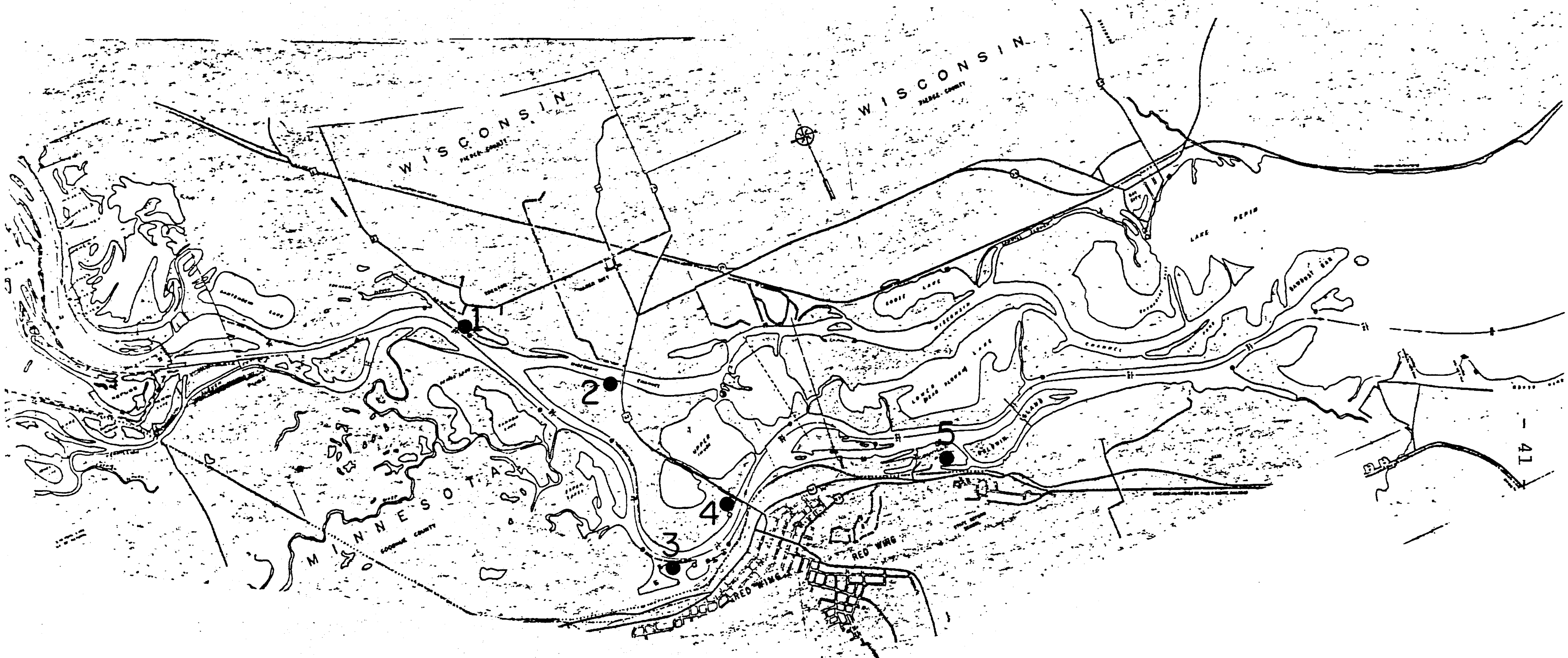


Fig. 15. Public access to Mississippi River below Dam No. 3.

1. Evert's Resort, R.M. 794.1
2. Hwy 63 to Wisc. Channel, 0.9 mi from branching point
3. Red Wing Yacht Club, R.M. 791.2
4. Hwy 63 to Mainstem, R.M. 790.7
5. Colville Park in Red Wing, R.M. 788.7

BIBLIOGRAPHY

1. Baker, Donald G., and Enz, John W., "Climate of Minnesota, Part XI - The Availability and Dependability of Solar Radiation at St. Paul, Minnesota," Technical Bulletin 316, Agricultural Experiment Station, University of Minnesota, 1979, 18 pp.

2. Brady, D. K., Graves, W. L., and Geyer, J. C., "Surface Heat Exchange at Power Plant Cooling Lakes," Research Project Report PR 4905, Johns Hopkins University, Dept. of Geography and Environmental Engineering, 1969.

3. Goff, J. A., and Gratch, S., "Low-Pressure Properties of Water from -160 to 212°F," Trans. American Society of Heating and Ventilation Engineers, Vol. 52, paper 1286, 1946, pp. 95-122.

4. Ryan, P. J., and Harleman, D.R.F., "Transient Cooling Pond Behavior," Proceedings of the 21st Annual Hydraulics Division Specialty Conference, ASCE, Bozeman, Montana, August, 1973.

5. Shulyakovskyi, L. G., "Formula for Computing Evaporation with Allowance for the Temperature of Free Water Surface," Soviet Hydrology, Selected Papers, No. 6, 1969.

6. Paily, P. P., Macagno, E. O. and Kennedy, J. F., "Winter Regime Surface Heat Loss from Heated Streams," Iowa Institute of Hydraulic Research, Report No. 155, Feb., 1974.

APPENDIX A - DETERMINATION OF K AND E VALUES

Determination of the bulk surface heat transfer coefficient K follows the method proposed by Brady, Graves and Geyer (2)*.

$$K = 15.7 + (\beta + 0.26)FW \qquad (A-1)$$

in which

$$\beta = 0.255 - 0.0085\, T_w + 0.000204\, T_w^2 \qquad (A-2)$$

$$T_w = \frac{T + T_d}{2} \qquad (A-3)$$

where T is the water surface temperature and T_d is the dewpoint temperature, both in ^{o}F. The river is assumed to be well mixed vertically. The water surface temperature is assumed to be near $32^{o}F$. T_d can be obtained from weather stations.

The wind function FW is adapted from a Shulyakovskyi(5) formulation by Ryan and Harleman (4).

$$FW = 14\, W_2 + 22.4\, (\Delta\theta_v)^{1/3} \qquad (A-4)$$

in which FW is in BTU $ft^{-2}\ day^{-1}\ {}^{o}F^{-1}$, W_2 is the wind velocity (mph) at 2 m above ground, and

$$\Delta\theta_v = T(1 + 0.378\,\frac{e_s}{p_a}) - AT(1 + 0.378\,\frac{e_a}{p_a}) \qquad (A-5)$$

where T = water temperature (^{o}R),

AT = air temperature (^{o}R),

p_a = air pressure,

e_s = saturated air vapor pressure at temperature T, and

e_a = actual air vapor pressure.

The terms e_s/p_a and e_a/p_a are small. Introducing a standard atmospheric pressure (1013 mb) in place of the actual atmospheric pressure

*See Bibliography, page 42.

will lead to only a trivial error, but save a lot of effort in collecting the required information. Therefore, instead of using Eq. A -5 to determine the convective term ($\Delta\theta_v$), the following equation will be used.

$$\Delta\theta_v = T\left(1 + 0.378 \frac{e_s}{1013}\right) - AT\left(1 + 0.378 \frac{e_a}{1013}\right) \qquad \text{(A-6)}$$

The determination of e_s and e_a can either be from a standard saturation vapor pressure table, or by calculation from the Goff-Gratch formula or its approximating formula in the following form:

$$e_s \simeq 33.8639 \left[(0.00738T + 0.8072)^8 + 0.001316 - 0.000019 \left| 1.8T + 16 \right|\right] \qquad \text{(A-7)}$$

$$e_a \simeq 33.8639 \left[(0.00738AT + 0.8072)^8 + 0.001316 - 0.000019 \left| 1.8AT + 16 \right|\right] \qquad \text{(A-8)}$$

where e_s and e_a are in millibars (mb), and T and AT in ^{o}C. The parameter RH in Eq. A-8 is relative humidity.

If the height above ground at which the wind velocity is recorded is known, the data can be transformed to wind velocity at 2 m above ground by using a power law equation. If not, the acquired wind velocity (without any transformation) is used.

When the first term on the right-hand side of Eq. A-5 is less than the second term, $\Delta\theta_v$ is set equal to zero.

Determination of the equilibrium temperature E, uses the simple relationship

$$E = T_d + H_s/K \qquad \text{(A-9)}$$

proposed by Brady et al (2).

where T_d = dewpoint temperature,

H_s = solar radiation received, and

K = bulk coefficient of surface heat transfer.

Measurements of H_s should be integral values over several hours.

TABLE A-1

K and E Values for
Mean Daily Rate of Surface Heat Loss*

	Air Temperature (^oF)	Wind Velocity (mph)	Dewpoint Temperature (^oF)	Solar Radiation (cal $cm^{-2} day^{-1}$)
November	31.20	11.10	24.10	135.00
	K = 93.59 BTU ft^{-2} day^{-1} $^oF^{-1}$ E = 29.42 ^oF			
December	18.10	10.40	9.40	113.00
	K = 100.73 BTU ft^{-2} day^{-1} $^oF^{-1}$ E = 13.54 ^oF			
January	12.40	10.50	2.30	135.00
	K = 104.61 BTU ft^{-2} day^{-1} $^oF^{-1}$ E = 7.76 ^oF			
February	15.70	10.70	9.70	243.00
	K = 103.71 BTU ft^{-2} day^{-1} $^oF^{-1}$ E = 18.34 ^oF			
March	27.40	11.30	20.30	315.00
	K = 100.33 BTU ft^{-2} day^{-1} $^oF^{-1}$ E = 31.98 ^oF			

* Input data from Table 5.

TABLE A-1 (cont'd)

K and E Values for
High Daily Rate of Surface Heat Loss (1968-1978 average)*

	Air Temperature (°F)	Wind Velocity (mph)	Dewpoint Temperature (°F)	Solar Radiation (cal $cm^{-2} day^{-1}$)
November	13.60	18.30	3.20	1.00
	K = 150.76 BTU ft^{-2} day^{-1} $°F^{-1}$ E = 3.22 °F			
December	-5.60	16.70	-16.40	13.60
	K = 157.79 BTU ft^{-2} day^{-1} $°F^{-1}$ E = -16.10 °F			
January	-13.90	18.30	-25.20	10.00
	K = 179.61 BTU ft^{-2} day^{-1} $°F^{-1}$ E = -24.88 °F			
February	-5.70	18.90	-18.60	7.00
	K = 174.09 BTU ft^{-2} day^{-1} $°F^{-1}$ E = -18.45 °F			
March	13.30	17.90	-1.30	23.00
	K = 149.75 BTU ft^{-2} day^{-1} $°F^{-1}$ E = -.76 °F			

* Input data from Table 6.

TABLE A-1 (cont'd)

K and E Values for

Low Daily Rate of Surface Heat Loss (Gain)

(1968-1978 average)*

	Air Temperature (^{o}F)	Wind Velocity (mph)	Dewpoint Temperature (^{o}F)	Solar Radiation (cal $cm^{-2}day^{-1}$)
November	51.70	4.60	42.90	281.00
	$K = 46.79$ BTU ft^{-2} day^{-1} $^{o}F^{-1}$ $E = 65.05$ ^{o}F			
December	36.00	3.90	31.50	273.00
	$K = 40.31$ BTU ft^{-2} day^{-1} $^{o}F^{-1}$ $F = 56.48$ ^{o}F			
January	31.40	4.60	27.70	312.00
	$K = 53.21$ BTU ft^{-2} day^{-1} $^{o}F^{-1}$ $E = 49.32$ ^{o}F			
February	34.60	4.00	28.90	417.00
	$K = 40.64$ BTU ft^{-2} day^{-1} $^{o}F^{-1}$ $E = 66.74$ ^{o}F			
March	49.30	4.60	38.90	598.00
	$K = 45.97$ BTU ft^{-2} day^{-1} $^{o}F^{-1}$ $E = 86.87$ ^{o}F			

*Input data from Table 6.

Alternative Determination of K and E Values

An alternative determination of the bulk surface heat transfer coefficient K and of the equilibrium temperature E follows the method proposed by Paily, Macagno and Kennedy (6). The bulk surface heat transfer coefficient is determined by the following regression equation.

$$K = 30.08958 + 7.07423W - 1.04632AT - 0.01656RH - 0.01093VI \qquad \text{(A-10)}$$

where W = wind velocity in m/sec^{-1},
AT = air temperature in ^{o}C,
RH = relative humidity in %,
VI = visibility in km, and
K = bulk surface heat transfer coefficient in cal cm^{-2} day^{-1} $^{o}C^{-1}$.

The equilibrium temperature E is determined by

$$E = -\frac{(\eta - H_s)}{K} \qquad \text{(A-11)}$$

where E = equilibrium temperature in ^{o}C and
H_s = net solar radiation in cal cm^{-2} day^{-1}.

η is given by the following regression equation.

$$\eta = a + b{*}W + c{*}AT + d{*}RH + e{*}VI + f{*}C + g{*}W{*}AT + h{*}W{*}RH + i{*}AT{*}RH + j{*}AT^2 + k{*}RH^{\frac{1}{2}} + \ell{*}C{*}\exp(-H) \qquad \text{(A-12)}$$

where C = cloud cover in tenths (0-10),
H = cloud height in km, and
η = base heat-loss rate without the net solar radiation, in cal cm^{-2} day^{-1}.

The coefficients a, b, c, d, e, f, g, h, i, j, k, and ℓ in Eq. A-12 have different values for clear skies (C=0) and cloudy skies ($0 < C \leq 10$). These values are given in Table A-2. In Eq. A-12, visibility (VI) is equal to zero if there is snowfall.

All the required meteorological data, namely air temperature, wind velocity, relative humidity, cloud cover, cloud height, and visibility are found in the Local Climatological Data for Minneapolis, Minnesota, which is published by the Department of Commerce.

TABLE A-2

Coefficients of the Regression Equation for
Base Heat Exchange Rate Without Solar Radiation

Coefficient	Value of Coefficient: Clear Sky (C = 0)	Value of Coefficient: Cloudy Sky ($0<C\leq 10$)	Variable to which Coefficient Applies	Unit of Variable
a	+ 291	+ 264	(constant)	
b	+ 29.3	+ 29.3	Wind velocity, W	m sec^{-1}
c	- 18.7	- 18.8	Air temperature, AT	^{o}C
d	- 1.75	- 1.73	Relative humidity RH	%
e	- 1.02	- 1.02	Visibility, VI	km
f	0.0	- 7.85	Cloud Cover, C	tenths
g	- 4.58	- 4.58	W*AT	
h	- 0.184	- 0.184	W*RH	
i	- 0.111	- 0.109	AT*RH	
j	+ 0.153	+ 0.154	AT*AT	
k	- 0.496	0.0	$\overline{RH}$	
ℓ	0.0	- 5.0	$C*e^{-H}$ (H: Cloud height)	(km)

APPENDIX B

ANALYSIS OF FLOW DIVISION BETWEEN THE MAINSTEM (M) AND THE WISCONSIN CHANNEL (W)

Basic relationships:

a) The flow through the Wisconsin channel plus the flow through the mainstem equals the total river flow.

$$Q_M + Q_W = Q_T$$

b) The head loss through the Wisconsin channel is equal to the headloss through the mainstem

$$\Delta h_W = \Delta h_M$$

c) Manning equation.

$$Q = \frac{1.49}{n} AR^{2/3} \; S^{1/2}$$

$$S = \frac{\Delta h}{\ell} = \left(\frac{Qn}{1.49 \; AR^{2/3}} \right)^2$$

Manning's equation is used to evaluate the headloss for each half mile segment of the two channels. The sum of the headlosses equals the total head loss for each channel.

$$\sum \left(\frac{Qn}{1.49 \; AR^{2/3}} \right)_W^2 d\ell = \sum \left(\frac{Qn}{1.49 \; AR^{2/3}} \right)_M^2 d\ell$$

$$n_W = n_M$$

$$d\ell_W = d\ell_M$$

$$Q_W^2 \sum \left(\frac{1}{AR^{2/3}} \right)_W^2 = Q_M^2 \sum \left(\frac{1}{AR^{2/3}} \right)_M^2$$

$$Q_W = \left[\frac{\Sigma \left(AR^{2/3} \right)_M^{-2}}{\Sigma \left(AR^{2/3} \right)_W^{-2}} \right]^{1/2} Q_M$$

$$\frac{Q_M}{Q_T} = \frac{Q_M}{Q_M + Q_W} = \frac{1}{1 + \left[\frac{\Sigma \left(AR^{2/3}\right)_M^{-2}}{\Sigma \left(AR^{2/3}\right)_W^{-2}}\right]^{1/2}}$$

Area is the average cross-sectional area between half mile stations in each channel. The hydraulic radius is the average hydraulic radius between half mile stations. The wetted perimeter is approximately equal to the surface width for wide, shallow channels. This approximation results in a 2.5 per cent error in wetted perimeter for the deepest and narrowest section of the mainstem.

TABLE B-1

Mississippi River Channel Hydraulic Characteristics
Between Lock & Dam No. 3 and Lake Pepin

Mainstem

For stage of 667.6 ft., Tailwater L&D #3
Discharge ≈ 7000 cfs

Mile	A Cross Section Area (ft^2)	P Wetted Perimeter (ft)	R=A/P Hydraulic Radius (ft)	$\bar{A}$ Ave. Area (ft^2)	$\bar{R}$ Ave. Hydraulic Radius (ft)	$\bar{A}\,\bar{R}^{2/3}$	$(\bar{A}\,\bar{R}^{2/3})^{-2}$ X10^{-9}
786	8,750	600	14.58				
				10,200	14.57	60,847	0.270
786.5	11.650	800	14.56				
				10,485	13.26	58,740	0.290
787	9,320	780	11.95				
				8,610	12.05	45,250	0.488
787.5	7,900	650	12.15				
				8,450	14.26	49,751	0.404
788	9,000	550	16.36				
				8,295	13.17	47,847	0.437
788.5	8,190	820	9.988				
				7,720	10.10	36,101	0.767
789	7,250	710	10.21				
				6,735	10.76	32,825	0.928
789.5	6,220	550	11.31				
				6,575	9.265	29,004	1.189
790	6,930	960	7.219				
				7,345	9.580	33,131	0.911
790.5	7,760	650	11.94				
				7,435	10.71	36,124	0.766
791	7,110	750	9.480				
				7,730	10.70	37,534	0.710
791.5	8,350	700	11.93				
				6,235	9.398	27,767	1.297
792	4,120	600	6.867				
				4,540	6.977	16,577	3.639
792.5	4,960	700	7.086				
				5,250	6.691	18,642	2.877
793	5,540	840	6.295				
				6,370	7.383	24,152	1.714
793.5	7,200	850	8.471				

Total $(\bar{A}\,\bar{R}^{2/3})^{-2}$: 16.69 X 10^{-9}

TABLE B-2

Mississippi River Channel Hydraulic Characteristics
Between Lock & Dam No. 3 and Lake Pepin

Wisconsin Channel

For Stage of 667.6 ft, Tailwater L&D #3
Discharge ≃ 7000 cfs

Mile	A Cross Section Area (ft^2)	P Wetted Perimeter (ft)	R=A/P Hydraulic Radius (ft)	$\bar{A}$ Ave. Area (ft^2)	$\bar{R}$ Ave. Hydraulic Radius (ft)	$\bar{A}\,\bar{R}^{2/3}$	$(\bar{A}\,\bar{R}^{2/3})^{-2}$ x10^{-8}
0.0	--	--	--				
				3,280	5.046	9,650	1.074
0.5	3,280	650	5.046				
				3,650	5.501	11,374	0.773
1.0	3,930	660	5.955				
				3,520	5.199	10,563	0.896
1.5	3,110	700	4.443				
				3,065	5.242	9,248	1.169
2.0	3,020	500	6.04				
				3,195	5.829	10,348	0.934
2.5	3,370	600	5.617				
				3,170	5.166	9,473	1.114
3.0	2,970	630	4.714				
				2,955	4.344	7,867	1.616
3.5	2,940	740	3.973				
				2,905	5.574	9,133	1.200
4.0	2,870	400	7.175				
				2,220	5.372	6,809	2.157
4.5	1,570	440	3.568				
				2,695	6.029	8,927	1.255
5.0	3,820	450	8.489				
				3,690	8.032	14,799	0.455
5.5	3,560	470	7.574				
				3,340	7.415	12,700	0.620
6.0	3,120	430	7.256				

Total $(\bar{A}\,\bar{R}^{2/3})^{-2}$: 13.263X10^{-8}

TABLE B-3

Mississippi River Geometry Between Lock & Dam No. 3 and Lake Pepin

Mainstem

Mile	Width (ft)	Average Width (ft)	Average Width (mi)	Area: Surface (mi^2)	Area: Cross Section (ft^2)
785.5	1100				at stage 667.00' 1929 Datum
		850	.1610	.0805	
786	600				8,750 at stage 667.40
		700	.1326	.0663	
786.5	800				11,650
		790	.1496	.0748	
787	780				9,320
		715	.1354	.0677	
787.5	650				7,900
		600	.1136	.0568	
788	550				9,000 at stage 667.60
		685	.1297	.0649	
788.5	820				8,190
		765	.1449	.0724	
789	710				7,250
		630	.1193	.0597	
789.5	550				6,220
		755	.1430	.0715	
790	960				6,930 at stage 667.9
		805	.1525	.0762	
790.5	650				7,760
		700	.1326	.0663	
791	750				7,110
		725	.1373	.0687	
791.5	700				8,350
		650	.1231	.0616	
792	600				4,120
		650	.1231	.0616	
792.5	700				4,960
		785	.1487	.0743	
793	870				5,540
		860	.1629	.0814	
793.5	850				7,200
		850	.1610	.0805	
794	850				
		875	.1657	.0829	
794.5	900				
		810	.1534	.0767	
795					
	Backwater channel, not used in computations				
795.5	720				
		730	.1382	.0691	
796	740				
		810	.1534	.0767	
796.5	880				
		795	.1506	.0753	
797	720				

Total surface Area 1.6497

TABLE B-4

Mississippi River Geometry Between Lock & Dam No. 3 and Lake Pepin

Wisconsin Channel

Mile	Width (ft)	Average Width (ft)	Average Width (mi)	Area: Surface (mi^2)	Area: Cross Section (ft^2)
0	800				at stage 667.90
		725	.1373	.0687	1929 Datum
0.5	650				3,280
		660	.1250	.0625	
1.0	670				3,930
		685	.1297	.0649	
1.5	700				3,110 at stage
		600	.1136	.0568	667.60
2.0	500				3,020
		500	.1042	.0522	
2.5	600				3,370
		615	.1165	.0582	
3.0	630				2,970
		690	.1307	.0653	
3.5	750				2,940 at stage
		575	.1089	.0545	667.40
4.0	400				2,870
		420	.07954	.0398	
4.5	440				1,570
		445	.08428	.0421	
5.0	450				3,820
		460	.08712	.0436	
5.5	470				3,560
		450	.0852	.0426	
6.0	430				3,120
		605	.1146	.0573	
6.5	780				
		940	.178	.0890	
6.8	1100				
		Total Surface Area		.7975	
Average =	615				

APPENDIX C

COMPUTER PROGRAM LISTINGS

VERSION 1 (BRADY ET AL. EQU.)

```
      PROGRAM HFLUX(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION AT(100),WIND(100),TD(100),HSOL(100)
C  WT IS WATER TEMPERATURE IN DEG. FAR.
      WT=32.
C  N IS NUMBER OF DATES TO BE USED
      READ(5,1003) N
      DO 10 I=1,N
      READ(5,1020) DATE1,DATE2
      WRITE(6,1021) DATE1,DATE2
      WRITE(6,1025)
C  AT IN FAR.,WIND IN MPH,TD IN FAR.,HSOL IN CAL/SQCM/DAY
      READ(5,1000) AT(I),WIND(I),TD(I),HSOL(I)
      WRITE(6,1002) AT(I),WIND(I),TD(I),HSOL(I)
C
C  COMPUTATION OF EQUILIBRIUM TEMPERATURE AND BULK HEAT EXCHANGE COEF.
      T=(WT+TD(I))/2.
      BETA=0.255-0.0085*T+0.000204*T**2
      ES=33.8639*((0.00738*(5.*(WT-32.)/9.)+0.8072)**8+0.001316-0.000019
     $*ABS(WT+16.))
      EA=33.8639*((0.00738*(5.*(TD(I)-32.)/9.)+0.8072)**8+0.001316-0.000
     $019*ABS(TD(I)+16.))
      FTWS=(460.+WT)*(1.+0.378*ES/1013.)
      FTAS=(460.+AT(I))*(1.+0.378*EA/1013.)
      IF(FTWS.LE.FTAS) DCONV=0.
      IF(FTWS.GT.FTAS) DCONV=22.*(FTWS-FTAS)**0.3333
      FW=14.*WIND(I)+DCONV
      BK=15.7+(BETA+0.26)*FW
      ET=TD(I)+3.688*HSOL(I)/BK
      ETC=5.*(ET-32.)/9.
      WRITE(6,1005) BK,ETC
C
C  BU,BM,BW ARE WIDTHS OF UPSTREAM,MAIN,WISCONSIN CHAN. RESPECTIVELY,IN FT
```

```
      BU=800. $ BM=730. $ BW=620.
C  AS IS THE SURFACE AREA DOWNSTREAM FROM DAM NO. 3
C  ASP=AS/24./3600./62.4 IS THE SURF. AREA CORRECTED FOR TIME UNITS
C  AND RHO*CP=62.4
C  THE LETTERS U,M,W STAND FOR UPSTREAM,MAIN,AND WISCONSIN CHANNEL RESPECTIVELY
      ASUP=2.3848 $ ASMP=5.71389 $ ASWP=4.12641
C  TO INIT. TEMP. IN CELSIUS,Q IN CFS
      READ(5,1000) TO,Q
      WRITE(6,1050) TO,Q
      QM=0.0000041*Q**2+0.5437*Q+1195.94
      QW=Q-QM
C  TI IS THE WATER TEMPERATURE AT THE BRANCHING POINT
      TI=ETC+(TO-ETC)*EXP(-BK*ASUP/Q)
      IF(TI.GT.0.) GO TO 15
C  LENGTH IN MILES OF OPEN WATER
      XX=-62.4*24.*3600.*Q/BU/BK*ALOG(-ETC/(TO-ETC))/5280.
      WRITE(6,1006) XX
C  TOTAL HEAT REJECTION RATIO
      WRITE(6,1016)
      GO TO 10
15    TM=ETC+(TI-ETC)*EXP(-BK*ASMP/QM)
      IF(TM.GT.0.) GO TO 26
      XX=-62.4*24.*3600.*QM/BM/BK*ALOG(-ETC/(TI-ETC))/5280.
      XX=XX+3.
      WRITE(6,1008) XX
26    TW=ETC+(TI-ETC)*EXP(-BK*ASWP/QW)
      IF(TW.GT.0.) GO TO 20
      IF(TM.LT.0.) GO TO 27
      WRITE(6,1060) TM
27    XX=-62.4*24.*3600.*QW/BW/BK*ALOG(-ETC/(TI-ETC))/5280.
      WRITE(6,1007) XX
      IF(TM.LT.0.) TM=0.
```

```
      THRR=(TO*QW+(TO-TM)*QM)/(TO*QW+TO*QM)
      WRITE(6,1011) THRR
      GO TO 10
   20 WRITE(6,1010) TM,TW
C  THIS PROGRAM ALWAYS ASSUMES THAT THE WISCONSIN CHANNEL FREEZES FASTER
C  THAN THE MAIN CHANNEL
      THRR=((TO-TW)*QW+(TO-TM)*QM)/(TO*Q)
      WRITE(6,1011) THRR
   10 CONTINUE
      STOP
 1000 FORMAT(8F10.0)
 1002 FORMAT(5X,8(F10.2,4X))
 1003 FORMAT(I5)
 1005 FORMAT(5X,2HK=,F10.2,15H BTU/SQFT/DAY/F,/5X,2HE=,F10.2,2H C)
 1006 FORMAT(5X,6HXMAIN=,F5.2,3H MI,10X,5HT=0 C/5X,29HWISC. CHAN. COMPLE
     $TELY FROZEN)
 1007 FORMAT(5X,6HXWISC=,F5.2,3H MI,10X,5HT=0 C)
 1008 FORMAT(5X,6HXMAIN=,F5.2,3H MI,10X,5HT=0 C)
 1010 FORMAT(5X,13HXMAIN=11.0 MI,10X,2HT=,F5.2,2H C/5X,12HXWISC=6.8 MI,1
     $0X,2HT=,F5.2,2H C)
 1011 FORMAT(5X,5HTHRR=,F4.2)
 1016 FORMAT(5X,7HTHRR=1.)
 1020 FORMAT(2A10)
 1021 FORMAT(//5X,2A10)
 1025 FORMAT(11X,5HAT(F),5X,9HWVEL(MPH),8X,5HTD(F),5X,26HHSOL(CAL/SQCM/1
     $2HRS,NIGHT))
 1050 FORMAT(5X,5HTDAM=,F5.2,2H C10X,2HQ=,F10.2,4H CFS)
 1060 FORMAT(5X,13HXMAIN=11.0 MI,10X,2HT=,F5.2,2H C)
      END
```

VERSION 2 (PAILY ET. AL. EQU.)

```
      PROGRAM HFLUX(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION C(100),H(100),VI(100),RH(100)
      DIMENSION AT(100),WIND(100),TD(100),HSOL(100)
C   N IS NUMBER OF DATES TO BE USED
      READ(5,1003) N
      DO 10 I=1,N
      READ(5,1020) DATE1,DATE2
      WRITE(6,1021) DATE1,DATE2
      WRITE(6,1025)
C   AT IN FAR.,WIND IN MPH,TD IN FAR.,HSOL IN CAL/SQCM/DAY
      READ(5,1000) AT(I),WIND(I),TD(I),HSOL(I)
C   CLOUD COVER IN TENTHS,CLOUD HEIGHT AND VISIBILITY IN KM,
C   RELATIVE HUMIDITY IN PERCENTAGE
      READ(5,1000) C(I),H(I),VI(I),RH(I)
      WRITE(6,1004) AT(I),WIND(I),TD(I),HSOL(I),C(I),H(I),VI(I),RH(I)
      IF(VI(I).EQ.99.) VI(I)=0.
C
C   COMPUTATION OF EQUILIBRIUM TEMPERATURE AND BULK HEAT EXCHANGE COEF.
      BK=30.08958+7.07423*WIND(I)*0.447-1.04632*(AT(I)-32.)*5./9.-0.0165
     +6*RH(I)-0.01093*VI(I)
      IF(C(I).EQ.0.) ETNA=291.+29.3*WIND(I)*0.447-18.7*(AT(I)-32.)*5./9.
     +-1.75*RH(I)-1.02*VI(I)-4.58*WIND(I)*0.447*(AT(I)-32.)*5./9.-0.184*
     +WIND(I)*0.447*RH(I)-0.111*(AT(I)-32.)*5./9.*RH(I)+0.153*((AT(I)-32
     +.)*5./9.)**2-0.496*SQRT(RH(I))
      IF(C(I).GT.0.) ETNA=264.+29.3*WIND(I)*0.447-18.8*(AT(I)-32.)*5./9.
     +-1.73*RH(I)-1.02*VI(I)-7.85*C(I)-4.58*WIND(I)*0.447*(AT(I)-32.)*5.
     +/9.-0.184*WIND(I)*0.447*RH(I)-0.109*(AT(I)-32.)*5./9.*RH(I)+0.154*
     +((AT(I)-32.)*5./9.)**2-5.*C(I)*EXP(-H(I))
      ETNA=ETNA-HSOL(I)
      ETC=-ETNA/BK
      BK=BK*2.05
      WRITE(6,1005) BK,ETC
C
```

```
C  BU,BM,BW ARE WIDTHS OF UPSTREAM,MAIN,WISCONSIN CHAN. RESPECTIVELY,IN FT
       BU=800. $ BM=730. $ BW=620.
C  AS IS THE SURFACE AREA DOWNSTREAM FROM DAM NO. 3
C  ASP=AS/24./3600./62.4 IS THE SURF. AREA CORRECTED FOR TIME UNITS
C  AND RHO*CP=62.4
C  THE LETTERS U,M,W STAND FOR UPSTREAM,MAIN,AND WISCONSIN CHANNEL RESPECTIVELY
       ASUP=2.3848 $ ASMP=5.71389 $ ASWP=4.12641
C  TO INIT. TEMP. IN CELSIUS,Q IN CFS
       READ(5,1000) TO,Q
       WRITE(6,1050) TO,Q
       QM=0.0000041*Q**2+0.5437*Q+1195.94
       QW=Q-QM
C  TI IS THE WATER TEMPERATURE AT THE BRANCHING POINT
       TI=ETC+(TO-ETC)*EXP(-BK*ASUP/Q)
       IF(TI.GT.0.) GO TO 15
C  LENGTH IN MILES OF OPEN WATER
       XX=-62.4*24.*3600.*Q/BU/BK*ALOG(-ETC/(TO-ETC))/5280.
       WRITE(6,1006) XX
C  TOTAL HEAT REJECTION RATIO
       WRITE(6,1016)
       GO TO 50
 15    TM=ETC+(TI-ETC)*EXP(-BK*ASMP/QM)
       IF(TM.GT.0.) GO TO 26
       XX=-62.4*24.*3600.*QM/BM/BK*ALOG(-ETC/(TI-ETC))/5280.
       XX=XX+3.
       WRITE(6,1008) XX
 26    TW=ETC+(TI-ETC)*EXP(-BK*ASWP/QW)
       IF(TW.GT.0.) GO TO 20
       IF(TM.LT.0.) GO TO 27
       WRITE(6,1060) TM
 27    XX=-62.4*24.*3600.*QW/BW/BK*ALOG(-ETC/(TI-ETC))/5280.
       WRITE(6,1007) XX
       IF(TM.LT.0.) TM=0.
```

```
      THRR=(TO*QW+(TO-TM)*QM)/(TO*QW+TO*QM)
      WRITE(6,1011) THRR
      GO TO 50
20    WRITE(6,1010) TM,TW
C  THIS PROGRAM ALWAYS ASSUMES THAT THE WISCONSIN CHANNEL FREEZES FASTER
C  THAN THE MAIN CHANNEL
      THRR=((TO-TW)*QW+(TO-TM)*QM)/(TO*Q)
      WRITE(6,1011) THRR
50    CONTINUE
10    CONTINUE
      STOP
1000  FORMAT(8F10.0)
1003  FORMAT(I5)
1005  FORMAT(5X,2HK=,F10.2,15H BTU/SQFT/DAY/F,/5X,2HF=,F10.2,2H C)
1006  FORMAT(5X,6HXMAIN=,F5.2,3H MI,10X,5HT=0 C/5X,29HWISC. CHAN. COMPLE
     $TELY FROZEN)
1007  FORMAT(5X,6HXWISC=,F5.2,3H MI,10X,5HT=0 C)
1008  FORMAT(5X,6HXMAIN=,F5.2,3H MI,10X,5HT=0 C)
1010  FORMAT(5X,13HXMAIN=11.0 MI,10X,2HT=,F5.2,2H C/5X,12HXWISC=6.8 MI,1
     $0X,2HT=,F5.2,2H C)
1011  FORMAT(5X,5HTHRR=,F4.2/)
1016  FORMAT(5X,7HTHRR=1./)
1020  FORMAT(2A10)
1021  FORMAT(//5X,2A10)
1025  FORMAT(10X,5HAT(F),6X,9HWVEL(MPH),8X,5HTD(F),6X,26HHSOL(CAL/SQCM/1
     $2HRS,NIGHT),3X,9HC(TENTHS),3X,5HH(KM),3X,6HVI(KM),3X,12HRH(PERCENT
     +S))
1050  FORMAT(5X,5HTDAM=,F5.2,2H C10X,2HQ=,F10.2,4H CFS)
1060  FORMAT(5X,13HXMAIN=11.0 MI,10X,2HT=,F5.2,2H C)
 1004 FORMAT(5X,F10.2,3X,F10.2,5X,F10.2,10X,F10.2,18X,F5.2,2(3X,F6.2),6X
     +,F6.2)
      END
```

APPENDIX D

MODEL VERIFICATION

TABLE D-1. Open Water Reach Verification

Date	Mainstem Length of Open Water from Dam No. 3		Wisconsin Channel Length of Open Water from Branching		Temperature at Dam No. 3
	Observed	Predicted	Observed	Predicted	(^{o}C)
NOVEMBER					
28/72	11.0	11.0	6.8	6.8	1.0
29/72	11.0	11.0	6.8	6.8	1.0
05/73	11.0	11.0	6.8	6.8	6.5
06/73	11.0	11.0	6.8	6.8	6.0
01/74	11.0	11.0	6.8	6.8	13.5
04/75	11.0	11.0	6.8	6.8	11.0
05/75	11.0	11.0	6.8	6.8	11.0
14/75	11.0	11.0	6.8	6.8	7.0
22/75	11.0	11.0	6.8	6.8	4.5
16/76	11.0	11.0	6.8	1.75	3.5
17/76	11.0	11.0	6.8	4.06	4.0
DECEMBER					
16/72	0.0	0.0	0.0	0.0	0.0
12/73	11.0	8.37	6.8	2.8	0.5
29/73	4.0	4.39	0.0	0.73	0.5
30/73	3.0	2.39	0.0	0.0	0.5
23/76	2.2	1.96	0.0	0.0	1.5
21/78	11.0	5.54	1.0	1.16	1.1
30/78	6.5	2.86	0.0	0.0	0.0
JANUARY					
04/73	0.0	0.0	0.0	0.0	0.0
16/74	0.0	9.82	0.0	3.24	0.5
30/75	9.0	6.26	0.0	1.51	1.0
07/76	0.0	1.1	0.0	0.0	0.5
16/76	4.4	5.34	0.0	1.11	1.0
09/77	0.0	0.58	0.0	0.0	0.5
10/77	0.0	0.72	0.0	0.0	0.5
04/78	2.2	8.91	0.0	3.15	1.0
05/78	1.7	10.56	0.0	4.04	1.0
08/79	1.0	3.15	0.0	0.06	1.1
09/79	2.5	4.12	0.0	0.47	1.1
18/79	1.0	5.06	0.0	0.89	1.1
FEBRUARY					
08/73	11.0	3.23	3.0	0.12	0.5
09/73	6.0	5.17	0.0	1.11	0.5
26/73	11.0	11.0	0.5	5.83	1.0
03/74	0.0	0.0	0.0	0.0	0.0
22/74	11.0	8.79	0.89	2.80	1.0
02/76	1.0	4.82	0.0	0.87	1.0
15/77	11.0	3.8	0.5	0.14	2.0
28/78	8.5	4.85	0.0	0.76	0.5

TABLE D-1. Open Water Reach Verification (Cont'd)

Date	Mainstem Length of Open Water from Dam No. 3		Wisconsin Channel Length of Open Water from Branching		Temperature at Dam No. 3
	Observed	Predicted	Observed	Predicted	(°C)
MARCH					
17/73	11.0	11.0	6.8	6.8	3.0
12/74	11.0	11.0	6.8	6.8	3.0
15/75	11.0	11.0	6.8	4.31	1.5
25/75	--	11.0	--	5.27	2.0
10/76	11.0	11.0	6.8	6.8	2.0
28/76	11.0	11.0	6.8	6.8	5.0
22/77	11.0	11.0	6.8	6.8	4.5
23/77	11.0	11.0	6.8	6.8	4.5
26/78	11.0	11.0	6.8	6.8	2.5
27/78	11.0	11.0	6.8	6.8	2.5
12/79	11.0	11.0	4.0	4.41	1.6

APPENDIX E

SOURCES OF OBSERVATIONAL AND ANALYTICAL ERRORS

(a) Satellite Image Interpretation

The interpretation of the satellite images hinges on the recognition of differences in darkness between open water and an ice cover as seen from the altitude of the satellite. If a snowfall occurs preceding the observation, the ice cover is likely to be very visible in Band 6 or 7. If air temperatures were above freezing for awhile, the ice surface would have more of a grayish tone due to water and would be less recognizable.

(b) Transient Conditions

Transient conditions can be due to weather or due to the Prairie Island Plant operation above Dam No. 3. Transient conditions are always present, but their magnitude determines whether a quasi-steady-state analysis has a chance of success or not.

(c) Initial Water Temperatures at Dam No. 3

Water temperatures at Dam No. 3 are reported to the nearest 0.5^{o}C. A sensitivity analysis shows that under mean winter flow conditions (7,000 to 9,000 cfs) the predicted open water length changes with initial water temperature. Table E-1 gives the sensitivity of open water lengths with respect to upstream water temperature T_o, equilibrium temperature E, and bulk heat exchange coefficient K. The predominant influence of T_o is very apparent.

Tables E-2, E-3 and E-4 give a detailed account of the discrepancies between observed open water lengths and predictions by two different methods and for two different sets of initial water temperatures T_o. The equilibrium temperature method with upstream temperature from the U. S. Geological Survey records gave the closest agreement with a mean error of -0.15 miles.

For maximum waste heat rejection from the Prairie Island Plant the predictions of open water lengths are also affected by the initial T_o value as shown in Table E-5. Differences are much less than those on individual days, even though an error of 0.5^{o}C in T_o was used in the evaluation. The predicted open water reaches for full waste heat rejection can therefore be considered as quite reliable.

TABLE E-1. Sensitivity of Predicted Open Water Lengths to Upstream Water Temperature T_o, Equilibrium Temperature E, and Bulk Heat Exchange Coefficient K

	Main Channel			Wisconsin Channel		
Date	$\frac{\Delta X}{\Delta T_o}\Big\vert_{E,K}$	$\frac{\Delta X}{\Delta E}\Big\vert_{T_o,K}$	$\frac{\Delta X}{\Delta K}\Big\vert_{T_o,E}$	$\frac{\Delta X}{\Delta T_o}\Big\vert_{E_1 K}$	$\frac{\Delta X}{\Delta E}\Big\vert_{T_o,K}$	$\frac{\Delta X}{\Delta K}\Big\vert_{T_o,E}$
12/12/73	15.67	.78	-.11	6.62	.41	-.06
12/29/73	7.96	.25	-.04	2.60	.13	-.02
12/30/73	4.30	.09	-.02	.67	0	0
12/23/76	1.26	.09	-.02	0	0	0
12/21/78	4.33	.33	-.04	1.98	.15	-.02
12/30/78	2.80	.12	-.02	.48	0	0
01/16/74	18.32	1.54	-.13	7.28	.73	-.06
01/30/75	5.50	.31	-.08	2.56	.14	-.03
01/07/76	2.19	.04	-.01	0	0	0
01/16/76	4.57	.29	-.04	2.17	.14	-.02
01/09/77	1.14	.02	-.01	0	0	0
01/10/77	1.43	.02	-.01	0	0	0
01/04/78	7.97	.50	-.10	4.25	.27	-.05
01/05/78	9.55	.64	-.13	5.10	.34	-.07
01/08/79	2.52	.09	-.03	.55	.04	-.01
01/09/79	3.23	.18	-.03	1.13	.08	-.01
01/18/79	3.99	.19	-.06	1.72	.08	-.03
02/08/73	5.71	.13	-.02	1.40	.07	-.01
02/09/73	9.54	.25	-.08	3.34	.13	-.04
02/26/73	13.77	1.39	-.26	6.66	.67	-.13
02/22/74	7.69	.99	-.07	3.72	.48	-.03
02/02/76	4.15	.15	-.06	1.84	.07	-.03
02/15/77	1.73	.17	-.04	.30	.03	-.01
02/28/78	8.98	.42	-.06	2.44	.17	-.02

TABLE E-2

Summary of Discrepancies Between
Predictions (Method 1)* and Observations

	Main Channel			Wisconsin Channel		
Date	Observed Open Water (mi)	Predicted Open Water* (mi)	Difference (mi)	Observed Open Water (mi)	Predicted Open Water* (mi)	Difference (mi)
12/16/72	0	0	0	0	0	0
12/12/73	11.0	8.37	+2.63	6.8	2.8	+4.0
12/29/73	4.0	4.39	-0.39	0.0	0.73	-0.73
12/30/73	3.0	2.39	+0.61	0	0	0
12/23/76	2.2	1.96	+0.24	0	0	0
12/21/78	11.0	5.54	+5.46	1.0	1.16	-0.16
12/30/78	6.5	2.86	+3.64	0	0	0
1/4/73	0	0	0	0	0	0
1/16/74	0.0	9.82	-9.82	0.0	3.24	-3.24
1/30/75	9.0	6.26	+2.74	0.0	1.51	-1.51
1/7/76	0.0	1.10	-1.10	0	0	0
1/16/76	4.0	5.34	-1.34	0.0	1.11	-1.11
1/9/77	0.0	0.58	-0.58	0	0	0
1/10/77	0.0	0.72	-0.72	0	0	0
1/4/78	2.2	8.91	-6.71	0.0	3.15	-3.15
1/5/78	1.7	10.56	-8.86	0.0	4.04	-4.04
1/8/79	1.0	3.15	-2.15	0.0	0.06	-0.06
1/9/79	2.5	4.12	-1.62	0.0	0.47	-0.47
1/18/79	1.0	5.06	-4.06	0.0	0.89	-0.89
2/8/73	11.0	3.23	+7.77	3.0	0.12	+2.88
2/9/73	6.0	5.17	+0.83	0.0	1.11	-1.11
2/26/73	11.0	11.0	0	0.5	5.83	-5.33
2/3/74	0	0	0	0	0	0
2/22/74	11.0	8.79	+2.21	0.89	2.80	-1.91
2/2/76	1.0	4.82	-3.82	0.0	0.87	-0.87
2/15/77	11.0	3.80	+7.20	0.5	0.14	+0.36
2/28/78	8.5	4.85	+3.65	0.0	0.76	-0.76
Mean Difference (mi)			-0.15			-0.67
Stand. Dev. of Difference (mi)			4.19			1.85
Mean Absol. Difference			2.89			1.21
Maximum Absolute Difference (mi)			9.82			5.33
Minimum Absolute Difference (mi)			0			0

*Based on the equilibrium temperature method and water temperatures T_o at Dam No. 3 T.W. given in the USGS Water Resources Data for Minnesota.

TABLE E-3

Summary of Discrepancies Between
Prediction (Method 2)* and Observations

	Main Channel			Wisconsin Channel		
Date	Observed Open Water (mi)	Predicted Open Water* (mi)	Difference (mi)	Observed Open Water (mi)	Predicted Open Water* (mi)	Difference (mi)
12/16/72	0	0	0	0	0	0
12/12/72	11.0	7.42	3.58	6.8	2.31	4.49
12/29/73	4.0	4.46	-.46	0	.76	-.76
12/29/73	3.0	2.73	.27	0	0	
12/23/76	2.2	2.70	-.50	0	0	
12/21/78	11.0	6.21	4.79	1.0	1.46	-.46
12/30/78	6.5	3.78	2.72	0	.35	-.35
1/4/73	0	0	0	0	0	
1/16/73	0	10.34	-10.34	0	3.49	-3.49
1/30/75	9.0	6.03	2.97	0	1.41	-1.41
1/7/76	0	1.61	-1.61	0	0	
1/16/76	4.0	5.70	-1.70	0	1.28	-1.28
1/9/77	0	.73	-.73	0	0	
1/10/77	0	.91	-.91	0	0	
1/4/78	2.2	8.6	-6.4	0	2.98	-2.98
1/5/78	1.7	11.0	-9.3	0	4.71	-4.71
1/8/78	1.0	3.63	-2.63	0	.27	-.27
1/9/79	2.5	5.08	-2.58	0	.88	-.88
1/18/79	1.0	5.06	-4.06	0	.89	-.89
2/8/73	11.0	3.38	7.62	3.0	0	2.8
2/9/73	6.0	4.82	1.18	0	.93	-.93
2/26/73	11.0	11.0	0	.5	4.44	-3.94
2/3/74	0	0	0	0	0	
2/22/74	11.0	11.0	0	.89	3.95	-3.06
2/2/76	1.0	5.52	-4.52	0	1.2	-1.2
2/15/77	11.0	5.04	5.96	0.5	.36	.14
2/28/78	8.5	4.88	3.62	0	.77	-.77
Mean Difference (mi)			-0.48			-0.73
Stand. Dev. of Difference (mi)			4.13			1.82
Mean Absol. Difference (mi)			2.90			1.28
Maximum Absolute Difference (mi)			10.34			4.71
Minimum Absolute Difference (mi)			0			0

*Based on the method by Paily et al and water temperatures T_o at Dam No. 3 T.W. given in the USGS Water Resources Data for Minnesota.

TABLE E-4

Summary of Discrepancies Between
Predictions (Method 3)* and Observations

	Main Channel			Wisconsin Channel		
Date	Observed Open Water (mi)	Predicted Open Water* (mi)	Difference (mi)	Observed Open Water (mi)	Predicted Open Water* (mi)	Difference (mi)
12/16/72	0	0	0	0	0	0
12/12/72	11.0	0	11.0	6.8	0	6.8
12/29/73	4.0	0	4.0	0	0	0
12/30/73	3.0	0	3.0	0	0	0
12/23/76	2.2	0.35	1.85	0	0	0
12/21/78	11.0	2.32	8.68	1.0	0	1.0
12/30/78	6.5	0.79	5.71	0	0	0
1/4/73	0	0	0	0	0	0
1/16/74	0	0	0	0	0	0
1/30/75	9.0	1.01	7.99	0	0	0
1/7/76	0	0.09	-0.09	0	0	0
1/16/76	4.0	0.96	3.04	0	0	0
1/9/77	0	0.26	-0.26	0	0	0
1/10/77	0	0.29	-0.29	0	0	0
1/4/78	2.2	1.10	1.10	0	0	0
1/5/78	1.7	1.21	.49	0	0	0
1/8/79	1.0	0.59	.41	0	0	0
1/9/79	2.5	1.11	1.39	0	0	0
1/18/79	1.0	1.39	-0.39	0	0	0
2/8/73	11.0	0	11.0	3.0	0	3.0
2/9/73	6.0	0	6.0	0	0	0
2/26/73	11.0	0	11.0	0.5	0	0.5
2/3/74	0	0	0	0	0	0
2/22/74	11.0	1.25	9.75	0.89	0	0.89
2/2/76	1.0	0.92	0.08	0	0	0
2/15/77	11.0	0.40	10.60	0.5	0	0.5
2/28/78	8.5	0.68	7.82	0	0	0
Mean Difference (mi)			3.84			.47
Stand. Dev. of Difference (mi)			4.11			1.41
Mean Absol. Difference (mi)			3.92			.47
Maximum Absolute Difference (mi)			11.0			6.8
Minimum Absolute Difference (mi)			0			0

*Based on the equilibrium temperature method and on water temperatures T_o at Dam No. 3 T.W. computed from the NSP Thermal Effluent Reports.

TABLE E-5

Predicted Open Water Lengths (miles) Below Dam No. 3
for Water Temperatures T_o or $T_o - 0.5^oC$ (in parenthesis) and
Full Waste Heat Rejection from the Prairie Island Plant

	Mississippi Mainstem				Wisconsin Channel			
Month	Case 1*		Case 2**		Case 1*		Case 2**	
November	11.0	(11.0)	11.0	(11.0)	6.8	(6.8)	6.53	(5.20)
December	11.0	(11.0)	5.50	(4.35)	6.8	(6.8)	1.26	(0.68)
January	11.0	(11.0)	4.11	(3.38)	5.96	(4.71)	0.52	(0.18)
February	11.0	(11.0)	4.68	(3.86)	6.8	(6.8)	0.78	(0.40)
March	11.0	(11.0)	10.62	(8.55)	6.8	(6.8)	4.05	(2.95)

* Referring to Table 8, p. 13 with data input from Tables 5, A-1 and 9.

** Referring to Table 8, p. 13 with data input from Tables 6, A-1 and 9.

APPENDIX F

FLOW AND WEATHER DATA

TABLE F-1

Estimates of
Mississippi River Flow Rates Between
Lock & Dam No. 3 & Lake Pepin*

Date	Flow (cfs)	Date	Flow (cfs)
Nov 28, 1972	19,400	Jan 7, 1976	8,020
Nov 29, 1972	15,400	Jan 16, 1976	9,070
Dec 16, 1972	12,100	Feb 2, 1976	9,250
Jan 4, 1973	11,900	Mar 10, 1976	14,600
Feb 8, 1973	11,400	Mar 28, 1976	33,900
Feb 9, 1973	11,100	Nov 16, 1976	3,010
Feb 26, 1973	9,460	Nov 17, 1976	3,660
Mar 17, 1973	61,700	Dec 23, 1976	3,420
Nov 5, 1973	21,300	Jan 9, 1977	3,680
Nov 6, 1973	21,100	Jan 10, 1977	3,730
Dec 12, 1973	12,000	Feb 15, 1977	3,880
Dec 29, 1973	12,200	Mar 22, 1977	18,300
Dec 30, 1973	11,400	Mar 23, 1977	17,900
Jan 16, 1974	9,100	Nov 11, 1977	14,700
Feb 3, 1974	8,430	Nov 12, 1977	16,300
Feb 22, 1974	9,450	Jan 4, 1978	13,200
Mar 12, 1974	17,700	Jan 5, 1978	13,400
Nov 1, 1974	7,580	Jan 23, 1978	9,200
Dec 7, 1974	9,780	Feb 28, 1978	7,030
Jan 30, 1975	8,680	Mar 26, 1978	23,100
Feb 8, 1975	8,330	Mar 27, 1978	25,500
Mar 15, 1975	9,240	Dec 21, 1978	8,840
Mar 25, 1975	13,800	Dec 30, 1978	7,920
Nov 4, 1975	10,300	Jan 8, 1979	7,460
Nov 5, 1975	10,100	Jan 9, 1979	7,390
Nov 14, 1975	13,000	Jan 18, 1979	7,620
Nov 22, 1975	15,600	Mar 12, 1979	8,000

*Prescott measurements lagged by one day.

TABLE F-2

Highest Daily Average Wind Speed (MPH) at St. Paul

	Nov	Dec	Jan	Feb	March
1968	14.7	19.1	15.7	18.0	18.8
1969	17.0	16.0	17.1	16.3	18.6
1970	24.2		15.4	17.1	16.7
1971	21.1	12.8	20.1	26.6	18.3
1972	15.8	16.8			
1973	16.7	17.5	17.3	20.4	14.4
1974	15.7	15.8	12.5	16.7	16.0
1975		14.5	25.3	22.4	20.4
1976	17.1	18.0	17.0	15.4	20.1
1977	22.6	17.8	21.4	19.0	19.0
1978	17.8	18.6	21.6	16.8	16.8
Mean	18.3	16.7	18.3	18.9	17.9

Lowest Daily Average Wind Speed (MPH) at St. Paul

	Nov	Dec	Jan	Feb	March
1968	3.5	2.5	5.5	4.0	4.5
1969	5.8	2.3	5.9	2.0	3.5
1970	4.5		5.3	3.0	3.7
1971	3.3	4.6	5.9	6.5	3.9
1972	3.6	3.9			
1973	5.8	3.9	3.5	4.9	5.3
1974	5.3	3.6	3.2	2.2	6.5
1975		4.2	4.3	3.9	3.5
1976	4.6	3.6	4.8	4.2	5.2
1977	5.5	5.0	2.3	6.8	5.2
1978	4.0	5.0	5.2	2.9	4.3
Mean	4.6	3.9	4.6	4.0	4.6

TABLE F-3

Highest Daily Average Air Temperature (°F) at St. Paul

	Nov	Dec	Jan	Feb	Mar
1968	53	39	35	31	62
1969	54	40	31	36	41
1970	43		33	35	37
1971	48	34	25	35	53
1972	48	32			
1973	51	37	38	34	54
1974	53	34	34	32	43
1975		37	33	30	39
1976	50	36	30	44	51
1977	56	38	28	39	55
1978	61	33	27	30	58
Mean	51.7	36.0	31.4	34.6	49.3

Lowest Daily Average Air Temperature (°F) at St. Paul

	Nov	Dec	Jan	Feb	Mar
1968	25	-16	-17	-2	21
1969	11	9	-11	-4	4
1970	10		-22	-13	18
1971	18	-4	-9	-12	14
1972	22	-11			
1973	21	-15	-10	-2	32
1974	21	11	-21	-2	5
1975		-2	-5	-10	6
1976	4	-13	-12	-5	11
1977	-3	-11	-22	-1	20
1978	7	-4	-10	-6	2
Mean	13.6	-5.6	-13.9	-5.7	13.3

TABLE F-4

Highest Daily Average Dew Point Temperature (°F) at St. Paul

	Nov	Dec	Jan	Feb	March
1968	42	43	31	28	44
1969	44	30	28	32	32
1970	37		30	28	33
1971	44	31	24	32	37
1972	41	30			
1973	41	34	33	31	46
1974	50	31	31	28	33
1975		32	32	25	33
1976	32	23	23	32	43
1977	52	38	20	29	44
1978	46	23	25	24	44
	42.9	31.5	27.7	28.9	38.9

Lowest Daily Average Dew Point Temperature (°F) at St. Paul

	Nov	Dec	Jan	Feb	March
1968	17	-27	-29	-19	-2
1969	8	7	-23	-16	-9
1970	-2		-29	-27	3
1971	5	-15	-23	-24	2
1972	10	-24			
1973	8	-25	-20	-20	5
1974	15	2	-30	-12	-15
1975		-18	-15	-22	-1
1976	-11	-27	-28	-17	6
1977	-13	-21	-31	-13	7
1978	-5	-16	-24	-16	-9
	3.2	-16.4	-25.2	-18.6	-1.3

TABLE F-5

Average Daily Dew Point Temperature (^{o}F) at St. Paul

	Nov	Dec	Jan	Feb	March
1968	28	11	8	3	22
1969	27	17	2	11	17
1970	24		0	8	15
1971	26	13	-3	9	18
1972	25	5			
1973	26		9	14	29
1974	27	19	5	9	18
1975		13	10	9	16
1976	13	1	3	18	22
1977	24	9	-9	12	27
1978	21	6	-2	4	19
Mean	24.1	9.4	2.3	9.7	20.3

TABLE F-6

Daily Solar Radiation (cal $cm^{-2} day^{-1}$) at St. Paul (1963-1977)

	Nov	Dec	Jan	Feb	March
Max. Rad.	281	273	312	417	598
Mean clear day Rad.	233	186	219	337	474
Min. Rad.	1	13	10	7	22

APPENDIX G

Aerial Observations on February 2, 1980

A set of aerial photographs taken on February 2, 1980, is presented in this appendix. The photos were taken between 10:30 and 11:30 a.m. February 2 was the first warm day after several days with air temperatures near and below 0^{o}F. One unit of the Prairie Island Plant was in operation (Fig. G-1). The ice cover was in a transition phase (breaking up and melting). Fig. G-2 is a close-up view of Dam No. 3 showing open water below the dam. More open water and drift ice are apparent in Figs. G-3 and G-4. Evert's Resort is on the right edge (center) of Fig. G-4. There was broken shore ice in front of the resort and a narrow man-made channel was made through it. The Wisconsin channel, shown in Fig. G-5, was frozen over solidly. As a result of the very cold weather, the river mainstem near Red Wing and in the lower part of the Delta was frozen over, as seen in Figs. G-6 and G-7. Several open water patches could be seen along the river mainstem. Also, the surface texture of the ice in the main channel appeared rougher and its color darker than in the backwaters.

Fig. G-1. Aerial View Showing Cooling Water Discharge from the Prairie Island Nuclear Plant. (February 2, 1980)

Fig. G-2. Aerial View of Tailwater
Below Dam No. 3.
(February 2, 1980)

Fig. G-3. Aerial View of Open Water and Drift Ice Below Dam No. 3. (February 2, 1980)

Fig. G-4. Aerial View of Open Water and Drift Ice Below Dam No. 3 Near Evert's Resort after Cold Weather Period with Air Temperatures Near and Below $0^{\circ}F$. (February 2, 1980)

Fig. G-5. Aerial View of the Branching Point Between Mississippi River Mainstem and Wisconsin Channel. (February 2, 1980)

Fig. G-6. Aerial View of the Mississippi River
and Red Wing, Minnesota.
(February 2, 1980)

Fig. G-7. Aerial View of the Mississippi River Delta Looking Upstream from Lake Pepin. (February 2, 1980)

APPENDIX H

NSP On-site Observations, Winter 1979/80

During the winter of 1979-1980, NSP employees under the direction of Tom Zajicek conducted on-site observations of ice conditions and river access. Observations were made from Lock & Dam No. 3, Everts Resort, and other river access points. Water and air temperature, extent of ice coverage, and number of boats on the river were recorded. The observations were made on a random basis and were not consistent in terms of the data taken or the locations from which observations were made. This, therefore, resulted in some discrepancies in the analysis of the data.

The observations were made at ground level. The river is termed "open" if it is open for as far down stream as the observer can see from the dam. It is termed "open" at the access points if there is an open channel and no shore ice exists. On at least one occasion, a boat was in the water even though there was shore ice at all access points.

The results of these observations, limited to only one winter (1979/80) and a total of 21 days, are reported in Tables H-1, H-2, and H-3. Accessibility of the water below Dam No. 3 reported in Table H-3 (field observations) and in Table 10 (satellite images) are in fair agreement.

TABLE H-1. NSP Water Temperature and Ice Observations at Lock and Dam No. 3

Date	Water* Temp. (°C)	Distance Open (mi)	No. of Boats Below Dam	Air Temp. (°F)
12-17-79	--	.7	0	--
12-21-79	--	open	2	40
12-26-79	0.5	open	0	34
1-27-79	0.5	open	1	--
1-2-80	--	open	2	30
1-8-80	--	.7	0	0
1-14-80	0.3	1.5	0	30
1-21-80	--	open	0	32
1-22-80	0.4	1.5	0	--
1-23-80	0.1	1.0	0	--
1-24-80	--	2.0	0	24
1-29-80	--	0.1	0	5
1-31-80	0.2	0.1	0	--
2-1-80	0.2	0.1	0	--
2-12-80	--	open	1	18
2-13-80	--	open	5+	--
2-18-80	0.5	open	5	29
2-19-80	--	open	--	34
2-20-80	--	open	11	38
2-25-80	--	open	1	10
2-26-80	--	--	0	16
2-27-80	0.4	1.0	1	--

*Water temperature taken just below roller gates.
+Based on number of cars at Everts' Resort landing.

TABLE H-2. Access to River

Date	Evert's Resort	Hwy 63 Wisc. Channel	Hwy 63 Main Stem	Colville Park	Bay Point Park
12-17-79	no	no	--	--	--
12-21-79	yes	no*	no*	no	no
12-26-79	yes	yes	yes	no	no
1-2-80	yes	yes	yes	no	no
1-8-80	no	no	no	no	no
1-14-80	no	no	no	no	no
1-21-80	no*	no	no	no	no
1-24-80	no	no	no	no	no
1-29-80	no	no	no	no	no
2-12-80	no*	no	no	no	no
2-13-80	yes	--	--	no	no
2-20-80	yes	no	no*	no	no
2-26-80	no	no	no	no	no

*Signifies open water but access prevented by presence of shore ice.

TABLE H-3. Accessibility of Tailwater Below Dam No. 3
(1979/80 observations by NSP)

Access	# of observ. made	# of observ. w/open water access	% of observ. w/open water access
Access from Everts Resort (Point 1)			
December	3	2	67
January	6	1	17
February	4	2	50
Access from Red Wing Yacht Club (Bay Point Park)(Point 3)			
December	3	0	0
January	6	0	0
February	4	0	0
Access from Hwy 63 at Mainstem (Point 4)			
December	2	1	50
January	6	1	17
February	3	0	0
Access from Hwy 63 at Wisc. Channel (Point 2)			
December	3	1	33
January	6	1	17
February	3	0	0
Accessibility based on observations of boats below Dam No. 3			
December	3	1	33
January	10	2	20
February	8	5	67

No access possible from Colville Park or Bay Point Park (Red Wing Yacht Club)

APPENDIX I

PREDICTION OF RIVER ICE COVER WITH AND WITHOUT PLANT HEAT DISCHARGE

A comparison of predicted ice covers below Dam No. 3 is given for monthly conditions for maximum waste heat rejection and for zero waste heat rejection from the Prairie Island Plant. The predictions are the output from a one-dimensional model presented earlier. Input data were median monthly flows and minimum monthly flows, as reported in Table 3. Ambient water temperatures at Dam No. 3 were averages of 1969-1974 as reported in Table 7. The first set of predictions assumes a plant heat rejection of $8.34*10^9$ BTU/hr resulting in a water temperature increment added to the values given in Table 7. The second prediction assumes zero plant discharge.

TABLE I-1. Prediction of Ice Cover

Month	Discharge	With Plant Discharge*		Without Plant Discharge	
		Open Water		Open Water	
		Main Stem	Wisc. Ch.	Main Stem	Wisc. Ch.
	(cfs)	(mi)	(mi)	(mi)	(mi)
Case 1: Mean weather, median flow**					
Nov	14,300	11.0	6.8	11.0	6.8
Dec	10,600	11.0	6.8	6.52	1.78
Jan	8,850	11.0	6.0	2.38	0.0
Feb	8,600	11.0	6.8	6.43	1.59
Mar	13,000	11.0	6.8	11.0	6.8
Case 2: High heat loss, median flow**					
Nov	14,300	11.0	6.5	7.83	2.60
Dec	10,600	5.5	1.3	0.32	0.0
Jan	8,850	4.1	0.5	0.0	0.0
Feb	8,600	4.7	0.8	0.0	0.0
Mar	13,000	10.6	4.0	3.86	0.46
Case 3: Low heat loss, median flow**					
Nov	14,300	11.0	6.8	11.0	6.8
Dec	10,600	11.0	6.8	11.0	6.8
Jan	8,850	11.0	6.8	11.0	6.8
Feb	8,600	11.0	6.8	11.0	6.8
Mar	13,000	11.0	6.8	11.0	6.8
Case 4: Mean weather, average minimum flow**					
Nov	11,600	11.0	6.8	11.0	6.8
Dec	7,480	11.0	6.8	4.89	0.80
Jan	7,460	11.0	5.56	2.01	0.0
Feb	7,560	11.0	6.8	5.78	1.19
Mar	8,270	11.0	6.8	11.0	6.8
Case 5: High heat loss, average minimum flow**					
Nov	11,600	11.0	5.62	6.53	1.83
Dec	7,480	5.47	1.10	0.23	0.0
Jan	7,460	4.12	0.50	0.0	0.0
Feb	7,560	4.68	0.75	0.0	0.0
Mar	8,270	9.55	3.06	2.66	0.0
Case 6: Low heat loss, average minimum flow**					
Nov	11,600	11.0	6.8	11.0	6.8
Dec	7,480	11.0	6.8	11.0	6.8
Jan	7,460	11.0	6.8	11.0	6.8
Feb	7,560	11.0	6.8	11.0	6.8
Mar	8,270	11.0	6.8	11.0	6.8

* Head rejection = $8.34*10^9$ BTU/hr.

** Case numbers referring to Table 8, p. 13.