University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 281

EFFECT OF THE HASTINGS HYDROPOWER PROJECT AT LOCK AND DAM NO. 2 ON DISSOLVED OXYGEN IN THE MISSISSIPPI RIVER

by

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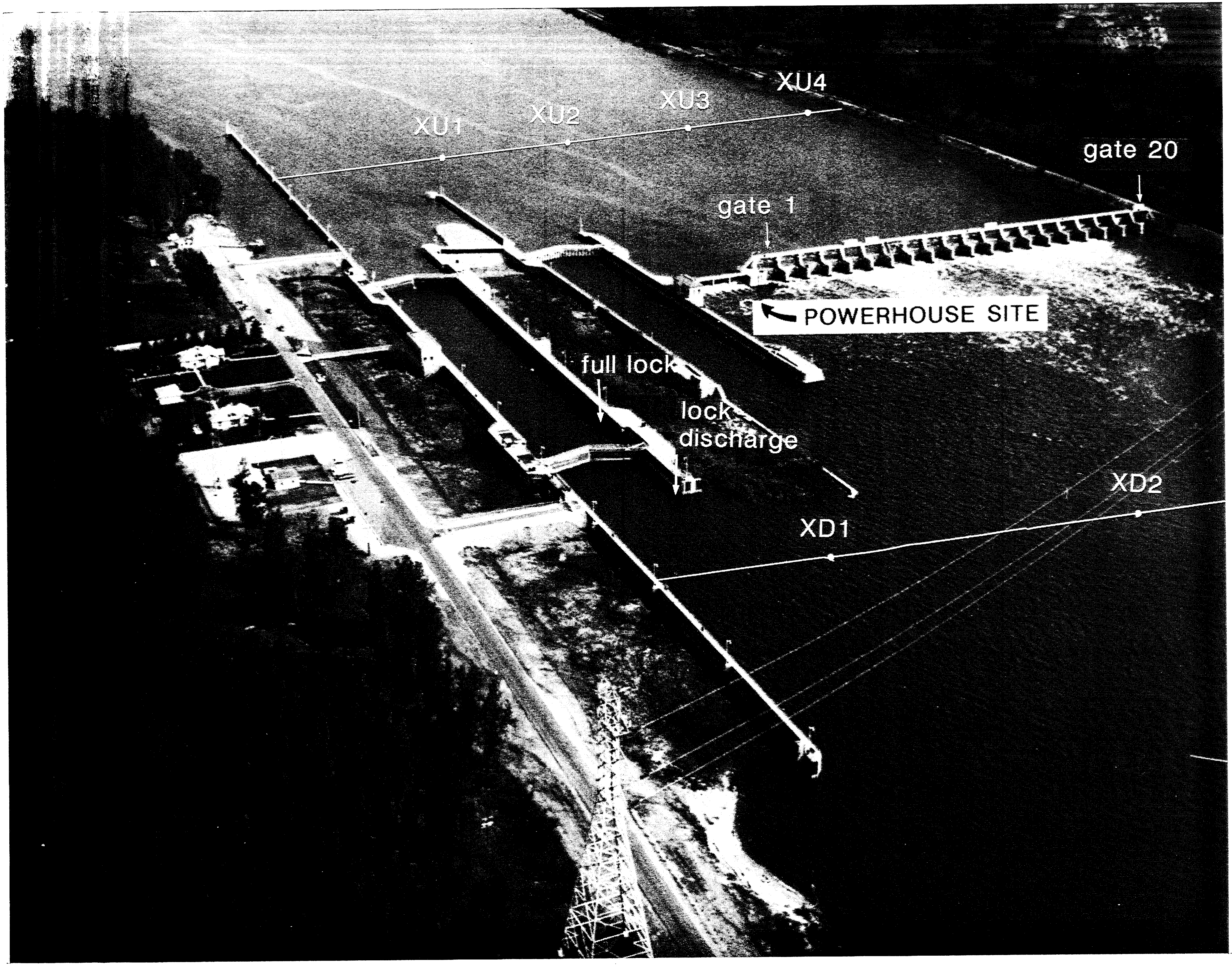
Frontispiece: Aerial view of Lock and Dam No. 2, May 1972, with sampling locations for the surveys from the boat for summer 1988.


XU1
XU2
XU3
XU4
gate 20
gate 1
POWERHOUSE SITE
full lock
lock discharge
XD1
XD2

ACKNOWLEDGEMENTS

The authors would like to thank the City of Hastings staff and the Corps of Engineers staff at Lock and Dam No. 2 for their cooperation and assistance during the field study. Anne Midje, John Groethe, Franz Westermeier, and Steve Wilhelms each assisted in a field survey. Anne Midje reduced and plotted most of the data. Franz Westermeier performed the analysis of the historical data. The authors would also like to thank Alan Rindels and the Metropolitan Waste Control Commission for providing their data. Chris Ellis provided information on the operation of Lock and Dam No. 2.

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I. INTRODUCTION

In 1987, the City of Hastings completed a new hydropower plant on the Mississippi River at Lock and Dam No. 2. That facility was constructed in the place of a fixed crest Boulé Dam. As part of the Federal Energy Regulatory Commission's licensing procedure, the City of Hastings is required to study and document the impact of their operation on dissolved oxygen (D.O.) downstream of the structure.

The development of hydropower at a site such as Lock and Dam No. 2 can impact the downstream dissolved oxygen (D.O.) concentration. Prior to development, water is spilled over spillways, bulkheads, and under tainter gates. When water is released in this fashion, large quantities of air are often entrained into the flow in the form of bubbles. These bubbles have a large surface area, which facilitates the transfer of oxygen to the water. This oxygen transfer, or reaeration, which occurs at hydraulic structures often improves water quality significantly. By diverting this flow away from the various aerating outlet structures to the hydropower plant, a significant loss in the improvement of water quality can occur. It is this loss, or impact, due to hydropower operation that is of concern.

The Minnesota Pollution Control Agency (MPCA) is responsible for establishing and enforcing the water quality criteria for the power plant operation. The following water quality criteria were given in a letter from the MPCA to the City of Hastings (December 23, 1986):

1. The instantaneous minimum D.O. water quality standard is 5.0 mg/ℓ downstream from the dam. The intake of water for the turbines should not **cause** D.O. downstream from the dam to fall below 5.0 mg/ℓ. Therefore, the hydroplant will be expected to meet the following conditions with regard to D.O.:

    a. Incoming water above the 5 mg/ℓ D.O. standard need not be reaerated.

    b. During the infrequent periods when the incoming D.O. is less than 5 mg/ℓ and the hydroplant is still operating, the water should be reaerated. The hydroplant only needs to replace the D.O. that the dam would have provided under similar conditions.

    c. When the hydroplant is not operating and water is going over the dam, the plant is not responsible for downstream water meeting the D.O. standard.

The letter goes on to list the requirements of an impact assessment for the Hastings hydroelectric project:

In summary, the assessment must include an analysis of the following factors:

Existing Conditions:

1. Analysis of flows for the various modes of water released at the dam.

2. A sampling program upstream, downstream, and at depth for a true dissolved oxygen profile of the existing conditions.

3. Analysis of the reaeration (r) values for various water releases based on the sampling program.

4. An analysis of how the calculated reaeration values and historical river water quality will affect the river at low flows.

5. An analysis of the potential impacts of the turbines in light of extended historical low flow and D.O. data. The data should be compared to Minnesota standards.

Predicted Conditions

1. An analysis of the flow with the turbines in place.

2. Predicted effects of the turbines at critical flows, especially low flows.

3. A predicted need for mitigation or other action.

4. Analysis of the acceptability of the reaeration system proposed and recommended further measures.

The MPCA recommended that, "This analysis would require that a simple model for assessing the impact also be developed."

The City of Hastings has contracted with the St. Anthony Falls Hydraulic Laboratory to provide the required impact assessment.

II. PHYSICAL CONDITIONS AND OPERATION OF LOCK AND DAM NO. 2

Lock and Dam No. 2 on the Mississippi River (Figs. II–1 and frontispiece), consists of one operational and one non–operational lock, twenty tainter gates of 30 ft width and, formerly one fixed crest Boulé Dam which was replaced by a four megawatt hydropower plant in 1987.

The gates are operated to maintain an upper pool elevation between 686.5 ft and 687.2 ft above mean sea level (1912 adj.), for river flows below 61,000 cfs (Table II–1 and Fig. II–2). Above this flow the gates are pulled completely out of the water, and the dam no longer controls the flow.

Gate 20 (farthest from the locks) has been permanently removed and a storage area has been constructed in its place. Before 1987, a Boulé spillway existed between the tainter gates and the locks (Fig. II–1 and frontispiece). Cross sections through the Boulé Dam and tainter gates are given in Figs. II–3 and II–4. The spillway was 100 ft wide with a crest at 686.0 ft, or 0.5 to 1.2 ft below the controlled pool elevation. Table II–2 gives the Boulé spillway discharge as a function of pool elevation.

Before development of hydropower, the dam was operated in the following manner [Corps of Engineers, 1973 and Yule, 1989]:

1) The Boulé Dam discharged from 132 cfs to 500 cfs (for normal pool elevations), at all times.

2) Two gates were bulkheaded to elevation 683.8 ft and water was allowed to discharge over the top of them as a free overfall. The combined discharges varied from 890 cfs to 1,250 cfs (for normal pool elevations).

3) Intermittently, water was released due to drainage of the lock.

4) Excess discharge, then, is released under the remaining 17 gates. First, at low river discharges, the gates were opened just 0.5 ft each. Thus, the number of gates operated was the total opening required divided by 0.5 ft. Then, at higher discharges, and once all 17 (remaining) gates were in use, they were opened uniformly at a single opening equal to the total opening required divided by 17. Gate discharge per foot of gate opening is given as a function of head in Table II–3.

The hydropower facility was constructed between the tainter gates and the locks, replacing the Boulé Dam and has been in operation since November

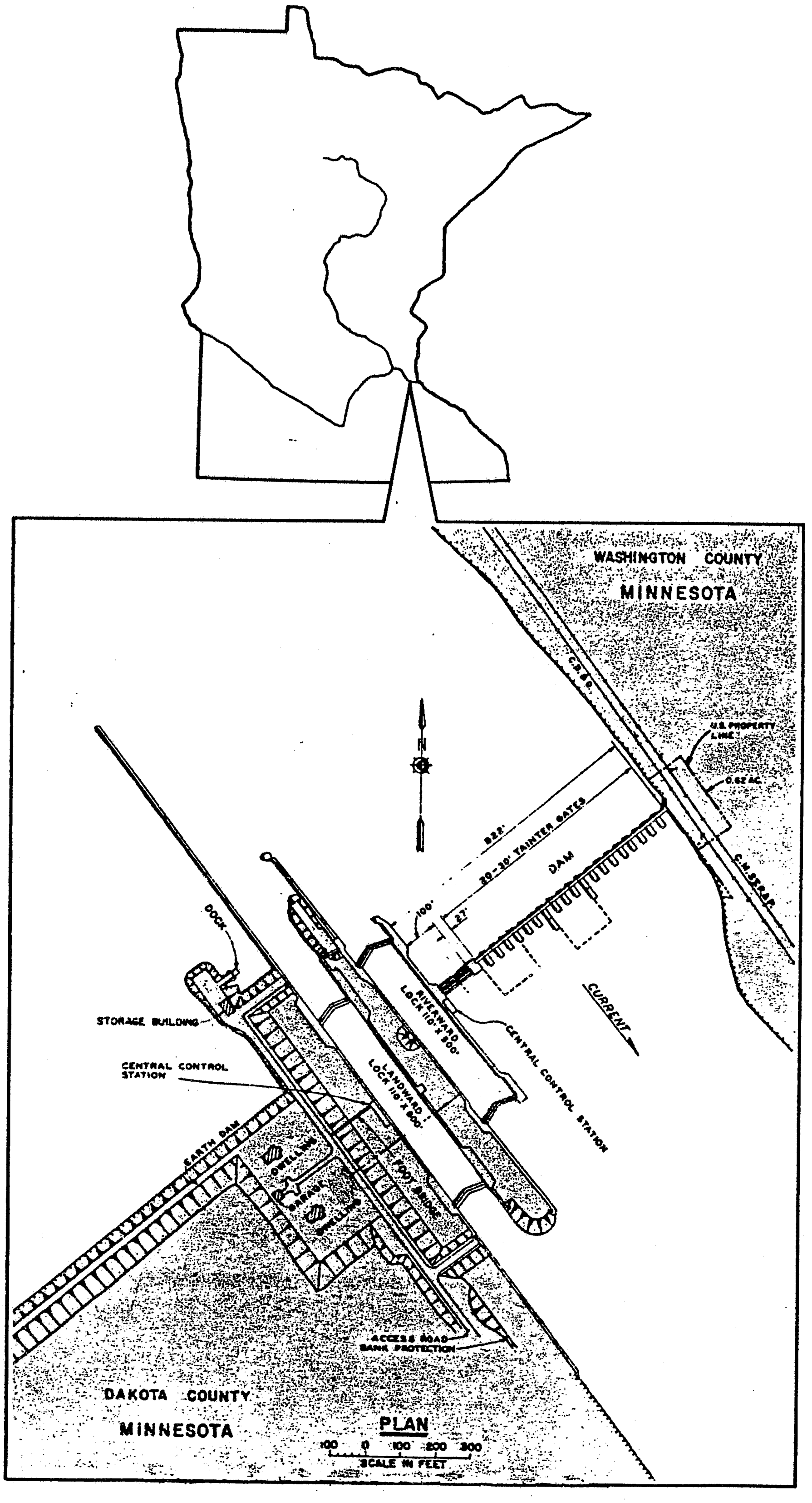

Fig. II–1. Lock and Dam No. 2 location map [Ellis and Stefan, 1987].

TABLE II–1 – Lock and Dam No. 2 – Tainter Gate (T.G.*) Regulation Schedule [from Corps of Engineers, 1973].

Total Discharge (cfs)	Total T. G. Opening (ft)	Elevation		Head (ft)	T.G. Discharge Per Foot Opening (cfs/ft)	Total T.G. Discharge (cfs)	Spillway Discharge (cfs)	Maximum Allowable T.G. Opening (ft) Gates #	
		Pool (ft)	T.W. (ft)					1 – 7 12 – 20	8 – 11
3,000	3.3	687.12	675.15	11.97	781	2,577	446	1.7	2.5
4,000	4.6	687.10	675.20	11.90	778	3,579	433	1.7	2.5
5,000	6.0	687.03	675.30	11.73	771	4,626	386	1.8	2.5
6,000	7.3	687.00	675.35	11.65	768	5,606	366	1.8	2.5
7,000	8.8	686.92	675.40	11.52	763	6,714	329	1.8	2.5
8,000	10.2	686.85	675.50	11.35	757	7.721	297	1.8	2.6
9,000	11.6	686.78	675.58	11.20	751	8,712	264	1.8	2.6
10,000	13.1	686.70	675.66	11.04	745	9,760	226	1.9	2.6
11,000	14.7	686.60	675.76	10.84	737	10,834	180	1.9	2.7
12,000	16.3	686.50	675.85	10.65	729	11,883	132	1.9	2.7
13,000	17.8	686.50	675.95	10.55	725	12,905	132	2.0	2.7
14,000	19.3	686.50	676.05	10.45	721	13,915	132	2.0	2.8
15,000	20.7	686.50	676.15	10.35	717	14,842	132	2.0	2.8
16,000	22.3	686.50	676.25	10.25	713	15,900	132	2.1	2.9
17,000	23.8	686.50	676.40	10.10	707	16,827	132	2.1	2.9
18,000	25.4	686.50	676.50	10.00	703	17,856	132	2.2	3.0
19,000	27.1	686.50	676.65	9.85	696	18.862	132	2.2	3.0
20,000	28.8	686.50	676.80	9.70	690	19,872	132	2.2	3.1
21,000	30.6	686.50	676.95	9.55	683	20,900	132	2.3	3.1
22,000	32.4	686.50	677.10	9.40	676	21,902	132	2.3	3.2
23,000	34.2	686.50	677.25	9.25	670	22,914	132	2.4	3.2
24,000	36.1	686.50	677.40	9.10	662	23,898	132	2.4	3.3
25,000	38.2	686.50	677.60	8.90	653	24,945	132	2.5	3.4
26,000	40.2	686.50	677.80	8.70	644	25,889	132	2.6	3.5
27,000	42.3	686.50	678.00	8.50	636	26,903	132	2.7	3.5
28,000	44.5	686.50	678.20	8.30	627	27,902	132	2.7	3.6
29,000	46.8	686.50	678.40	8.10	618	28,922	132	2.8	3.7
30,000	49.3	686.50	678.65	7.85	607	29,925	132	2.9	3.8
31,000	51.7	686.50	678.90	7.60	597	30,865	132	3.0	3.9
32,000	54.5	686.50	679.15	7.35	586	31,937	132	3.1	4.1

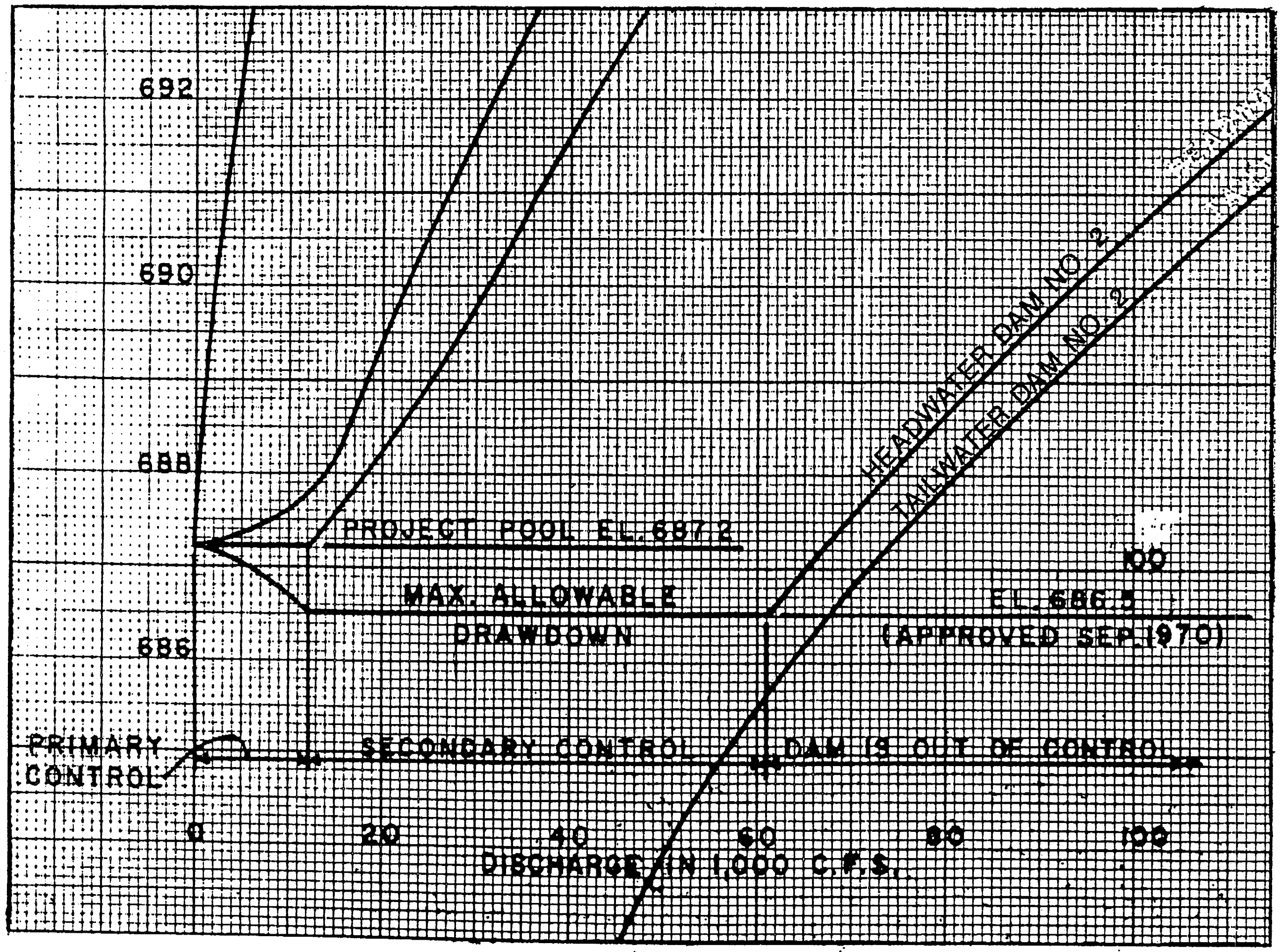

Fig. II–2. Lock and Dam No. 2 operating curves [Corps of Engineers, 1973].

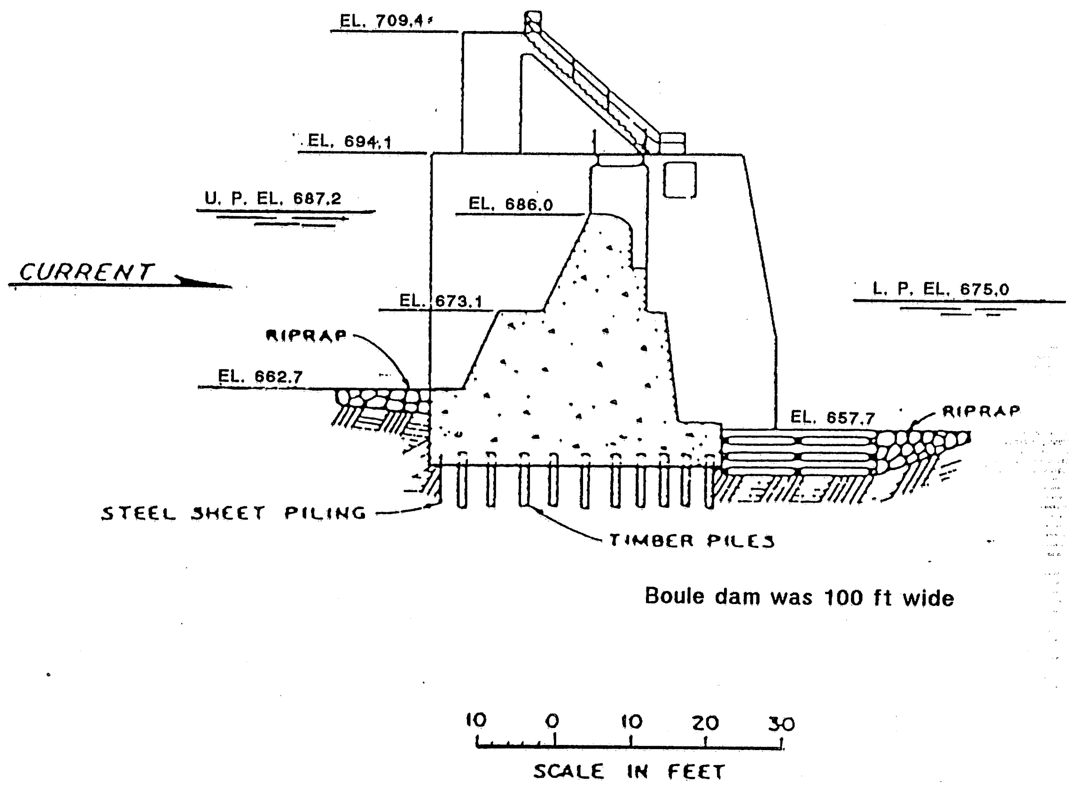

Fig. II–3. Cross section through the Boulé Dam [Corps of Engineers, 1973].

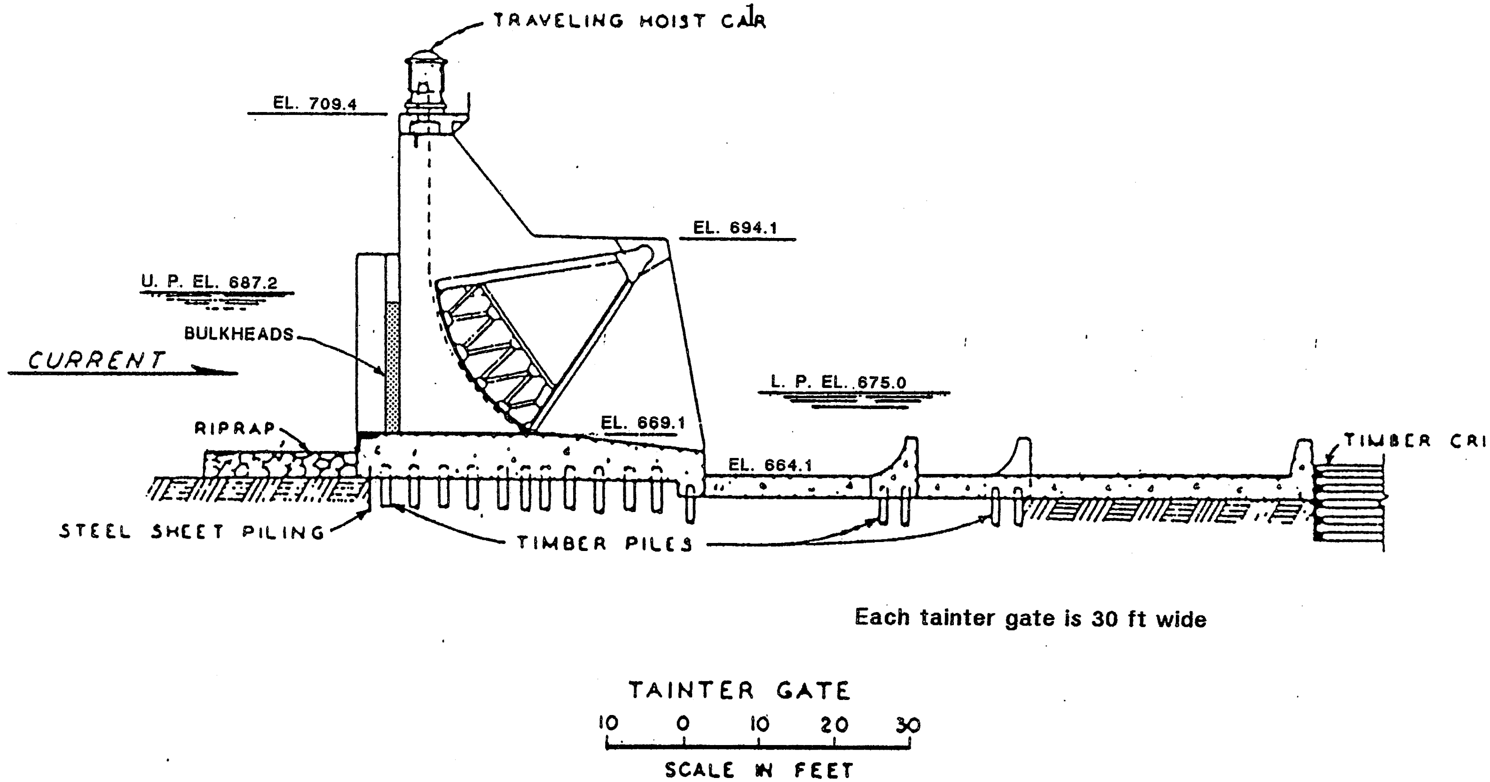

Fig. II–4. Cross section through tainter gates (No. 1–19) and stilling basin (No. 8–11) [Corps of Engineers, 1973].

TABLE II–2. Lock and Dam No. 2
Boulé Spillway Discharge

Pool Elevation	Discharge (cfs)
686.50	107
686.45	120
686.50	132
686.55	156
686.60	180
686.65	203
686.70	226
686.75	250
686.80	273
686.85	297
686.90	320
686.95	343
687.00	366
687.05	400
687.10	433
687.15	467
687.20	500
687.25	533
687.30	566
687.35	600
687.40	633

Note: When Lock and Dam No. 2 total discharge = 61,000 cfs, Pool No. 2 is at Elev. 686.5, and the dam is out of control [from Corps of Engineers, 1973].

TABLE II–3. Lock and Dam No. 2 Tainter Gate Discharge in cfs per foot of Gate Opening (Head = Pool Elevation – T.W. Elevation)

Head in Feet	Discharge in cfs/ft	Head in Feet	Discharge in cfs/ft	Head in Feet	Discharge in cfs/ft	Head in Feet	Discharge in cfs/ft
9.00	658	10.00	703	11.00	743	12.00	782
.05	660	.05	705	.05	745	.05	783
.10	662	.10	707	.10	747	.10	785
.15	665	.15	709	.15	749	.15	787
.20	667	.20	711	.20	751	.20	789
.25	670	.25	713	.25	753	.25	791
.30	672	.30	715	.30	755	.30	793
.35	674	.35	717	.35	757	.35	795
.40	676	.40	719	.40	759	.40	796
.45	679	.45	721	.45	761	.45	798
.50	681	.50	723	.50	763	.50	800
.55	683	.55	725	.55	764	.55	802
.60	685	.60	727	.60	766	.60	804
.65	687	.65	729	.65	768	.65	805
.70	690	.70	731	.70	770	.70	807
.75	692	.75	733	.75	772	.75	809
.80	694	.80	735	.80	774	.80	811
.85	696	.85	737	.85	776	.85	812
.90	699	.90	740	.90	778	.90	814
.95	701	.95	742	.95	780	.95	816

From Corps of Engineers [1973]

1987. It has a design capacity of 5,400 cfs. During the summer of 1988, the dam was required to discharge approximately 400 cfs for "water quality" purposes. Before July 29, that flow was released under gate 7; afterwards it was discharged over two bulkheaded gates, operating as overflow weirs. This minimum flow (Q_{min}) was set somewhat arbitrarily, pending a better water quality assessment. Thus for river flows below 5,400 cfs plus Q_{min}, the powerhouse operates below capacity to maintain the proper pool elevation and the dam passes Q_{min}. For river flows above this level, the powerhouse discharges 5,400 cfs while the dam passes the remaining flow. Because of decreasing head with increasing river flow, the hydropower facility is not operated at flows greater than 38,000 cfs.

In addition to the powerhouse and tainter gates, there is an intermittent discharge of water through the lock. The volume of water discharged by each lockage can be determined from the dimensions in the lock chamber, the head difference [Corps of Engineers, 1973], and the average number of lockages per day from Table II–4 (Corps of Engineers data). The discharge from the lock then, is given by

$$Q_L = n\ A\Delta h/T$$

where Q_L is the discharge through the lock (cfs), A is the plan area of the lock (ft^2), Δh is the lift of the lockage (ft), n is the number of lockages per month, and T is the number of seconds per month(s).

Data from the Corps of Engineers for the periods of June through September of 1983 to 1988 give the monthly average number of lockages as 843. With this figure the average discharge through the lock is:

$$Q_L = \frac{(843)(600')\,(110')(12.2')}{(30.5\ \text{days/mo})(86400\ \text{s/day})} = 258\ \text{cfs}$$

In the dissolved oxygen transfer model (Section VI), a lower value of Q_L = 200 cfs was used because many lockages will not require the filling and draining of the lock chamber.

The Metropolitan Waste Control Commission maintains an automatic water quality monitoring station at Lock and Dam No. 2 (RM 815.3). The monitor is located at the upstream end of the guidewall and withdraws water approximately 1 m below the water surface. The D.O. probe is calibrated once per week and the data from 1980–88 were made available by the MWCC.

TABLE II–4. Lock No. 2 Lockages

		1983	1984	1985	1986	1987	1988	Average
Commercial:				JUNE				
	single:	74	66	93	110	50	*	79
	double	159	149	110	87	113		124
	total:	392	364	313	284	276		326
Other:		17	5	15	12	10		12
Private:		382	303	407	499	504		419
Total:		791	672	735	795	790		757
Commercial:				JULY				
	single:	86	77	91	87	62	80	80
	double	153	133	122	116	112	85	120
	total:	392	342	335	319	286	250	321
Other:		23	26	15	23	15	16	20
Private:		581	530	644	649	1004	835	707
Total:		996	898	994	991	1305	1101	1048
Commercial:				AUGUST				
	single:	70	97	87	84	64	68	78
	double	202	144	124	144	143	128	148
	total:	474	385	335	372	350	324	373
Other:		16	21	20	12	12	17	16
Private:		468	492	508	575	558	461	510
Total:		958	898	863	959	919	802	900
Commercial:				SEPTEMBER				
	single:	100	100	84	72	51	*	81
	double	198	146	103	83	88		124
	total:	496	392	290	238	227		329
Other:		20	20	23	18	15		19
Private:		251	283	313	332	413		318
Total:		767	695	626	588	655		666
Average monthly lockages (June–Sept. 83–88)								843
Average monthly commercial								337
Average monthly private								489
Average monthly "other"								17

*Not available
Data from Corps of Engineers, St. Paul District [1988]

III. MODEL OF OXYGEN TRANSPORT AT LOCK AND DAM NO. 2

A model of oxygen transport for Lock and Dam No. 2 is needed to assess the impact of the Hastings hydropower development. This model can serve as a study and operational guide. A simple model is given as:

$$Q\bar{C}_d = Q\bar{C}_u + Q_L\Delta C_L + Q_b\Delta C_b + Q_g\Delta C_g + Q_T\Delta C_T + Q_{sp}\Delta C_{sp} \quad \text{(III-1)}$$

where

Q = total river flow
Q_L = flow through lock (intermittent)
Q_b = flow over bulkheads
Q_g = flow under tainter gates
Q_T = flow through turbine
Q_{sp} = flow over Boulé Dam (fixed crest spillway)
$\bar{C}_u$ = average D.O. concentration upstream of dam
$\bar{C}_d$ = average D.O. concentration downstream of dam
ΔC_L, ΔC_b, ΔC_g ΔC_T, ΔC_{sp} = D.O. increments of flow through lock, over bulkheads, under taintergates, through turbine, and over Boulé spillway, respectively.

Equation III–1 applies to the total river and the downstream D.O. concentration. $\bar{C}_d$ is the average concentration after the individual flows through the tainter gates, the powerhouse, the lock, etc. have become well–mixed.

The changes in D.O., called ΔC, are each dependent upon the type of outlet structure, the discharge, water temperature and upstream concentration. The values of ΔC will be computed using the reaeration constants (deficit ratio, r) as reported in Section V. Deficit ratio is given by:

$$\frac{1}{r} = \frac{C_s - C_d}{C_s - C_u} \qquad \text{(III-2)}$$

where C_s is the D.O. saturation concentration (a function of water temperature), C_u is the upstream concentration and C_d is the downstream concentration of the water discharged by the particular structure (mg/ℓ). (These C_u and C_d terms are different from the $\bar{C}_u$ and $\bar{C}_d$ terms in Eq. III–1.) The D.O. increment ΔC at a particular outlet structure is $\Delta C = C_d - C_u$.

Using the deficit ratio, the change ΔC can be computed from

$$\Delta C_i = \left[1 - \frac{1}{r_i}\right](C_s - C_u) \qquad \text{(III-3)}$$

It is important to note that besides being dependent on C_s, deficit ratio also is temperature dependent.

When the model is implemented, discharge, upstream concentration, and temperature will be varied to assess the impact of hydropower operation. Discharge will be set for the operating conditions given in Section II. The range of upstream concentrations and water temperatures to be used will be determined in Section IV–D. The use of this model will be covered in Section VI.

The average change in concentration can be computed as

$$\Delta\bar{C} = \frac{\Sigma\, \Delta C_i\, Q_i}{Q} \qquad \text{(III-4)}$$

and with that the average downstream concentration $\bar{C}_d$ is:

$$\bar{C}_d = \bar{C}_u + \Delta\bar{C} \qquad \text{(III-5)}$$

IV. FIELD INVESTIGATIONS – SUMMER 1988

The field investigation program during the summer of 1988 was to provide basic data for impact analysis and included:

a) Sampling of D.O. upstream, downstream, and at depth to identify the existing D.O. conditions.

b) Special surveys to determine the reaeration values (r) for the various water releases (lock, tainter gates, bulkheaded gates and powerhouse).

Methods used and the data obtained are discussed in detail in this chapter.

A. INSTRUMENTATION AND SAMPLING TECHNIQUES

During the field studies dissolved oxygen (D.O.) and temperature measurements were taken. A YSI 5700 series polarographic D.O. probe and a YSI model 54 meter was used. A stirrer was attached to the probe. Specifications for the D.O. meter and probe, as given by the manufacturer, are presented in Table IV–1. The probe was air calibrated in the field based on atmospheric pressure. Water samples were also taken for Winkler analysis in the laboratory to check the calibration. A D.O. sampler like the one described in *Standard Methods* [APHA, 1980, sec. 421.A] was used to collect surface water samples (from 0.5 m depth below the water surface). The water samples were fixed immediately after collection and stored in a cooler. The samples were titrated (D.O. determination) upon return to the SAFHL. The method used for the analysis of the samples was the Azide Modification of the Winkler titration method [APHA, 1980, Sec. 421B]. Therefore, the samples are sometimes also referred to as "Winkler samples" or as "grab samples." These samples were taken a) to check the calibration of the YSI probe and b) at locations where no profile could be taken because of high velocities or high air entrainment that could cause false probe readings, e.g. downstream of bulkheaded gates or the outlet of the powerhouse. In case (b) the temperature of the sample was determined by a thermometer.

A discrepancy was noted between the probe temperature readings and the thermometer readings, the thermometer usually showing a higher temperature. The thermometer had a tolerance of ± 1°C. In the last surveys (Sept. 1988) a mercury thermometer was used and good agreement between the probe and the thermometer was obtained. The D.O. concentrations given by probe readings and the Winkler samples did not usually differ by more than ± 5%. Probe readings of D.O. were multiplied

TABLE IV–1. D.O. Meter and Probe Specifications

D.O. Meter YSI Model 54

Oxygen Measurement

Ranges: 0–10 and 0–20 mg/ℓ.

Accuracy: ± 1% full scale at calibration temperature (± 0.1 mg/ℓ on 0–10 scale).

Readability: 0.05 mg/ℓ on 0–10 sccale; 0.1 mg/ℓ on 0–20 scale.*

Temperature Measurement

Range: –5° to + 45°C

Accuracy: ± 0.5°C

Readability: 0.25°C*

Temperature Compensation

Automatic temperature compensation accurate to ± 1% at D.O. readings made within ± 5°C of calibration temperature. Accurate to ± 3% of D.O. readings from –5° to + 45°C.

Ambient Temperature

Instrument and probe operating range is –5° to + 45°C.

System Response Time

Typical response time for temperature and D.O. readings is 90% in 10 seconds at constant temperature of 30°C.

*Oxygen readings were recorded to 0.01 mg/ℓ (0–10 scale), although accuracy is no better than 0.1 mg/ℓ and temperature to 0.1°C.

D.O. PROBE YSI 5700 SERIES

Cathode—Gold
Anode—Silver
Membrane—.001" FEP Teflon
Electrolyte—Half saturated KCℓ

Pressure Compensation—effective to 1/2% of reading over a 100 psi range (230 ft water)
Response Time—90% D.O. value in 10 seconds
Polarizing Voltage—0.8 volts nominal
Probe Current—Air at 30°C = 19 microamps nominal
Nitrogen at 30°C = .15 microamps or less

by a correction factor, CF. CF was calculated as the average of the correction factors obtained throughout a survey day, as

$$CF = \frac{\text{Winkler value}}{\text{Probe reading}}$$

Reported values are corrected values. In Appendix A–4 the correction factors are given. The range of the values for a given day is also given. The maximum variation in CF over a day was 0.06. This would give a ± 3% uncertainty for CF which for a concentration of 10 mg/ℓ results in 0.3 mg/ℓ difference. Thus, the accuracy of the data is good.

In front of the powerhouse intake and upstream of open gates, the D.O. probe was tied to streamlined weights. At high flows, even with the weights, only a few readings could be obtained before a large deflection of the suspensions cable (angle ~ 60° to the vertical) was observed, and readings at greater depths were not possible.

B. TYPES OF SURVEYS

1. Survey from the Structure

A survey from the structure was the standard type of survey in this study. It was performed weekly, except for weeks in which other surveys were performed. Upstream of the dam, D.O. and temperature profiles were measured at the following locations:

a) Two locations directly in front of the powerhouse intakes.

b) near the MWCC sampling station

c) in front of the operating tainter gate, and

d) in front of a closed gate.

Downstream of the structure, probe readings were taken downstream of the operating gate, a closed gate, and the bulkheaded gates, if any. Grab samples were taken in the tailrace of the powerhouse as close to the center of the outlet as possible.

Calibration (Winkler) samples were taken at the beginning, the end, and during the course of the survey to check for calibration drift with time. Measurements from the structure were usually made during the morning before photosynthesis and reaeration in the pool usually cause an increase in D.O. Exact sampling times are given in Appendix A.1. Sampling locations are described in Table IV–2 and shown on Fig. IV–1 and the frontispiece.

TABLE IV–2. Description of Sampling Locations for the Summer 1988 Surveys

<u>Sampling locations from the structure</u>	
UG#	upstream of gate number (#)
DG#	downstream of gate number (#)
L,R	if following any of the two above specificationsd they denote left or right side (looking downstream)
A	upstream, right of gate 1 along the wall
B	upstream from the powerhouse in recirculating eddy: in front of left intake low velocity facilitated measurement of vertical profile
B2, C2	upstream from the powerhouse in front of center of left, right intake, respectively.
C	upstream of powerhouse by right wall
D	3 m downstream of MWCC sampling station, or pier
DPH	downstream from powerhouse in front of diffuser, usually in outflow
DPHRB	downstream from powerhouse from right bank
<u>Sampling locations from the boat</u>	
XD	cross section located 350 m downstream from the structure
XU	cross section located 250 m upstream from the structure
XU1	along axis of old lock
XD1	between old and new lock
XD2,XU2	along centerline of gate 1
XD3,XU3	along centerline of gate 7
XD4,XU4	along centerline of gate 16
BL	1300 m downstream of the structure (near public boat launch) in the middle of the river

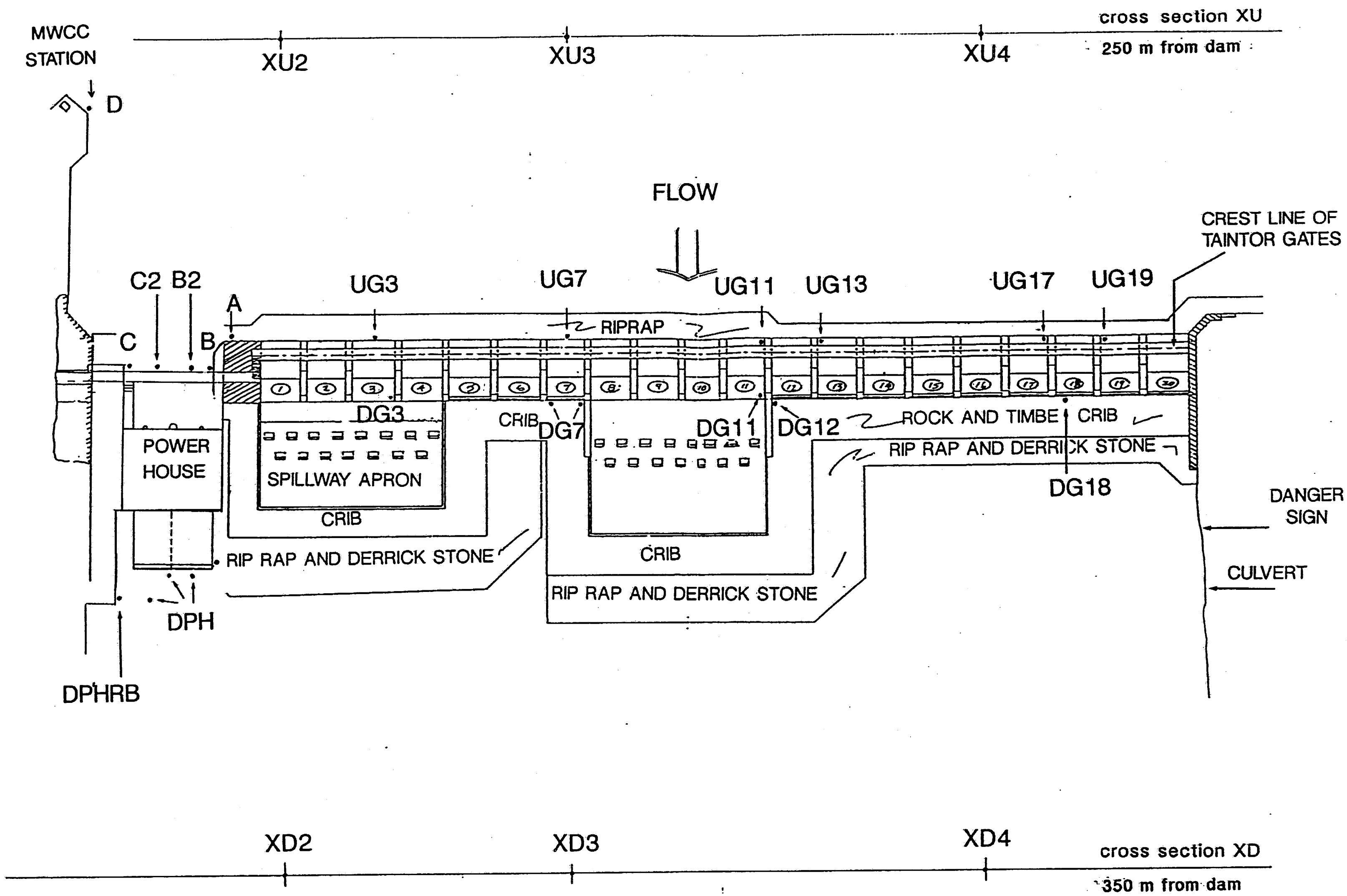

Fig. IV–1. Sampling locations during surveys from the structure for summer 1988.

2. Survey from the Boat

This type of survey was performed in order to examine how samples taken from the structure compare to values in the pool upstream and the river downstream of the structure (July 15, 1988 and July 29, 1988).

On the upstream side, measurements were taken from the structure as described in the first type of survey. Subsequently, D.O. profiles were measured at four stations across the river approximately 250 m upstream of the structure. Then the sampling from the dam was repeated to account for possible trends in D.O. concentration. In addition, the downstream sampling points described for the first type of survey were approached by boat and samples were taken at those locations immediately downstream from the structure. Access of sampling points near the structure from the boat minimized the time interval between measurements. D.O. profiles were taken at 4 stations across the river approximately 350 m downstream of the dam where the flow was almost uniform across the width. Subsequently, the sampling immediately downstream of the structure was repeated.

Sampling time was recorded to account for possible trends in D.O. and temperature during the day.

3. Diurnal D.O. Survey

This survey was performed on August 24 and 25, 1988, and it involved taking profiles and samples as in the case of the Type 1 survey, every three hours for a period of 30 hours in order to show the diurnal variation of the oxygen concentrations. Nine sets of data were obtained starting at 5:00 a.m. on August 24, 1988, through 10:00 a.m. on August 25, 1988. No readings were taken at the 2 a.m., August 25 sampling period, since smaller variations are expected during the night hours.

The sampling locations for this study were

- near the MWCC station
- two points upstream of the powerhouse
- downstream of the powerhouse (grab sample)
- upstream and downstream of gate 3 (closed),
- upstream and downstream of gates 12 and 18 (bulkhead)

Gates 8–11 were open 0.5 ft each until 8:00 a.m. on August 24; after that no gates were open.

The weather was very windy and partly cloudy, causing vertical mixing.

4. Survey for the Determination of Deficit Ratio

This type of survey was undertaken in order to evaluate the D.O. deficit ratios at operating gates, bulkheaded gates and the lock. Measurements upstream and downstream of the structures were made. To reduce uncertainty and obtain reliable results, these surveys were performed in the morning when the D.O. was expected to be low (high D.O. deficit) and no large stratification was present in the pool

a. Operating gate

This survey was performed at Gate 8 on September 9, 1988. Profiles upstream of the gate were taken, followed by measurements from a boat downstream of the gate. Measurements were made for four gate openings (0.5, 1, 1.5 and 2 ft). Finally, oxygen profiles upstream of the gate were measured again to check variation with time.

b. Bulkheaded gates

This survey was performed at Gates 12 and 18 (August 4, 1988). Profiles upstream on both sides of the gates were taken. Then samples downstream of the gates in the outflow were taken from a boat, and then the upstream sampling was repeated.

c. Locks

A D.O. profile was taken in the lock when the lock was full and then readings were taken downstream near the lock discharge as the water level in the lock was lowered (July 22, 1988).

Sampling locations used in the D.O. surveys are described in Table IV–2 and shown on Fig. IV–1 and the frontispiece.

C. DATA INTERPRETATION

1. Summary

All the data obtained during the summer 1988 surveys are listed in Appendix A–1. Graphical representation of D.O. and temperature profiles as well as some comparisons of D.O. distribution across a given cross section are given in detail by Midge and Daniil [1988]. In this section the spatial and temporal variability of dissolved oxygen upstream and downstream of Lock and Dam No. 2 is discussed and a summary of the data is presented.

The two main sources for dissolved oxygen in the pool are reaeration (transfer through the air–water interface) and photosynthesis. Both depend on weather conditions; reaeration increases when wind is present, and photosynthesis depends on sunlight and, therefore, occurs only during the day. High algae populations during sunny days can increase dissolved oxygen to concentrations above saturation in the afternoon hours. Water temperature stratification contributes to the development of D.O. stratification. Mixing by wind or by cooling destroy stratification and make the D.O. vertically more uniform.

A summary of all the D.O. data taken during the summer of 1988 is presented in Table IV–3. For days with multiple sets of data, the data sets

TABLE IV-3. Summary of Depth Averaged D.O. Data at Lock & Dam No. 2, Summer 1988

	SURVEY FROM THE STRUCTURE											SURVEY FROM THE BOAT								
	UPSTREAM OF STRUCTURE						DOWNSTREAM OF STRUCTURE					250 M UPSTREAM OF DAM				350 M DOWNSTREAM OF DAM				1300 M DS
			CLOSED GATE	OPEN GATE	BULKHEADS			CLOSED GATE	OPEN GATE	BULKHEADS										
DATE	D	UPH	UG3	UG7	UG12	UG18	DPH	DG3	DG7	DG12	DG18	XU1	XU2	XU3	XU4	XD1	XD2	XD3	XD4	BL
29-Jun-88	6.10	6.30	6.36	6.42			6.45	6.12	6.45											
05-Jul-88	8.79	8.68	8.31	9.09			8.53	8.01	8.86											
15-Jul-88	4.86	5.20	6.04	7.09			6.00	4.85	5.40			7.48	6.30	5.43	6.66	5.38	4.91	4.83	4.81	
22-Jul-88	7.04	6.63	6.77	7.65			6.42	5.93	6.25											
29-Jul-88	6.04	6.28	6.27	6.29			6.10	5.45	5.80	7.03	6.70	6.62	6.19	4.81	5.35	5.92	5.66	6.12	6.31	7.65
04-Aug-88	5.01	5.15		5.79	6.12	5.82			5.17	6.50	6.53					5.35	5.36	5.71	5.81	
11-Aug-88	8.17	8.86			8.06	7.41	7.63			7.84	7.78									7.20
18-Aug-88	8.14	8.24	7.75		7.36	7.59	8.02	6.80		7.56	7.34									
24-Aug-88	6.19	6.04	6.17		6.20	6.06	6.31	6.09		8.02	8.02									
25-Aug-88	6.64	6.90	6.66		6.60	6.37	6.67	6.35		8.06	7.91									
09-Sep-88	6.94		6.78	7.33					7.20											

taken in the morning hours (~ 8 a.m. to 12 noon) are given to obtain a more consistent set. Depth averaged D.O. values are given.

Point D is located 3 m downstream of the MWCC monitoring station. The value upstream of the powerhouse (UPH) is an average of all profiles taken across the intake (usually 2 or 3). Data for a closed gate and an open gate, usually 3 (UG3) and 7 (UG7), respectively, are given. The bulkheads (Gate 12 and 18) were not operating during the first four surveys.

The data given in this table cannot be used for the computation of the reaeration capacity of the bulkheads because they are depth average values and some were taken at different times. The same applies for the open gate (UG7).

The D.O. values downstream of the powerhouse (DPH) are from grab samples taken approximately 0.5 m below the surface. Complete profiles taken on July 29, 1988 and August 18, 1988 indicate that outflow from the powerhouse is well mixed (D.O. concentration is virtually uniform from top to bottom). D.O. values measured downstream from the gates are reported as DG3 (closed gate), DG7 (open gate), DG12 and DG18 (bulkheaded gates). BL refers to the boat launch ~ 1,300 m downstream, and the profile was taken in the middle of the stream.

Data for river discharge, solar radiation, and wind are given in Table IV–4 for the summer months of 1988. Solar radiation and surface wind data were obtained from the University of Minnesota, Department of Soil Science. Radiation measurements represent total incoming radiation and were taken at the climatological observatory on the St. Paul campus. Wind also measured on the St. Paul campus is given as "miles of wind" per day. Wind direction was not recorded. Riverflow data (at St. Paul, MN) were obtained from the St. Paul U.S. Geological Survey Office and are listed as tentative. The discharges listed with the survey data in Appendix A–1 were obtained from the Lockmaster at Lock and Dam No. 2 on the day of each survey.

2. Diurnal D.O. Variation

A diurnal D.O. survey was performed on August 24 and 25, 1988, for a 30–hour period, during which nine data sets were obtained. Figures IV–2 and IV–3 show the D.O. for different points along the structure at the upstream and downstream side, respectively. Depth average values are shown.

The reservoir was well mixed due to a very strong NW blowing wind, and the vertical variations were very small, ranging from 0.05 to 0.6 mg/ℓ. The minimum values were observed around 8–9 a.m. and the maximum values were observed around 5–7 p.m. The observed diurnal variation was 2.2 mg/ℓ for the upstream side.

The diurnal variation on the downstream side was 1.8 mg/ℓ at the powerhouse outflow, 1.4 mg/ℓ downstream of the closed gates and 0.7 mg/ℓ

Table IV–4. Summary of Flow and Weather Data for Summer 1988

Date	Discharge (cfs)	Rad (lys/day)	Wind (miles/day)
01–Jun–88	4640	567	54
02–Jun–88	4800	381	60
03–Jun–88	4880	587	73
04–Jun–88	4320	691	38
05–Jun–88	3640	720	44
06–Jun–88	3450	737	62
07–Jun–88	2940	752	51
08–Jun–88	2970	534	103
09–Jun–88	3470	785	91
10–Jun–88	2950	788	46
11–Jun–88	2650	768	87
12–Jun–88	2390	697	123
13–Jun–88	2240	596	125
14–Jun–88	2250	627	151
15–Jun–88	2110	614	110
16–Jun–88	2160	728	52
17–Jun–88	2180	683	118
18–Jun–88	2150	641	136
19–Jun–88	1840	667	151
20–Jun–88	2010	742	57
21–Jun–88	2390	471	76
22–Jun–88	2250	643	92
23–Jun–88	1330	337	63
24–Jun–88	1690	677	162
25–Jun–88	2080	754	149
26–Jun–88	1570	737	68
27–Jun–88	1730	726	32
28–Jun–88	1590	661	108
29–Jun–88	1500	544	232
30–Jun–88	1380	785	140

Table IV-4 (Cont.)

Date	Discharge (cfs)	Rad (1ys/day)	Wind (miles/day)
01-Jul-88	1620	676	49
02-Jul-88	1800	576	40
03-Jul-88	1520	711	51
04-Jul-88	1470	722	128
05-Jul-88	1440	711	137
06-Jul-88	1390	691	141
07-Jul-88	1380	612	124
08-Jul-88	1350	488	63
09-Jul-88	1360	411	34
10-Jul-88	1420	647	87
11-Jul-88	1390	669	73
12-Jul-88	1360	711	71
13-Jul-88	1370	664	157
14-Jul-88	1310	707	61
15-Jul-88	1260	663	150
16-Jul-88	1400	697	115
17-Jul-88	1530	556	37
18-Jul-88	1360	616	72
19-Jul-88	1300	222	36
20-Jul-88	1460	350	44
21-Jul-88	1460	674	30
22-Jul-88	1310	596	20
23-Jul-88	1320	573	44
24-Jul-88	1270	645	82
25-Jul-88	1150	718	78
26-Jul-88	1130	631	61
27-Jul-88	1130	678	100
28-Jul-88	1160	687	135
29-Jul-88	1090	398	118
30-Jul-88	1070	664	75
31-Jul-88	1080	540	111

Table IV–4 (Cont.)

Date	Discharge (cfs)	Rad (1ys/day)	Wind (miles/day)
01–Aug–88	1080	609	103
02–Aug–88	1130	413	162
03–Aug–88	1510	469	67
04–Aug–88	1720	392	88
05–Aug–88	1370	568	120
06–Aug–88	1410	666	113
07–Aug–88	1440	604	128
08–Aug–88	1640	491	78
09–Aug–88	1560	635	53
10–Aug–88	1400	632	72
11–Aug–88	1360	518	86
12–Aug–88	1340	559	115
13–Aug–88	1760	296	102
14–Aug–88	1840	616	126
15–Aug–88	2770	616	60
16–Aug–88	2880	605	109
17–Aug–88	1930	576	116
18–Aug–88	2380	154	116
19–Aug–88	2370	381	85
20–Aug–88	3860	463	34
21–Aug–88	3800	285	97
22–Aug–88	4720	102	123
23–Aug–88	5100	564	121
24–Aug–88	5410	587	139
25–Aug–88	4510	577	161
26–Aug–88	4860	553	84
27–Aug–88	4360	527	130
28–Aug–88	3830	389	100
29–Aug–88	3970	539	32
30–Aug–88	4310	588	37
31–Aug–88	3670	448	72

Table IV–4 (Cont.)

Date	Discharge (cfs)	Rad (lys/day)	Wind (miles/day)
01–Sep–88	3470	296	155
02–Sep–88	3670	413	55
03–Sep–88	3290	194	126
04–Sep–88	3330	471	133
05–Sep–88	3140	417	69
06–Sep–88	2730	550	29
07–Sep–88	2410	517	115
08–Sep–88	2700	302	133
09–Sep–88	2690	512	119
10–Sep–88	2460	389	54
11–Sep–88	2140	456	152
12–Sep–88	2290	146	141
13–Sep–88	2730	502	91
14–Sep–88	2060	515	46
15–Sep–88	2510	109	99
16–Sep–88	2300	251	150
17–Sep–88	2550	471	50
18–Sep–88	2670	240	
19–Sep–88	2400	84	
20–Sep–88	2820	155	220
21–Sep–88	2740	285	66
22–Sep–88	3020	177	85
23–Sep–88	2350	455	103
24–Sep–88	2580	375	65
25–Sep–88	2940	392	55
26–Sep–88	4100	386	138
27–Sep–88	4700	409	61
28–Sep–88	4350	69	178
29–Sep–88	4410	95	123
30–Sep–88	4410	285	42

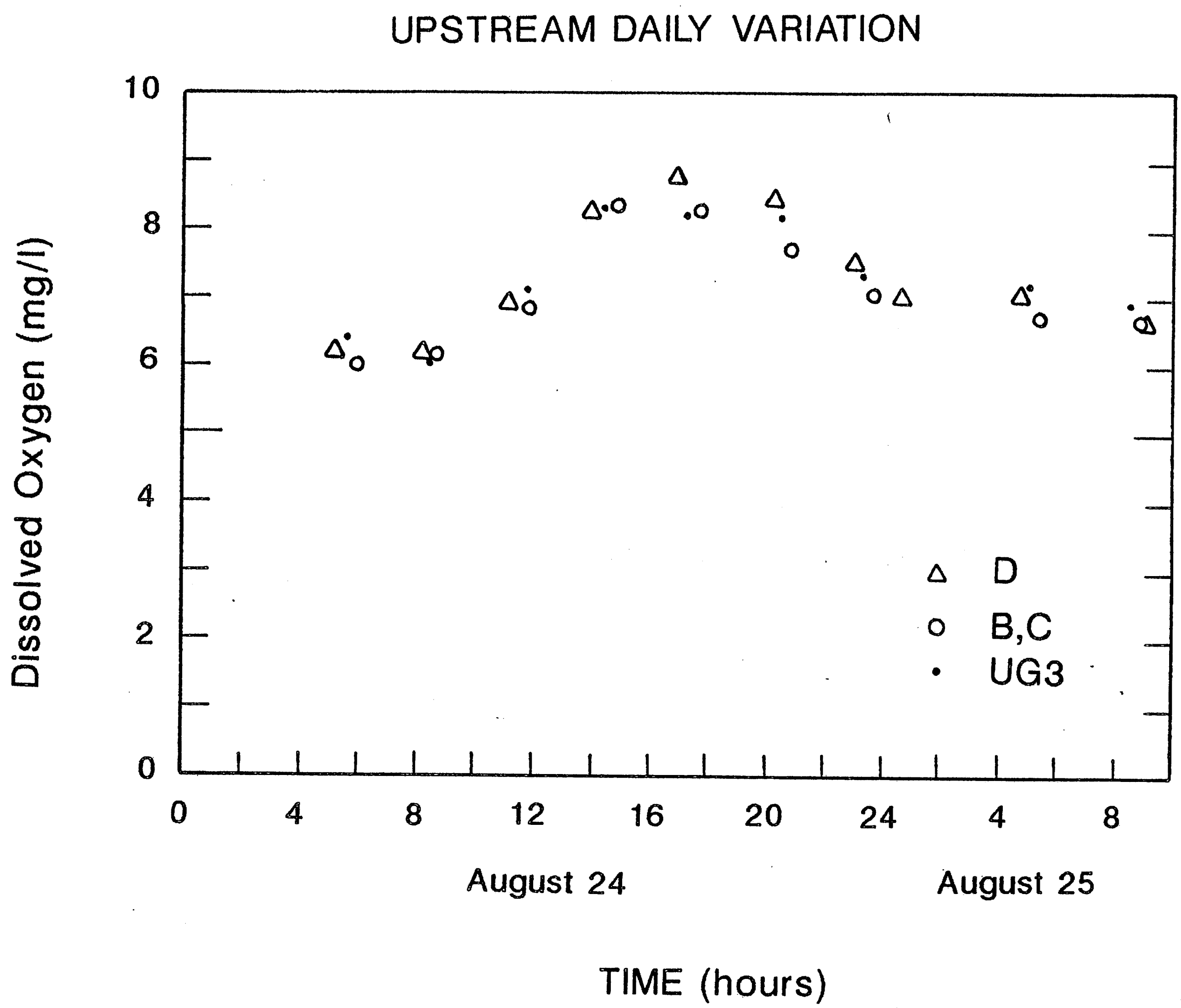

Fig. IV–2. Upstream diurnal D.O. variation on August 24 and 25, 1988.

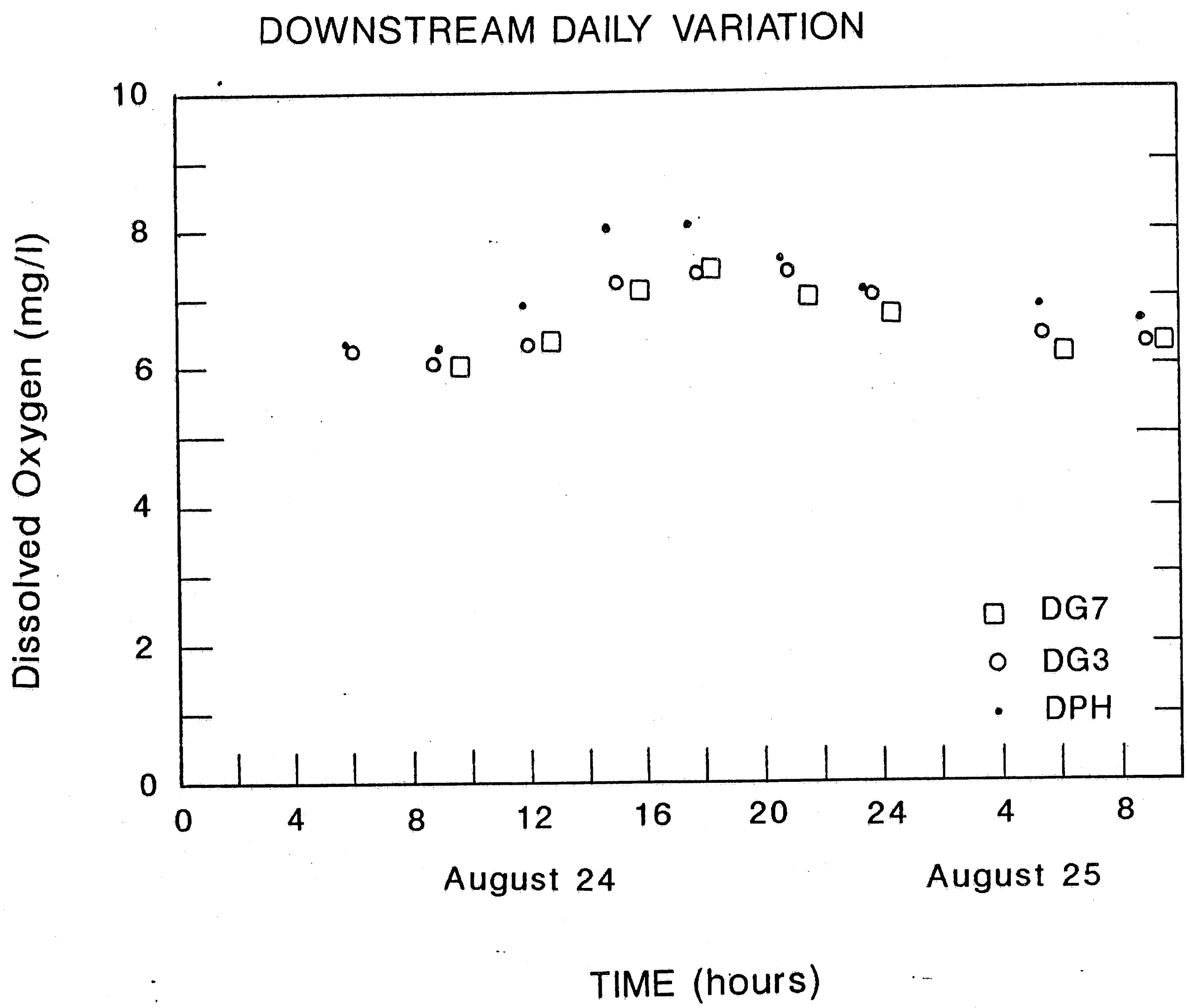

Fig. IV–3. Downstream diurnal D.O. variation on August 24 and 25, 1988.

downstream of the bulkheaded gates. The variation downstream of the powerhouse corresponds well to the variation of the measured upstream values (Figs. IV–2 and IV–4). Upstream of the powerhouse, measurements were taken only to a depth of 2 to 3 m because both units were running at full capacity and the probe, even with the weights, was swept towards the intakes.

The variations downstream of the closed gates were lower than those at the upstream side of the structure. This can be attributed to the northeastern orientation of the structure. The structure shades the area immediately downstream of the closed gates where the water is still and the shade reduces photosynthetic rates. The structure also sheltered the water on the downstream side from the prevailing N–NW winds in the afternoon hours of August 24, 1988.

The bulkheaded gates aerate the flow to values close to saturation and therefore only allow a small diurnal D.O. variation.

3. Vertical D.O. Stratification in Pool No. 2

a. Close to the structure

High summer air temperatures and solar radiation cause the upper water layer of pool 2 to warm and become very slightly less dense than the lower layer, resulting in temperature and D.O. stratification. Wind action or surface cooling during the night causes mixing and can destroy the developed stratification. On calm days stratification in the pool increases during the day and weakens or is destroyed during the night. During most of the surveys no strong stratification was observed. This may be partly due to the fact that most surveys were completed during the morning hours. As a measure of the observed stratification the difference between the maximum and the minimum D.O. concentration from a given profile is reported in Table IV–5.

Strong stratification on the upstream side of the dam was observed on July 15 and July 22. Air temperature reached 102°F on July 15. In Fig. IV–5 the profiles upstream of a closed and an open gate for these days are plotted. The stratification is stronger for the open gate (UG7). On July 15 two sets of data were taken. The second set shows the effects of mixing because of either wind or towboat traffic. Surface D.O. values had become lower and high D.O. values were found at larger depths after the mixings.

On the same days strong stratification was also observed upstream from the powerhouse. Profiles are presented in Fig. IV–6.

b. Away from the structure

Surveys from the boat indicated that farther upstream from the structure the stratification is stronger. In the deepest portion of the pool, D.O. values down to 0.15 mg/ℓ were measured. The lowest value recorded in front of the intakes, however, was 4.90 mg/ℓ. This is probably the result of

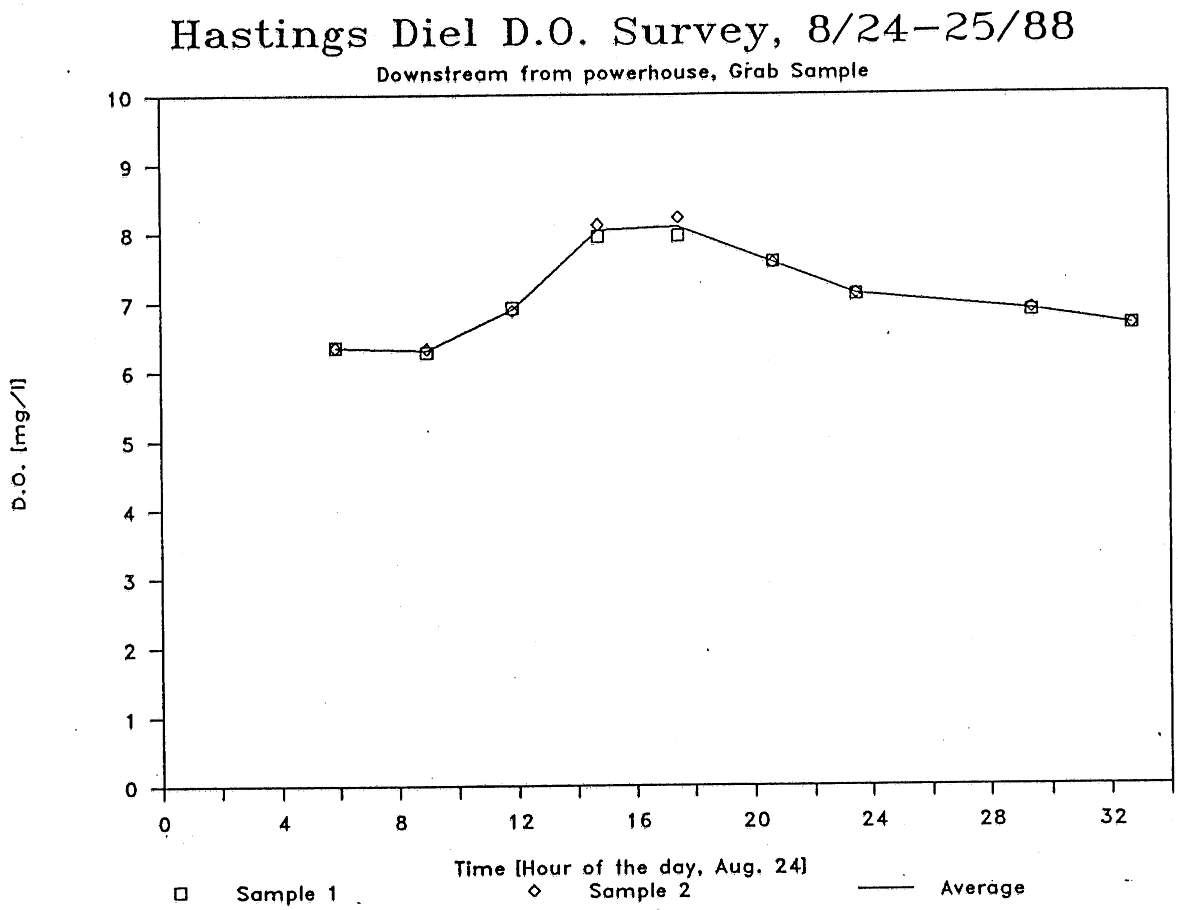

Fig. IV–4. D.O. diurnal variation at the powerhouse outflow on August 24 and 25, 1988.

TABLE IV-5. Observed Stratification in Surveys from the Structure Expressed as Difference Between Max and Min D.O. (mg/ℓ) Values of a Given Profile

Location	D	C/C2 Powerhouse	B/B2	UG3 (closed)	UG7 (open)	UG12/UG18 Bulkheaded	DPH Powerhouse	DG3 (closed)	DG7 (open)	DG12/DG18 Bulkheaded
	UPSTREAM						DOWNSTREAM			
Date										
June 29	0.24	0.47	0.29	* 0.47	0.26 (W)				0.05 (W)	
July 5	0.18	0.32	1.00	0.74	0.53			0.19	0.08	
July 15	2.90	3.50	4.90	7.65	9.90		0.20(S)	0.25	0.20(S)	
	2.90		4.60	3.45	7.30			0.20		
July 22	1.10	3.78	3.05	3.05	6.72		0.08(W)	0.11	0.10	
									0.20(W)	
July 29	1.50	1.87		0.30	0.90		0.80	0.10	0.50	0.40(S)
	0.85	1.20		0.60	1.70			0.25		
August 4	0.15	1.00			* 1.15	0.15-0.80				0.15(S)
						2.50				0.40(S)
August 11	* all samles at 0.5 m for this survey									
August 18	1.38		1.22	* 0.84		0.34	0.20			1.02
	0.36		0.92			0.92	0.41			out/in jet
August 24	DIURNAL survey									
set 1	0.10			0.37				0.14		
set 2	0.40			0.30				0.09		
set 3	0.41			0.30				0.25		
set 4	0.27			0.16				0.11		
set 5	0.16			0.32				0.10		
set 6	0.21			0.05				0.24		
set 7	0.33			0.16				0.04		
August 25										
set 8	0.17			0.08				0.06		
set 9	0.20			0.37				0.25		
September 9	0.30			0.1-0.84						

Notes: (S) denotes difference in surface value readings
(W) denotes difference between winkler samples
* value measured at a location other than indicated but with same characteristics

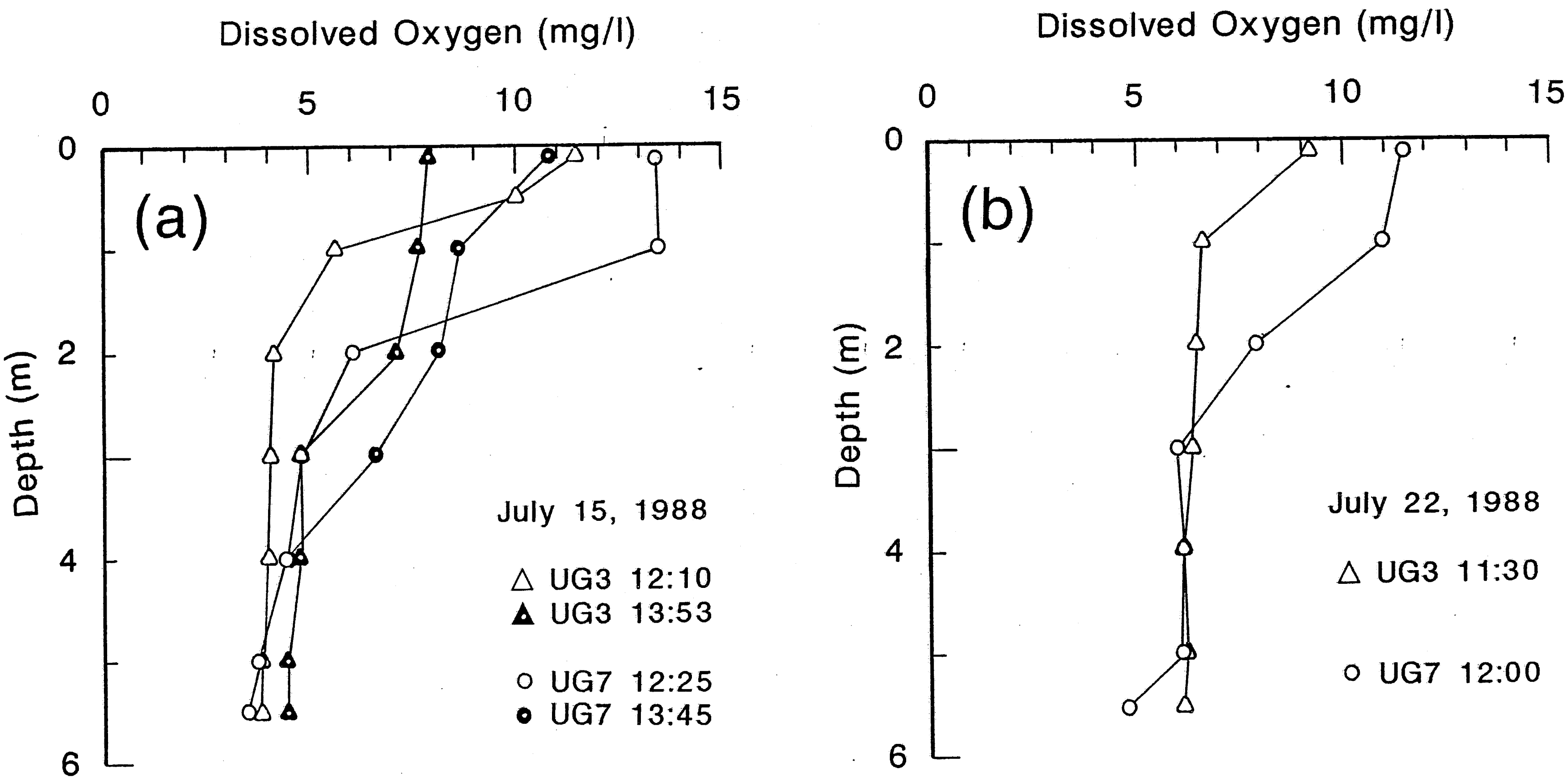

Fig. IV–5. Comparison of D.O. profiles upstream of an open (UG7) and a closed (UG3) gate for days with strong stratification on (a) July 15, 1988, and (b) July 22, 1988.

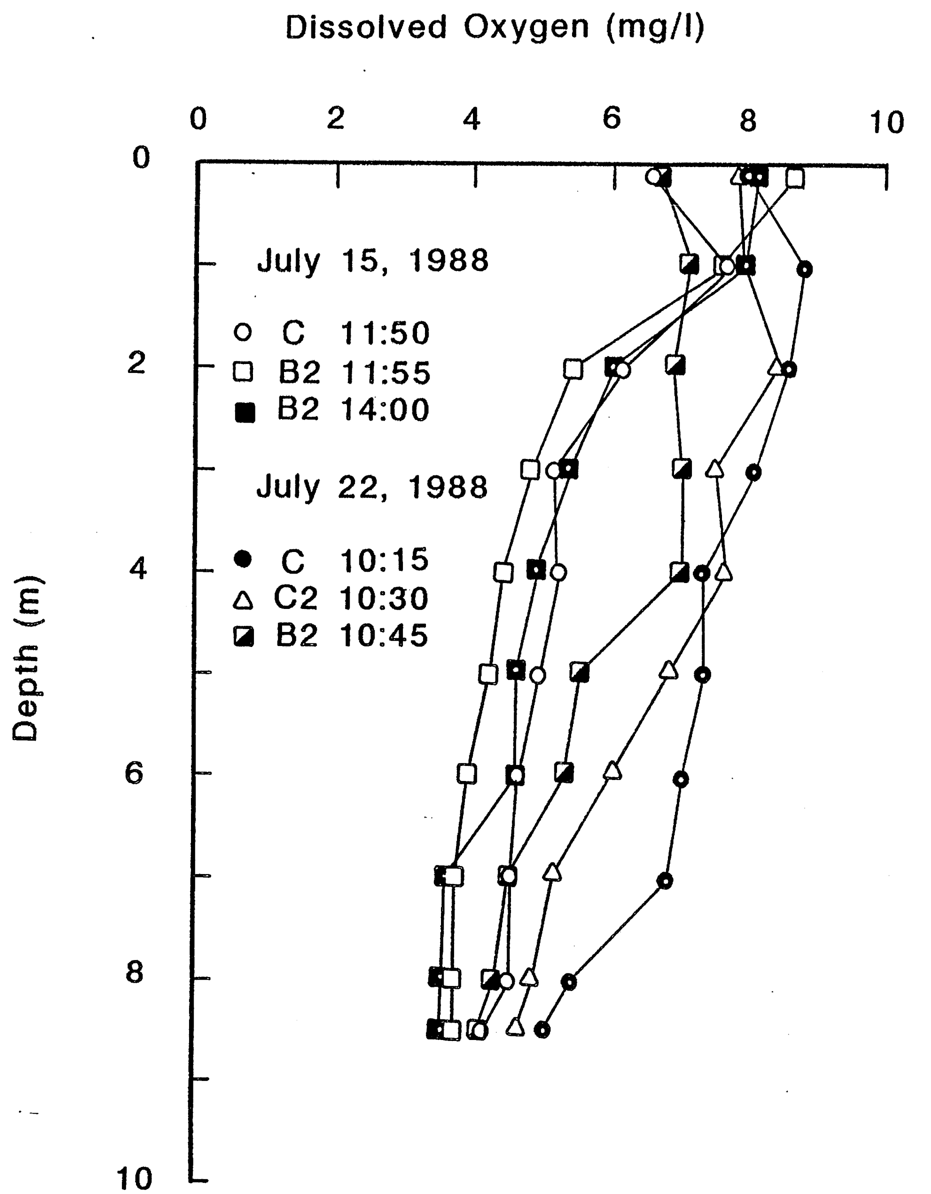

Fig. IV–6. D.O. profiles upstream of the powerhouse on (a) July 15, 1988, and (b) July 22, 1988.

a ridge (bar) extending from the dam across the intake channel. This ridge was observed in the physical model constructed by the St. Anthony Falls Hydraulic Laboratory at the time of the powerplant construction. In Fig. IV–7, measurements at cross section XU (250 m upstream from the dam) are presented. Measurements at cross section XU were taken on July 15, 1988 and July 29, 1988. On July 15, 1988, strong stratification was observed down to 3 m in profiles taken at cross section XU as well as in profiles near the structure. On July 29, 1988 the upper 5 m layer of cross section XU was well mixed, although a stronger and more permanent temperature and D.O. stratification was present below. This did not extend to the structure, however, probably because the water depth in front of the gates is only 5.5 m. In front of the powerhouse a submerged ridge, previously mentioned, prevents the lower strata from reaching the intakes.

At the downstream cross section XD, virtually no stratification was observed on July 15, 1988, and the water body was well mixed from top to bottom despite the strong upstream XU stratification (Fig. IV–8). In Fig. IV–8, profiles for July 29 are also presented and a stratification is noted for XD3 and XD4, that extends down to 2–3 m depth. This is not caused by temperature stratification, but by the bulkheads that were operated on that day aerating the flow. Apparently 350 m downstream from the dam (location XD) lateral and vertical mixing are still not complete.

4. Lateral (transverse) D.O. variations

In the last two subsections we have used the data to illustrate D.O. variations at an hourly timescale and at a depth–scale measured in meters. To apply the D.O. transport model presented in Chapter III, it is necessary to be concerned about D.O. variations over the width of the river. There is also the question whether D.O. values recorded at the MWCC monitor are representative of the entire pool upstream from the dam. In the next two subsections, we shall briefly examine horizontal variability of D.O. and variations in D.O. throughout the summer of 1988 as reflected in the data collected.

a. Far from the structure

Lateral variations in D.O. measured 250 m upstream and 350 m downstream from the dam (boat surveys) were very small. D.O. values measured at the same depth but at different locations across the river were within ± 1.5 to ± 0.1 mg/ℓ. The agreement of different D.O. profiles is clearly shown in Fig. IV–7a, IV–7b, and IV–8a. An exception appears in Fig. IV–8b for the downstream section. The surface D.O. at two locations is on the order of 6 mg/ℓ, but approximately 8.5 mg/ℓ at the other two. The higher values were measured in the aerated plumes downstream from two bulkheaded gates. The measurements indicate that transverse mixing of the aerated water with the unaerated river water was not completed at 350 m downstream from the dam. The apparent transverse D.O. gradient is the result of dam operation more than river dynamics.

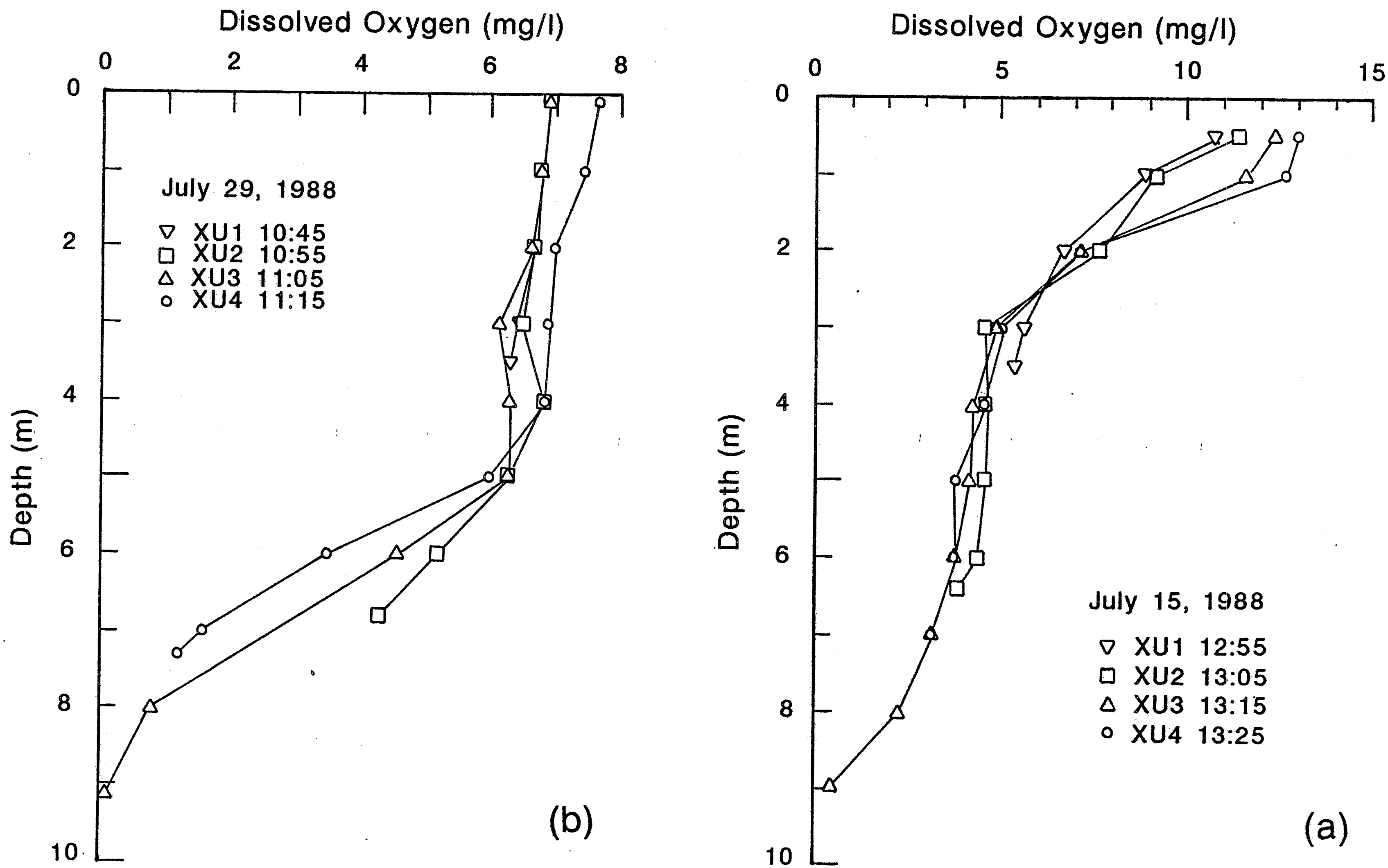

Fig. IV–7. D.O. profiles at cross section XU, 250 m upstream from the dam on a) July 15, 1988, and b) July 29, 1988.

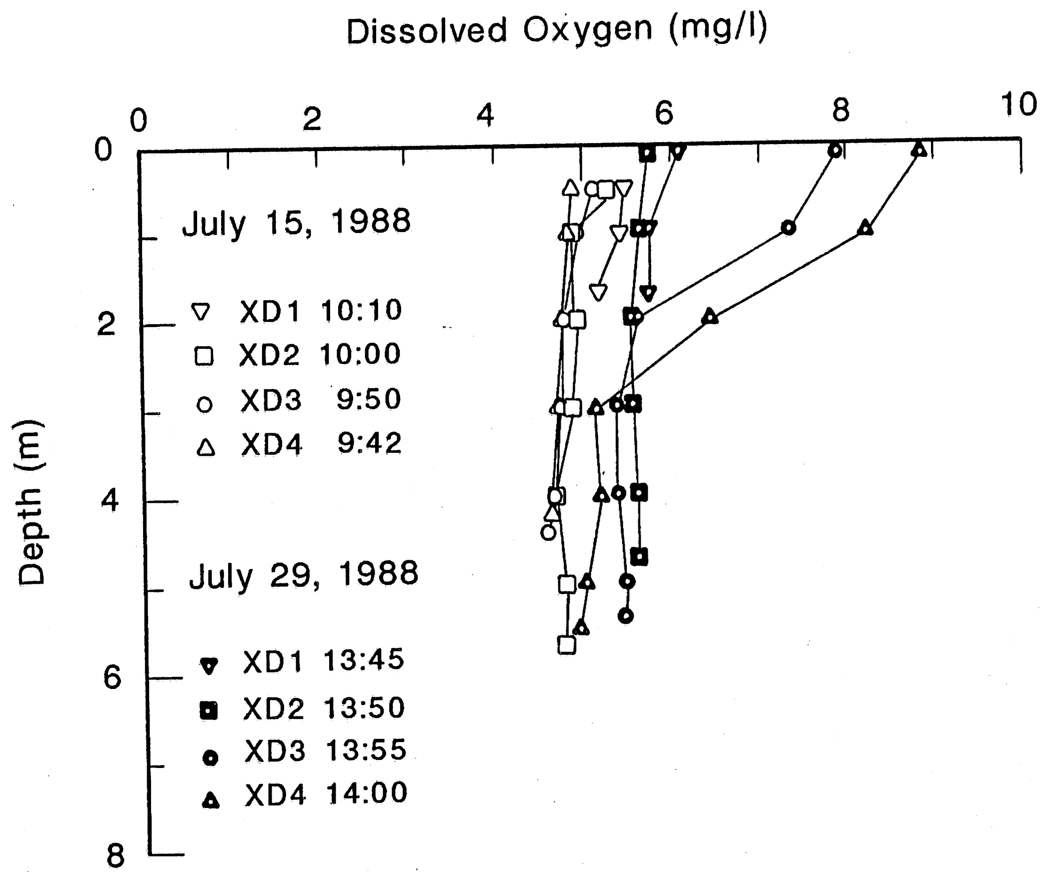

Fig. IV–8. D.O. profiles at cross section XD, 350 m downstream from the structure on (a) July 15, 1988, and (b) July 29, 1988.

The D.O. profiles in Fig. IV–7a and IV–7b indicate a shallow surface mixed layer (~ 1 m) and a deep mixed layer (~ 5 m), respectively. These are the result of rather different and extreme weather conditions (July 15 was sunny and air temperature reached 102°F, wind was low, whereas July 29th was a cloudy day with air temperature of 76°F and SW winds of 10 to 20 mph). It can therefore be interpolated that under common conditions D.O. values in the pool are laterally fairly uniform. The same applies downstream from the dam unless part of the flow is aerated at selective gates.

Upstream lateral D.O. uniformity can be disturbed very near the structure by the local flow field into the powerhouse intake or flow towards bulkheaded or tainter gates.

b. Close to the structure

Figure IV–9 and IV–10 give depth averaged D.O. values at sampling points immediately upstream and downstream from the structure, respectively. Differences in D.O. within a transect upstream from the structure ranged from 0.2 mg/ℓ to 2.2 mg/ℓ with an average of 0.9 mg/ℓ. With the exception of the July 15 and August 11 data, the variation of D.O. along the structure is less than 1.1 mg/ℓ.

The data for August 11, 1988 were from grab samples at 0.5 m depth and taken under storm conditions which could rapidly change surface D.O. values.

July 15 was the hottest day of the survey with a high of 102°F and low wind which caused strong vertical stratification. Blowing wind contributed to the deepening of the mixed layer later in the day and smoothing of the vertical D.O. gradient (see Fig. IV–5b). The variation across the structure can be partly attributed to the different sampling times. Sampling for the points shown in Fig. IV–9 was performed from 11:45 to 12:25. Given that the measurements were taken near noon when hourly changes are higher and the fact that July 15 was a very hot day and that the sampling sequence (D, UPH, UG3, UG7) is consistent with the increase shown in Fig. IV–9, at least part of the variation can be attributed to the daily variation.

In conclusion, the lateral D.O. variation, just upstream of the structure of 1 mg/ℓ appears to be typical, without any specific trend. Immediately downstream from the structure, lateral (transverse) variations in D.O. were also observed (Fig. IV–10). Aeration at bulkheads and taintergates contribute to larger transverse variations in D.O. Differences in D.O. ranged from 0.2 mg/ℓ to 1.9 mg/ℓ with an average of 1.0 mg/ℓ.*

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*On July 15 and July 22, a lateral variation across the powerhouse intakes of approximately 1 mg/ℓ was observed. The water color also appeared different, as if some mixing from the bottom was occurring. This was not observed at any of the other surveys.

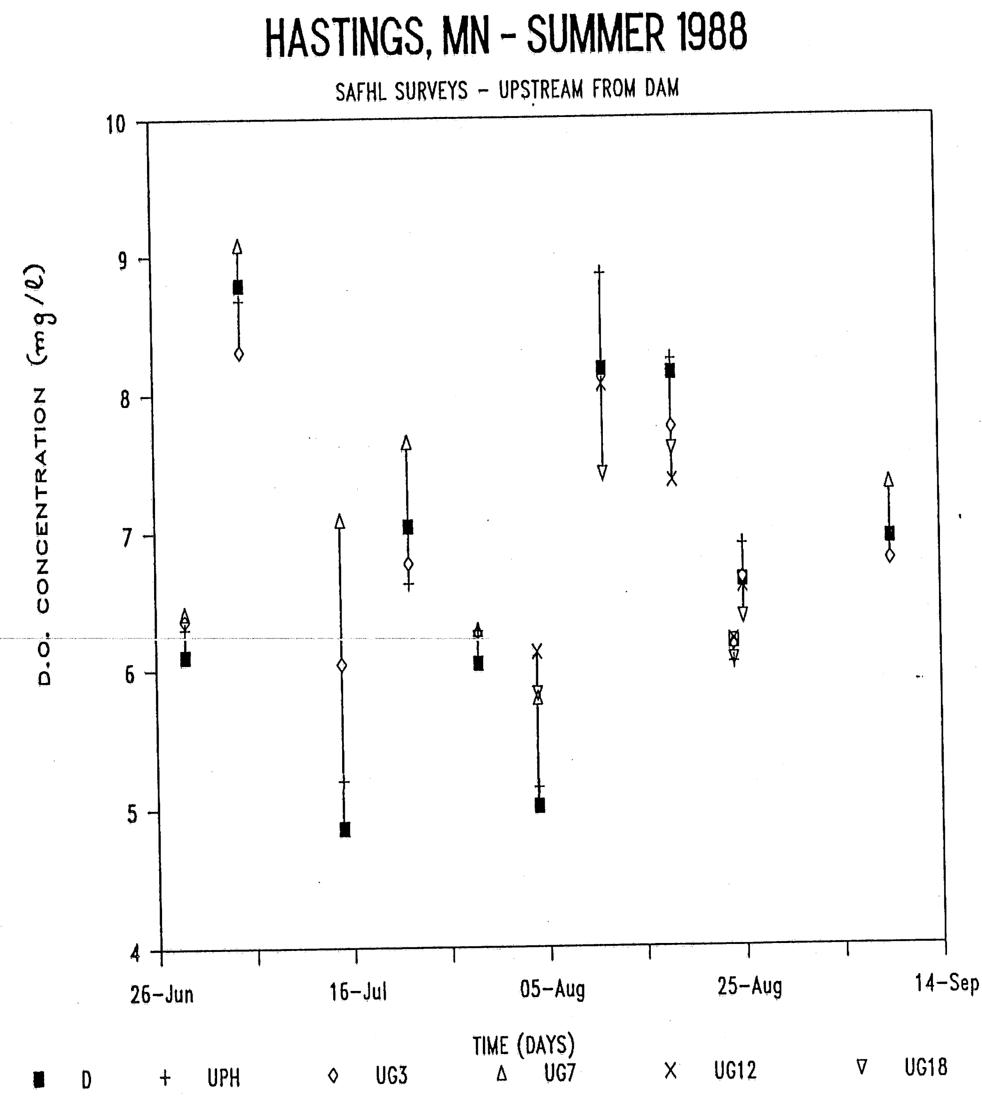


Fig. IV–9. Variations of depth–averaged D.O. values transverse to the river upstream from the dam throughout the summer 1988 season.

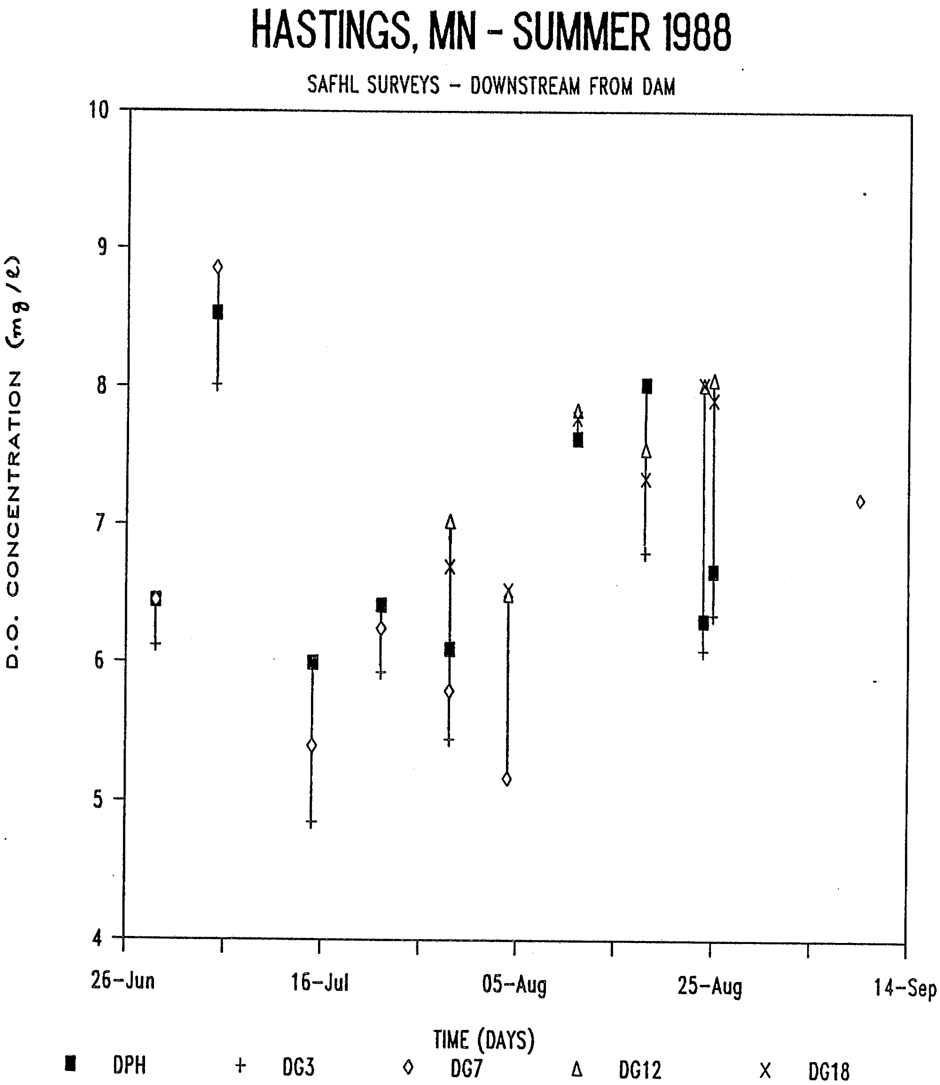


Fig. IV–10. Variations of depth averaged D.O. values transverse to the river downstream from the dam throughout the summer 1988 season.

5. Seasonal Variation

The seasonal variation in dissolved oxygen concentration immediately upstream and downstream from the structure is shown in Figures IV–11 and IV–12, respectively, as perceived from the data collected during the summer 1988 field surveys.

The maximum and minimum depth average values for each survey are shown as a continuous line. Surveys were conducted approximately once a week during the critical summer period.

Both upstream and downstream depth averaged values ranged from a low of 4.8 mg/ℓ to a high of 9 mg/ℓ.

D. HISTORICAL D.O. RECORDS

The Metropolitan Waste Control Commission maintains an automatic water quality monitor at Lock and Dam No. 2 (River Mile 815.3) approximately 200 ft upstream of the powerhouse on the riverward side of the riverward lock. Data are recorded every 15 minutes. However, only the daily minimum, mean, and maximum values were readily available.

The summer of 1976 was a period of record low flows and concern about the oxygen dynamics in the Mississippi River upstream from Lock and Dam No. 2 was expressed [Stefan and Wood, 1976]. D.O. data obtained from the *Water Resources Data* for Minnesota [U.S. Geological Survey, 1976, p. 421] indicate that the lowest D.O. concentration minimum daily recorded during that period was 6.1 mg/ℓ. This was recorded on June 23. Data for June 24 through July 21 are not given. Recorded mean daily D.O. values ranged from 6.4 to 11.2 for the June–September period.

It is questionable whether the 1976 data are directly comparable to present data because of changes in the waste loading of the river.

Dissolved oxygen and water temperature data for the years 1980–88 for the June–Sept period were analyzed by Westermeier and Stefan [1989]. Examination of the data revealed a bias related to the days on which the instrument was calibrated. MWCC reports the data as recorded without any adjustment to data taken before calibration even if the deviation is high. The average absolute correction in calibration for the period of 1980–87 was 1.1 mg/ℓ and the arithmetic mean was –0.2 mg/ℓ. The negative sign indicates that recorded values tend to be less than actual. Although these made the quality of the data questionable, still some information may be obtained regarding the expected D.O. levels at the site. Drift in calibration due to build up of slime, etc. cannot be avoided in long–term deployment of D.O. monitors. D.O. data were analyzed by Westermeier and Stefan [1988] as reported, without any corrections. Westermeier and Stefan [1988] reached the following conclusions:

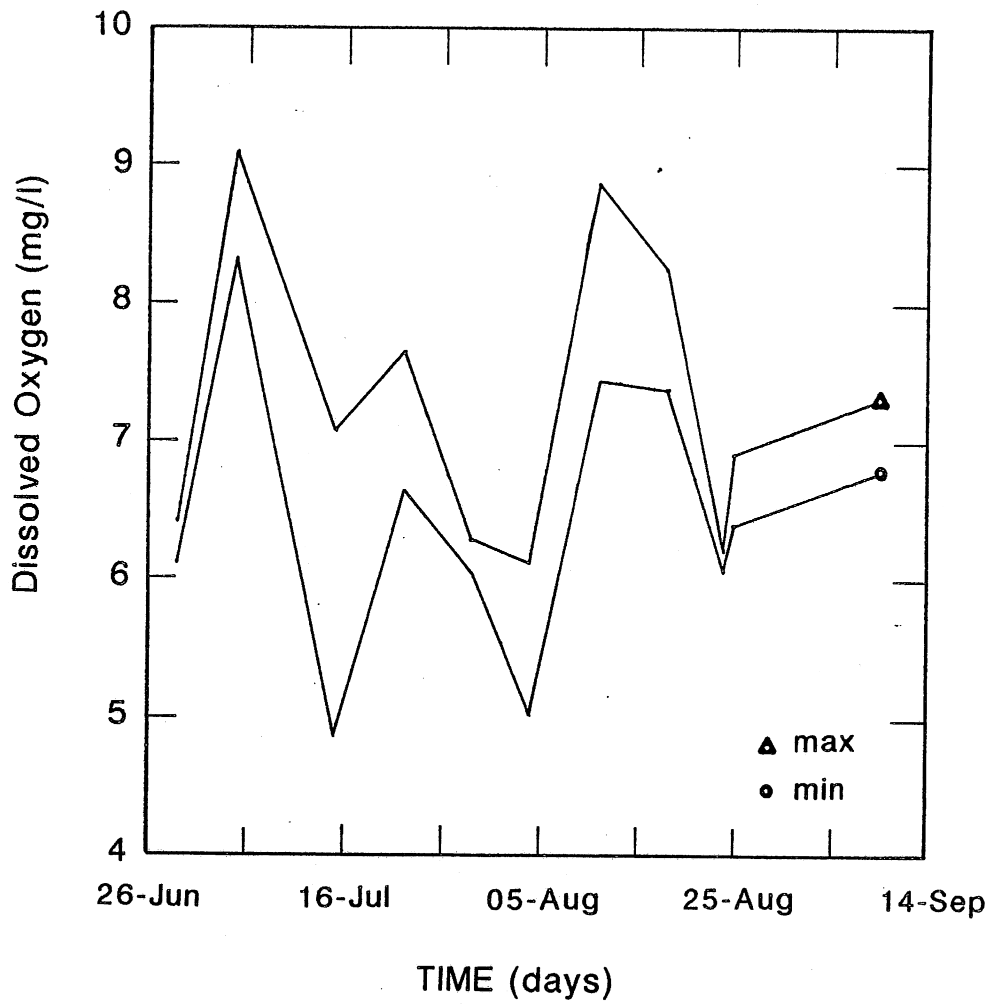


Fig. IV–11. D.O. variation during summer 1988, upstream from the structure.

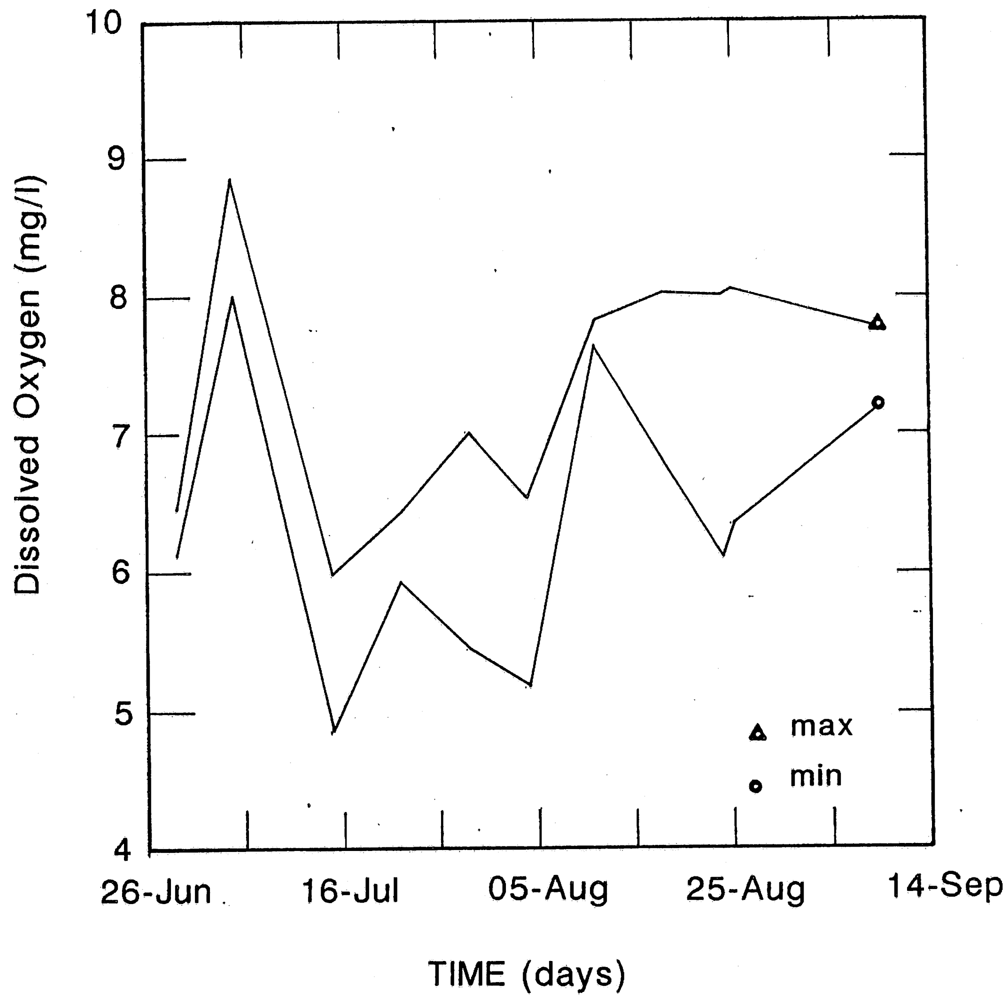


Fig. IV–12. D.O. variation during summer 1988, downstream from the structure.

- Low D.O. concentrations occurred most often with river discharges less than 15,000 cfs.

- Water temperatures greater than 23°C and mean daily wind speeds of less than 5 mph (wind was measured at the St. Paul Campus of the University of Minnesota) appeared to coincide with low D.O. measurements.

- No correlation between radiation and D.O. level could be obtained, contrary to expectations, since photosynthesis is one of the main D.O. sources.

The frequency of occurrence of minimum D.O. values below 5 mg/ℓ (the current D.O. standard) is given in Table IV–6 for years 1980–88.

The period from 1980–87 was wetter than normal, while 1988 had an exceptionally dry summer with extremely low flows. This low flow, however, was not associated with exceptionally low D.O. values.

The percentage of days with mean daily D.O. less than 5 mg/ℓ in 1988 is almost the same as the long–term (1980–87) average. The percentage of days with daily minimum D.O. < 5 though is higher. This may be due to the fact that deviations of the monitor from July 15 through August 16, 1988 were consistently negative ranging from –3.2 mg/ℓ to –1.4 mg/ℓ. During this period 16 days out of the total of 30 with minimum D.O. < 5 were encountered. Of the six calibrations in that period, four gave an initial reading lower than 5 mg/ℓ and the corresponding value after calibration was higher than 6 mg/ℓ. MWCC continuous monitoring data for the summer of 1988, as provided by MWCC, are given in Appendix A–5.

We believe that the MWCC monitor data, because of the exceptionally large calibration deviations (Appendix A–5), cannot be used at present to determine hydropower plan operation.

Table IV–7 gives the frequency of occurrence (% of days) of D.O. lower than 5, 4, 3, 2 mg/ℓ for the 1980–87 period and for 1988 for the MWCC data.

No values below 2 mg/ℓ were recorded. Some "conventional monitoring" data are also periodically collected by MWCC. These are data taken from a boat at 1 m depth at UM 815.6 in the main channel (Appendix A.2). During June 1988 a cooperative MWCC/MPCA low flow survey was performed. Data at UM 815.9 were collected twice a day. These data are given in Appendix A.3. The lowest recorded value during that survey was 6.9 mg/ℓ on the morning of June 17th.

Figure IV–13 presents D.O. data from the MWCC monitor (max, mean, min) as well as data from conventional monitoring, the MWCC/MPCA low flow survey and SAFHL surveys for point D at 1 m. In Fig. IV–14 the corresponding temperature data are given.

TABLE IV-6. Frequency of Occurrence of D.O. ≤ 5 mg/ℓ (Given as a Percentage of the Number of Days for Which D.O. Records Exist)

Year	Daily Max. D.O. ≤ 5 mg/ℓ	Daily Mean D.O. ≤ 5 mg/ℓ	Daily Min D.O. ≤ 5 mg/ℓ
1980	3	16	36
1981	0	0	0.4
1982	1.2	8	18
1983	0.8	15	33
1984	0	0	1.2
1985	0	0	0
1986	0	0	1.7
1987	0	3	19
1980–87	1.2	6	16
1988	0	5.4	26.8

TABLE IV-7. Frequency of Occurrence (Percent of Days*) of Low D.O. Values for the 1980–87 Period and for 1988, for the MWCC Monitor

	Daily Max. D.O.		Daily Mean D.O.		Daily Min D.O.	
	1980–87	1988	1980–87	1988	1980–87	1988
D.O. < 5 mg/l	1.2	0	6	5.4	15.8	26.8
D.O. < 4 mg/l	0.4	0	1.2	0	6.7	8.9
D.O. < 3 mg/l	0	0	0	0	1.7	1.8
D.O. < 2 mg/l	0	0	0	0	0	0

*Percentage is based on the number of days for which records exist. There are many gaps in the record. No assumptions were made for days with no records. This results in unequal weighing of the eight years, but equal weighing of all days with records.

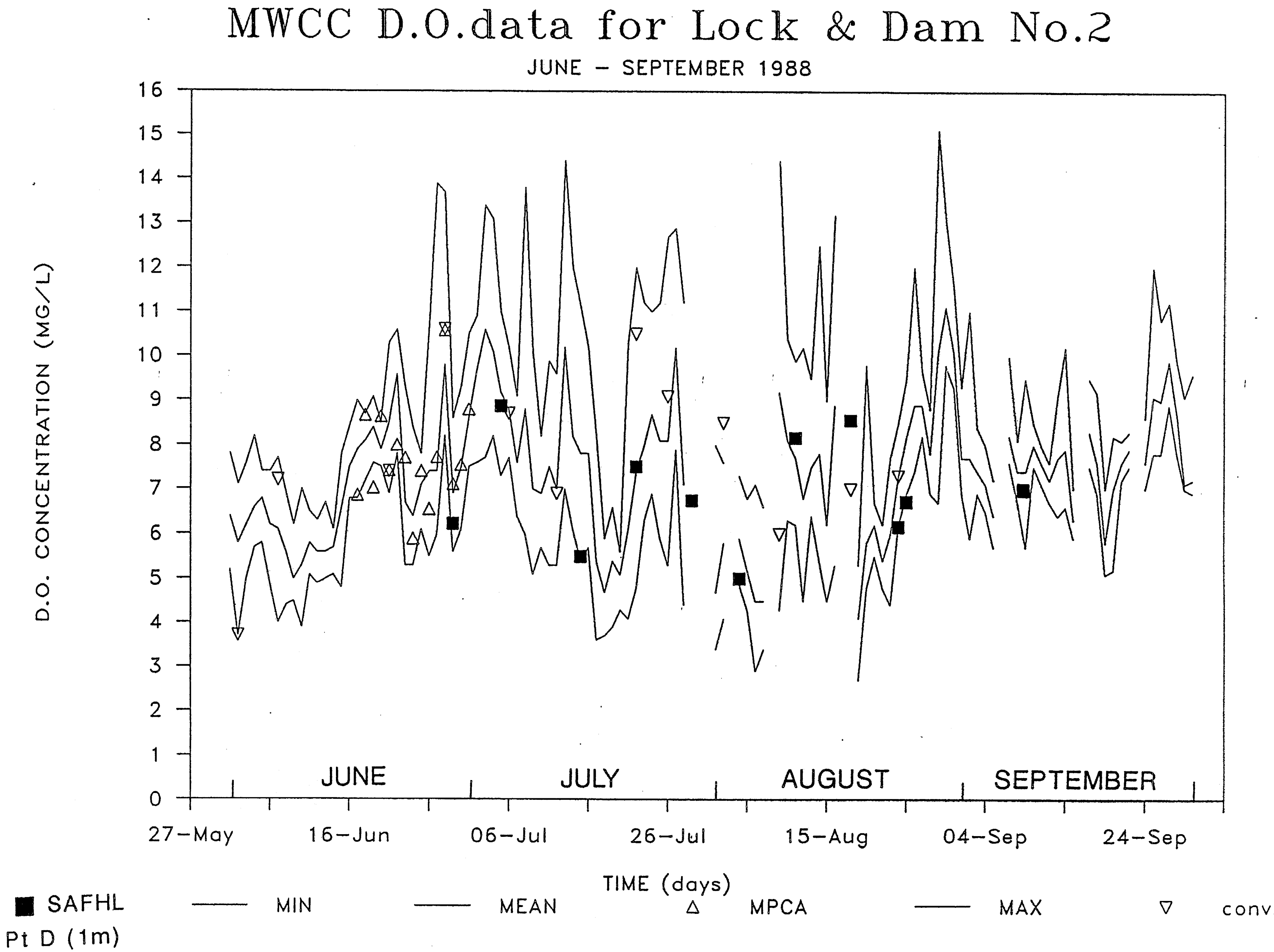


Fig. IV–13. D.O. data from the MWCC monitor and other survey during summer 1988.

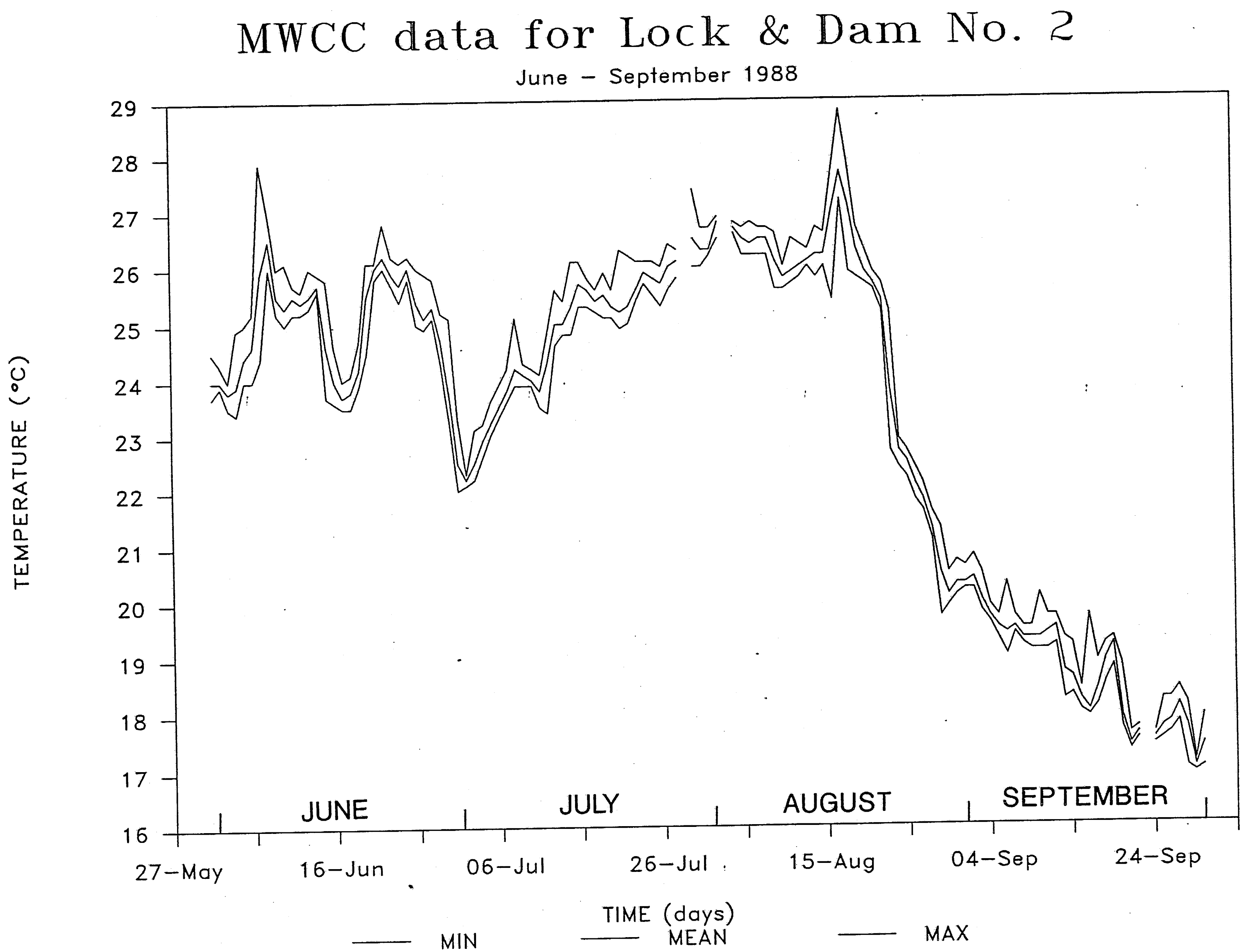


Fig. IV–14 Water temperature during summer 1988.

D.O. data collected at point D (1 m depth) of the SAFHL summer 1988 survey are further compared to MWCC monitor data in Fig. IV–15. For most cases, Point D data fall between the daily minimum and the daily mean, as expected, since most of the surveys were performed before noon.

Although in a general sense the agreement is good, no strong correlation could be obtained either with the minimum or the mean reported value. Unfortunately the 15 minute data were not available for a more dependable comparison.

The average daily range (max–min) for the 1980–87 period [Westermeier and Stefan, 1988] was 1.8 mg/ℓ, which compares well with the variations measured during the diurnal study (2.2 mg/ℓ) on August 24 and 25, 1988. However, the average daily range for 1988, as derived from the MWCC monitor data, is 3.4 mg/ℓ, significantly higher than the long–term average.

E. USE OF DATA

SAFHL surveys during summer 1988 indicated the following:

A diurnal variation in D.O. of 2 mg/ℓ can be expected. This is the long–term average computed from the MWCC data, as well as the variation observed during the diurnal survey. The diurnal survey was performed during a windy day resulting in well mixed conditions. On calm days a higher diurnal variation can be expected near the surface.

Vertical stratification was observed near the structure only on very warm days. About 250 m upstream from the dam strong stratification was observed and very low D.O. values were recorded in the deepest layers of Pool 2. These, however, did not reach the powerhouse intake, probably because of a fully submerged ridge extending across the powerhouse intake.

Downstream from the structure (350 m) no stratification was observed. Only when the bulkheaded gates were operated, both a vertical and lateral variation in D.O. was observed immediately downstream from the dam. Lateral D.O. variation across the structure downstream was of the order of 1 mg/ℓ without following any specific pattern.

Based on the comparison presented in Fig. IV–15 and considering possible stratification effects and lateral variability, as well as the accuracy and accessibility of MWCC data, it is suggested that the MWCC data are not used for the control of the powerplant's operation.

Monitoring in the tailrace (in the powerplant's outflow) would be more appropriate, since the water there is well mixed and D.O. of the powerplant outflow would be known and no assumptions would need to be made to estimate it.

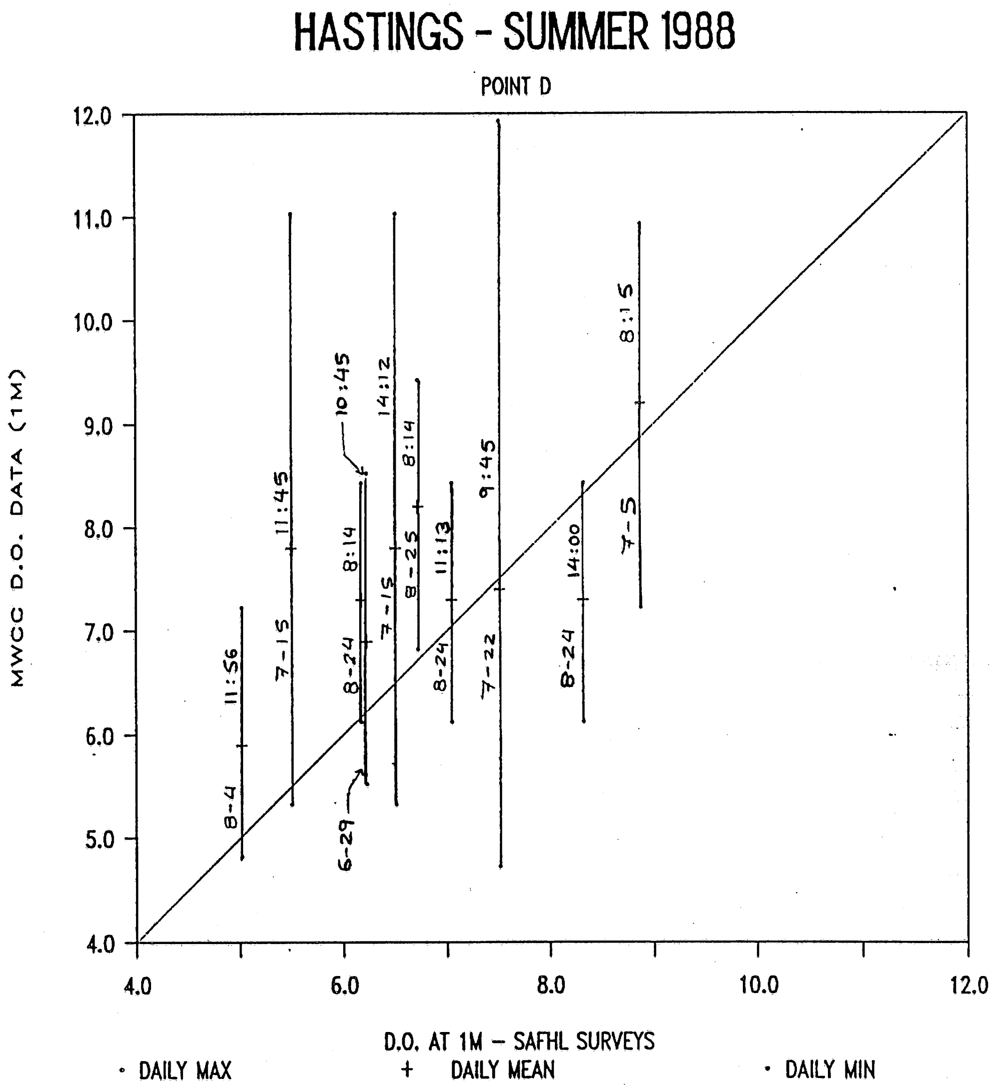


Fig. IV–15. Comparison of MWCC data and SAFHL summer 1988 surveys data.

V. REAERATION AT LOCK AND DAM NO. 2

A. INTRODUCTION

As part of the oxygen transfer model for Lock and Dam No. 2, reaeration capacities are required for the various discharge structures: the tainter gates and bulkheads, the lock, powerhouse and old Boulé Dam. Those capacities are reported in this section after some background on reaeration is reviewed.

B. THEORY OF GAS TRANSFER AT HYDRAULIC STRUCTURES

Waterside controlled mass transfer across the air–water interface for chemicals such as oxygen can be described by the equation

$$\frac{dC}{dt} = K_L \frac{A_s}{V} (C - C_s) \tag{V-1}$$

where K_L = liquid film coefficient (LT^{-1}),
A_s = surface area available for mass transfer (L^2)
C_s = saturation concentration (ML^{-3}),
C = instantaneous gas concentration (ML^{-3}) in water, and
V = control volume in which C is measured (L^3)

By following a control volume across a hydraulic structure and assuming $K_L A_s/V$ is a constant, this differential equation can be solved to yield:

$$\frac{1}{r} = \frac{C_s - C_d}{C_s - C_u} = \exp\left[-\frac{K_L A_s}{V} t\right] \tag{V-2}$$

where r = dimensionless deficit ratio,
C_u = upstream dissolved gas concentration,
C_d = downstream dissolved oxygen concentration, and
t = time of passage

The deficit ratio, r, has been a commonly used parameter which characterizes the oxygen transfer capacity for a given hydraulic structure. It is important to note the effect of water temperature on C_s. As temperature increases, C_s, and thus the maximum concentration attainable, decreases. In this section we will report the best estimate of r for the different outlet works of Lock and Dam No. 2. These deficit ratios will then be incorporated into the dissolved oxygen model of Section III.

The deficit ratio is also dependent on temperature; therefore the results of measurements will need to be adjusted to the temperature at which they are used. In this report, the temperature conversion relationship of Gameson [1958] will be used:

$$\frac{\ln r_T}{\ln r_{To}} = 1.0 + 0.018\ (T - T_o) \qquad \text{(V-3)}$$

where r_{To} is the known value at temperature T_o(°C) and r_T is the desired value at temperature T(°C). It is important to note that the deficit ratio increases with increasing temperature.

C. REAERATION CAPACITIES

The deficit ratios (at 20°C), as determined in Appendix B, are reported in Table V–1. The deficit ratios are adjusted to several other water temperatures which may be useful for modeling purposes

The inverse of deficit ratio, 1/r, is referred to here because it has a limited range (0 = complete transfer; 1 = no transfer) and changes in 1/r better reflect changes in reaeration than do changes in r.

The deficit ratios in Table V–1 should be seen as estimates only. The values listed there are the best values currently available for Lock and Dam No. 2. For details of their derivation, the reader can refer to Appendix B.

Photographs of the various outlet structures are presented in the following pages in order to demonstrate the reaeration occuring at each. In Fig. V–1, the powerplant can be seen to have little or no significant air entrainment, which gives the result 1/r = 1.0. Figure V–2 shows the old Boulé Dam spillway operating before the hydropower plant was constructed. On the date shown, the head drop was small, indicating a high river discharge and a low spillway discharge. The Boulé Dam was a good aerator. Fig. V–3 shows the discharge from the operational lock. Some air was entrained in the drainage of the lock. The reaeration was small (1/r = .90) as was the discharge (200 cfs).

Figure V–4 shows the outflow from a bulkheaded gate, showing the air remaining in the flow after it passes under the gate. Figure V–5 shows the wake of the discharge from gate 12.

Figures V–6 and V–7 each show a series of photographs of the discharge under gate 8 during the reaeration survey of September 9, 1988. Each series gives a different view of the discharge at gate openings of 0.5, 1.0, 1.5, and

TABLE V–1. Lock and Dam No. 2 Deficit Ratios

Structure	Source	Q (cfs)	1/r 20°C	22°C	24°C	26°C	28°C	30°C
Powerhouse	M	–	1.00	1.00	1.00	1.00	1.00	1.00
Boulé Dam	M	157	0.57	0.56	0.55	0.54	0.53	0.52
Lock	M	–	0.90	0.90	0.89	0.89	0.89	0.88
Bulkhead	A	160	0.43	0.42	0.41	0.39	0.38	0.37
	A	250	0.49	0.48	0.46	0.45	0.44	0.43
	M	350	0.53	0.52	0.51	0.49	0.48	0.47
	M	465	0.54	0.53	0.52	0.51	0.49	0.48
	A	800	0.62	0.61	0.60	0.59	0.58	0.57
Tainter Gate	M	390	0.80	0.79	0.79	0.78	0.77	0.77
	M	780	0.76	0.75	0.75	0.74	0.73	0.72
	M	1170	0.57	0.56	0.55	0.54	0.53	0.52
	M	1560	0.61	0.60	0.59	0.58	0.57	0.56

Notes: M denotes a measured value
A denotes an adjustment of a measured value
Values at 20°C are determined in Appendix B
Values at other temperatures are adjusted from 20°C by Eq. V–3
Taintergate openings of 0.5, 1.0, 1.5, and 2.0 ft correspond to the discharges of 390, 780, 1170, and 1560 cfs, respectively, listed above.

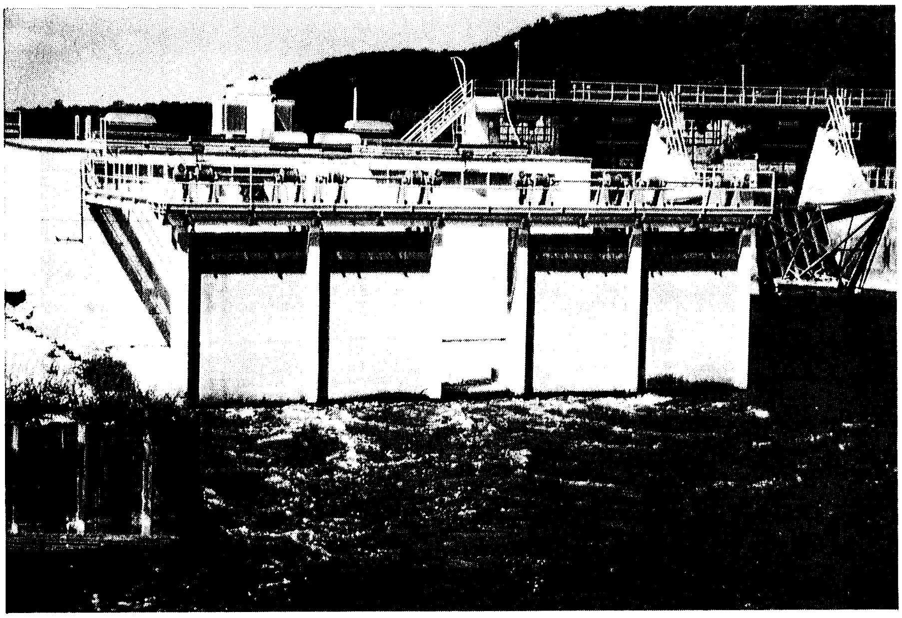


Fig. V–1. Powerplant discharge.

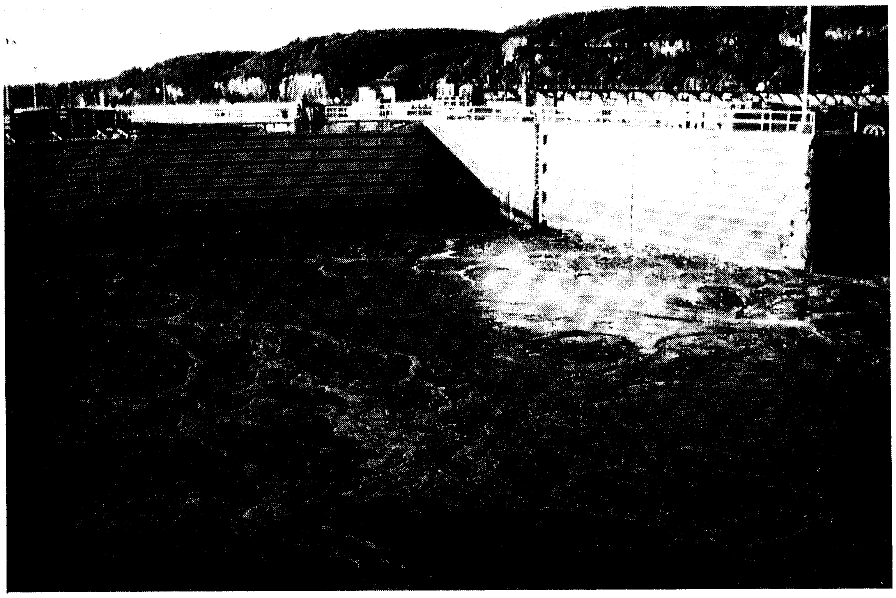
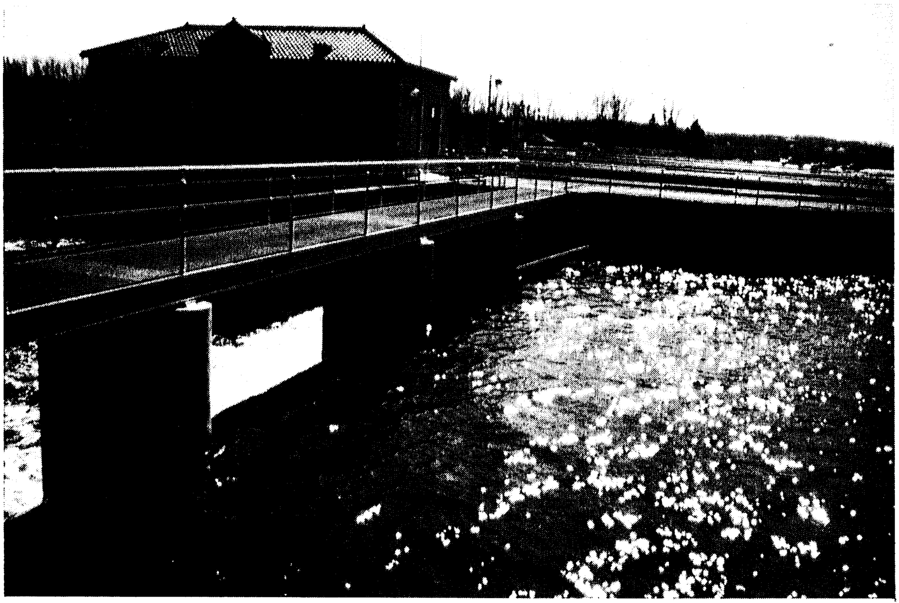


Fig. V–3. Discharge from operational lock.

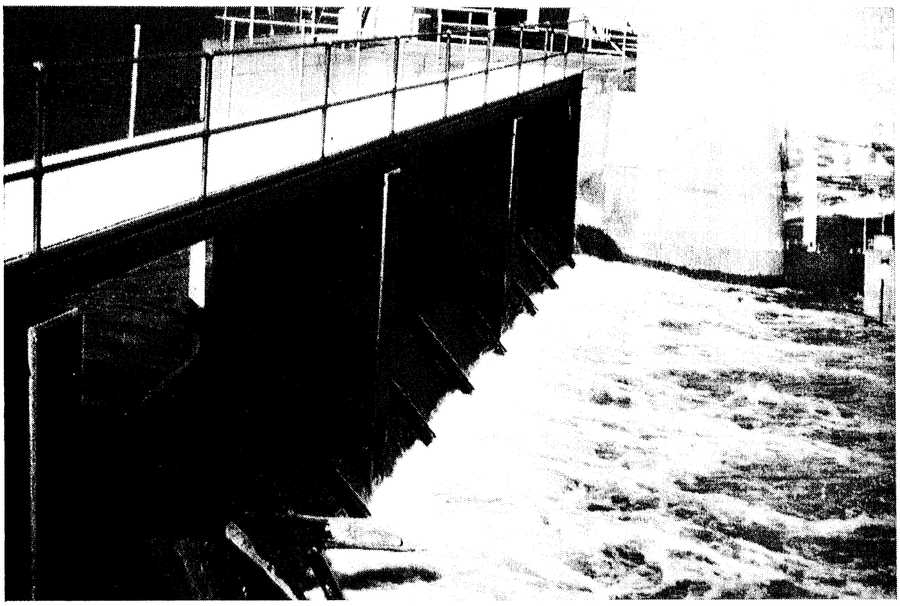
Fig. V–2. Boulé dam fixed crest spillway under operation before construction of the hydropower plant at a higher river discharge and therefore low head and low spillway discharge.

a) View from upstream.

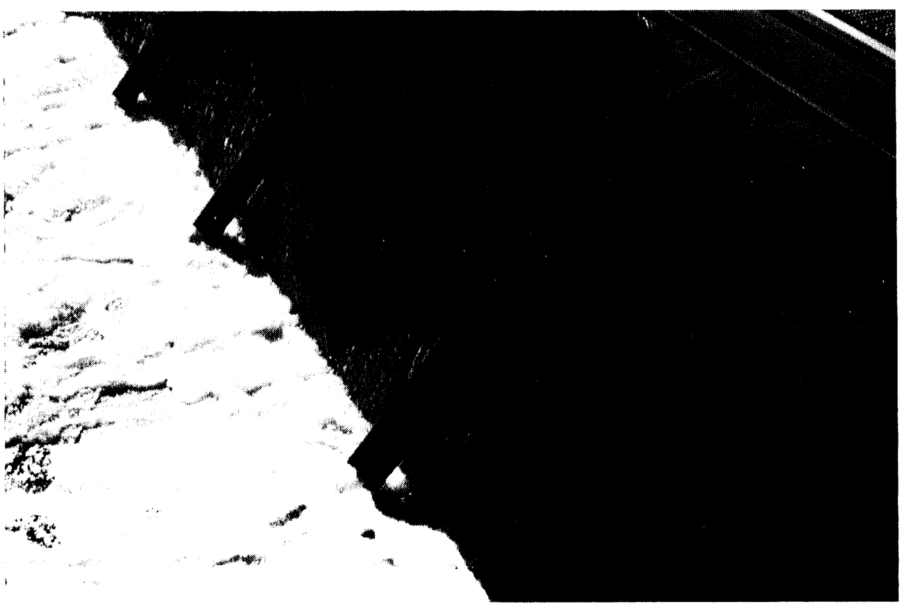
b,c) View from downstream.



(a)



(b)



(c)

Fig. V–4. Outflow from a bulkheaded gate. The bulkhead is upstream from the gate and not visible. The water flows over the bulkhead as a free overfall and entrains air when it impinges on the tailwater in front of the gate.

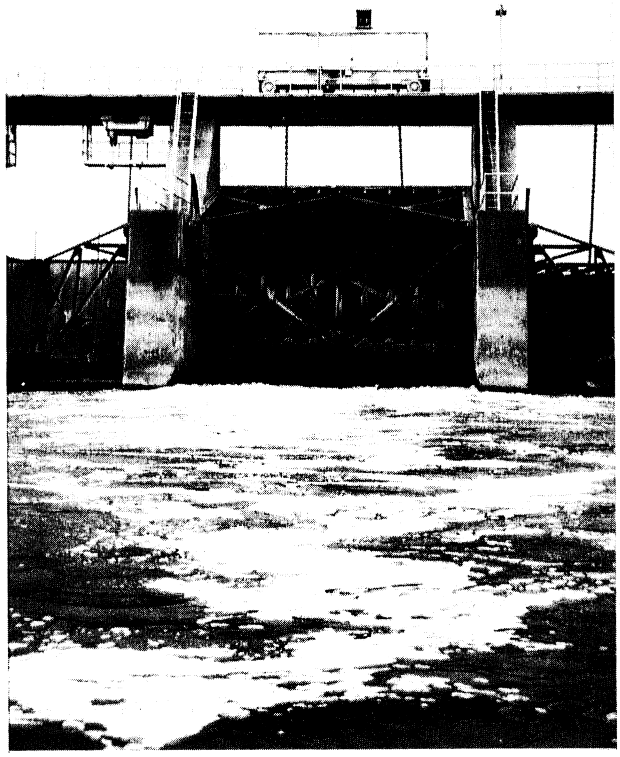
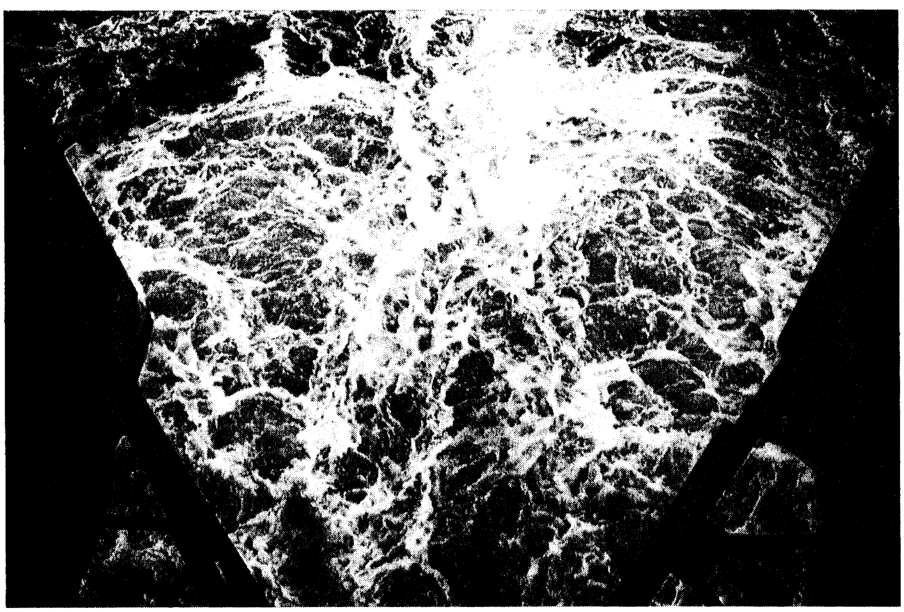


Fig. V–5. Wake of discharge from bulkheaded gate No. 12.



0.5 ft gate opening

1.0 ft gate opening

1.5 ft gate opening

2.0 ft gate opening

Fig. V–6. Discharge underneath gate no 8 at four openings, view from downstream.


0.5


1.0


1.5


2.0

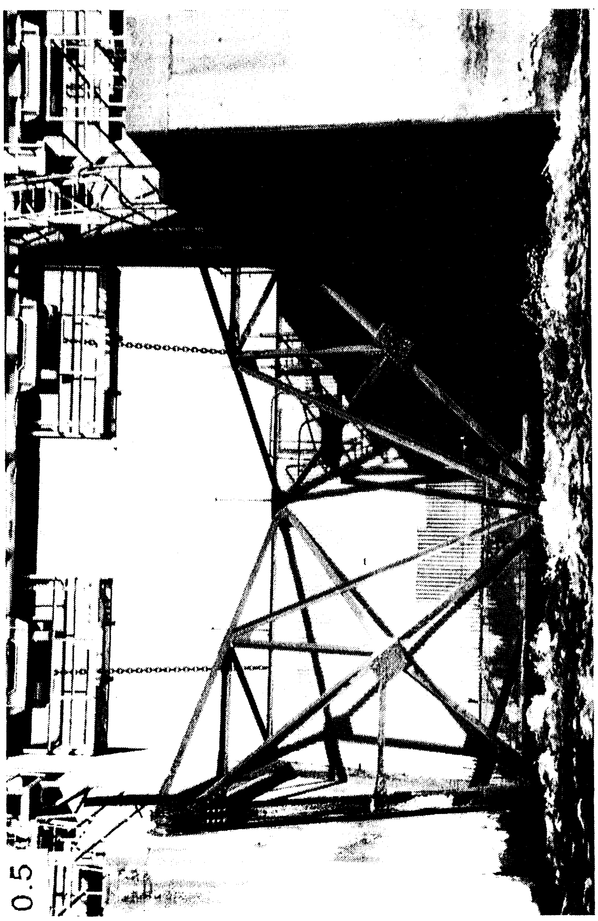
0.5 ft gate opening

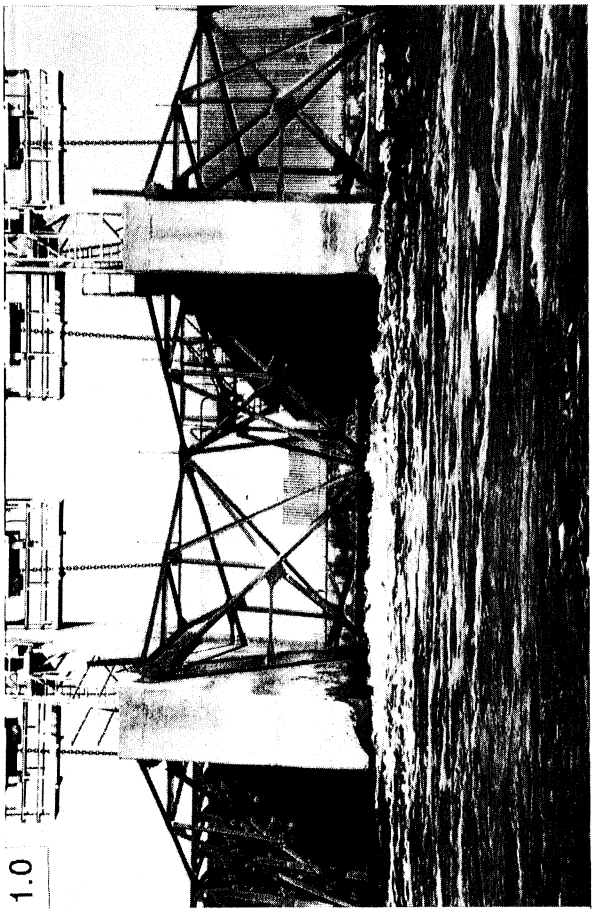
1.0 ft gate opening

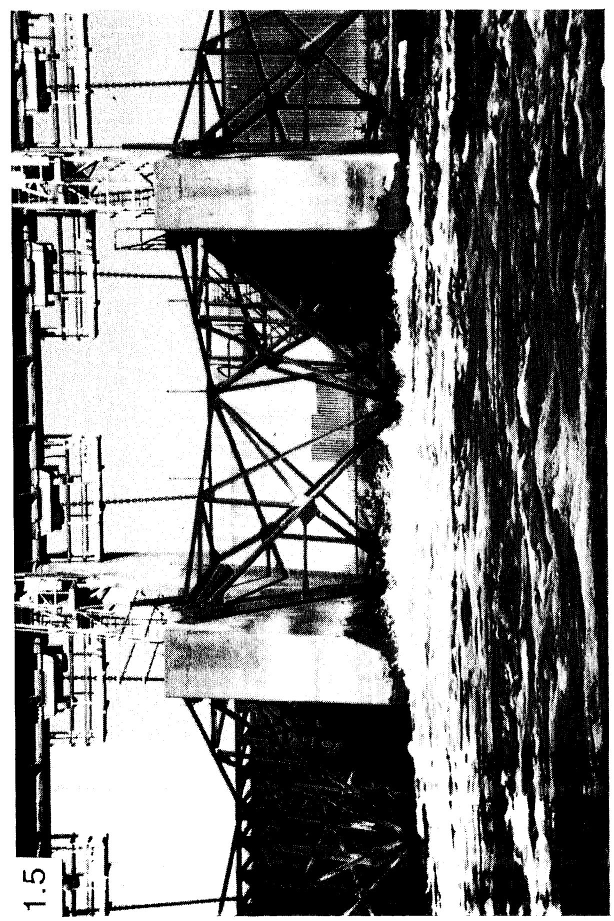
1.5 ft gate opening

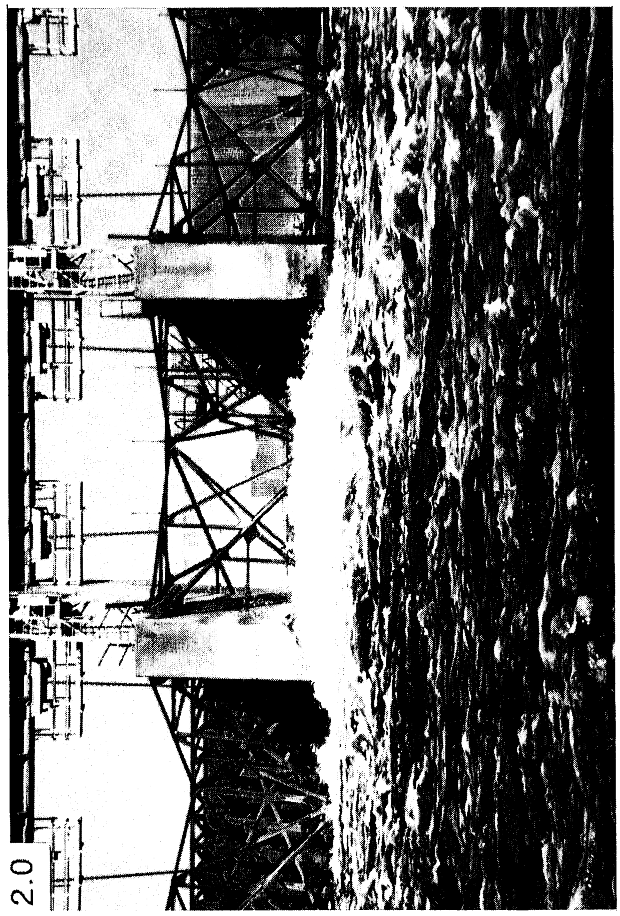
2.0 ft gate opening

Fig. V–7. Discharge from gate no. 8 at four openings, view from boat. Note changes in air entrainment.


0.5


1.0


1.5


2.0

2.0 feet. Note that in the cases of the 0.5 and 1.0 ft openings, the hydraulic jump is submerged and the air entrainment and reaeration are small. For the case of the 1.5 and 2.0 ft gate openings, the jump is non–submerged and the amount of air entrained is greatly increased. Thus, as can be seen in Table V–1, there is a large increase in the reaeration capacity of the tainter gates with the change from the 1.0 ft opening to the 1.5 ft opening. For a non–submerged hydraulic jump, the reaeration decreases with increasing flow because the air entrainment does not increase at the same rate as the discharge.

Finally, Fig. V–8 shows the wake of the discharge from gate 8 operating at a 2.0 ft gate opening.

Fig. V–8. Wake of discharge from gate no. 8 at 2.0 ft gate opening.

VI. APPLICATION OF MODEL

Some documentation is needed to demonstrate how the D.O. transport model given in Section III was implemented. The D.O. model was given by Eq. III–1. The deficit ratios that were used are given in Section V. They were adjusted for temperature by Eq. V–3. The deficit ratios for the bulkheads and tainter gates were adjusted for discharge and gate opening as detailed in Appendix B. Also needed for the model is a relationship for C_s, or saturation concentration; that of Rich [1973] for one atmosphere air pressure is used:

$$C_s = 14.652 - 4.1022\times10^{-1}T + 7.991\times10^{-3}T^2 - 7.77774\times10^{-5}T^3 \quad \text{(VI–1)}$$

where C_s is given in mg/ℓ and T is water temperature in °C. That value is corrected to the elevation of Lock and Dam No. 2 (675 ft) by multiplying by 0.976 [Cole, 1983]. The change in concentration for each discharge structure is determined from Eq. III–3.

The pool and tailwater elevations are determined as a function of river flow from Table II–1, as is the discharge per foot opening of the tainter gates and the Boulé spillway discharge. The bulkhead discharge, Q_b, is determined by

$$Q_b = 100\ h^{3/2} \quad \text{(VI–2)}$$

where h is the difference between the pool elevation and the top of the bulkheads (ft) and Q is in cfs. Equation VI–2 is that of a simple sharp–crested weir and was found to fit the discharge curve given by the Corps of Engineers [1973].

With the above information and that from Section IV, the model simply computes the cross–sectionally averaged downstream concentration as given by Eqs. III–4 and III–5, or:

$$\bar{C}_d = \bar{C}_u + \frac{\Sigma\ \Delta C_i\ Q_i}{Q} \quad \text{(VI–3)}$$

A typical output from the model appears as the example given in Table VI–1. Thus for the given releases from the dam, an upstream concentration of 4.2 mg/ℓ and water temperature of 26°C, a net increase of 0.46 mg/ℓ may be expected. From Table VI–1 it can be seen that the bulkheads are the most efficient aerators (especially at these low bulkhead discharges).

TABLE VI–1. Typical Model Output

	Q (cfs)	No. (–)	Open (ft)	T_w (°C)	1/r (–)	C_s (mg/ℓ)	C_u (mg/ℓ)	C_d (mg/ℓ)	ΔC (mg/ℓ)
Turbines	5400			26.0	1.00	7.83	4.20	4.20	.00
Gts. 1–7	1488	4	.5	26.0	.78	7.83	4.20	4.99	.79
Gts.8–11	2976	4	1.0	26.0	.74	7.83	4.20	5.15	.95
Gts.12–19	0	0	0	26.0	1.00	7.83	4.20	4.20	.00
Bulkheads	314	2		26.0	.39	7.83	4.20	6.41	2.21
Lock	200			26.0	.89	7.83	4.20	4.60	.40
Boulé	0			26.0	0.54	7.83	4.20	4.20	.00
Total	10378			26.0	NA	7.83	4.20	4.66	.46

A. ASSESSMENT OF HYDROPOWER IMPACT ON DISSOLVED OXYGEN

In order to assess the impact of the hydropower plant on D.O., it was necessary to choose several river discharges of concern and corresponding release scenarios to apply the model. The river flows for which dissolved oxygen below 5 mg/ℓ sometimes occurs are generally below 14,000 cfs [Westermeier and Stefan, 1988]. The range of water temperature of concern was generally from 22°C to 30°C, with 26°C being the temperature most commonly associated with D.O. < 5 mg/ℓ. Therefore the model results presented here will be at those temperatures and discharges.

Because of the poor quality and uncertain nature of the historical D.O. record, it was also necessary to choose several upstream oxygen concentrations for the assessment. The assessment was made for upstream concentrations of C_u = 2.0, 3.0, 4.0 and 4.5 mg/ℓ, even though concentrations as low as 2.0 and 3.0 mg/ℓ are extremely rare (Table IV–7).

The model was run for the conditions listed in Tables VI–2 and VI–3. These conditions are based on the operational rules given in Section II. Maximum allowable gate openings were not exceeded. Before hydropower, the model was run with only the locks, Boulé Dam and tainter gates operating.

The model was also run to simulate hydropower generation, first without any mitigation measures to improve D.O. and second with mitigation. The first study was conducted without any discharge over bulkheads or other mitigation measures in order to test the maximum impact of operation. The discharge characteristics for the first study are given in Table VI–3.

Model results for the before hydropower case at water temperatures of 22, 26, and 30°C and for an upstream concentration of 2.0 mg/ℓ are presented in Figure VI–1. There is a small variation in $\Delta\bar{C}$ with this range of temperature. Because of this and because D.O. < 5.0 mg/ℓ is most commonly associated with T_w = 26°C [Westermeier and Stefan, 1989], the impact analysis was performed at a single temperature of 26°C.

The results of several runs to determine the impact of hydropower development are given in Table VI–4. These results are plotted versus river discharge in Figs. VI–2 through VI–5. The impact of the hydropower development is expressed as the difference in the downstream D.O. concentration before and after the hydropower operation for the same total river discharge. In the cases where the D.O. concentration before the hydropower operation was above 5 mg/ℓ, the impact is defined as the difference between the 5 mg/ℓ D.O. standard and the downstream concentration with hydropower operation.

For river flows of 3,000 cfs or less, the bulkheads and the Boulé Dam were used exclusively; thus to determine the impact, the uppermost line in

Table VI–2. Discharge and Elevation Data for Model Input: Before Hydropower

Nominal Q (cfs)	1100	2000	3000	4000	6000	8000	10000	12000	15000	20000
Pool elev. (ft)	87.20	87.16	87.12	87.10	87.02	86.85	86.70	86.50	86.50	86.50
T.W. elev. (ft)	75.00	75.17	75.15	75.20	75.32	75.50	75.66	75.85	76.15	76.80
Head (ft)	12.20	11.99	11.97	11.90	11.70	11.35	11.04	10.65	10.35	9.70
Gates: cfs/ft open	789	782	781	778	770	757	744	729	716	690
No. of gates	1	1	3	5	11	17	17	17	17	17
Opening (ft)	0	0.12	0.49	0.56	0.5	0.5	0.68	0.87	1.13	1.6
Q, gates (cfs)	0	94	1148	2178	4237	6435	8599	10782	13758	18771
Q, spillway (cfs)	500	474	446	433	366	297	226	132	132	132
Q, lock (cfs)	200	200	200	200	200	200	200	200	200	200
Q, bh (2 @ el 683.8)	372	1232	1210	1199	1156	1065	988	887	887	887
Total Q	1072	2000	3004	4010	5958	7997	10012	12001	14977	19990

Table VI–3. Discharge and Elevation Data for Model Input: After Hydropower, No Mitigation

Nominal Q (cfs)	1100	2000	3000	4000	6000	8000	10000	12000	15000	20000
Pool elev. (ft)	87.20	87.16	87.12	87.10	87.02	86.85	86.70	86.50	86.50	86.50
T.W. elev. (ft)	75.00	75.17	75.15	75.20	75.32	75.50	75.66	75.85	76.15	76.80
Head (ft)	12.20	11.99	11.97	11.90	11.70	11.35	11.04	10.65	10.35	9.70
Gates: cfs/ft open	789	782	781	778	770	757	744	729	716	690
No. of gates	0	0	0	0	1	6	11	17	17	17
Opening (ft)	0	0	0	0	0.52	0.53	0.54	0.52	0.77	1.23
Q, gates (cfs)	0	0	0	0	401	2407	4418	6444	9375	14430
Q, turbines (cfs)	900	1800	2800	3800	5400	5400	5400	5400	5400	5400
Q, lock (cfs)	200	200	200	200	200	200	200	200	200	200
Total Q	1100	2000	3000	4000	6001	8007	10018	12044	14975	20030

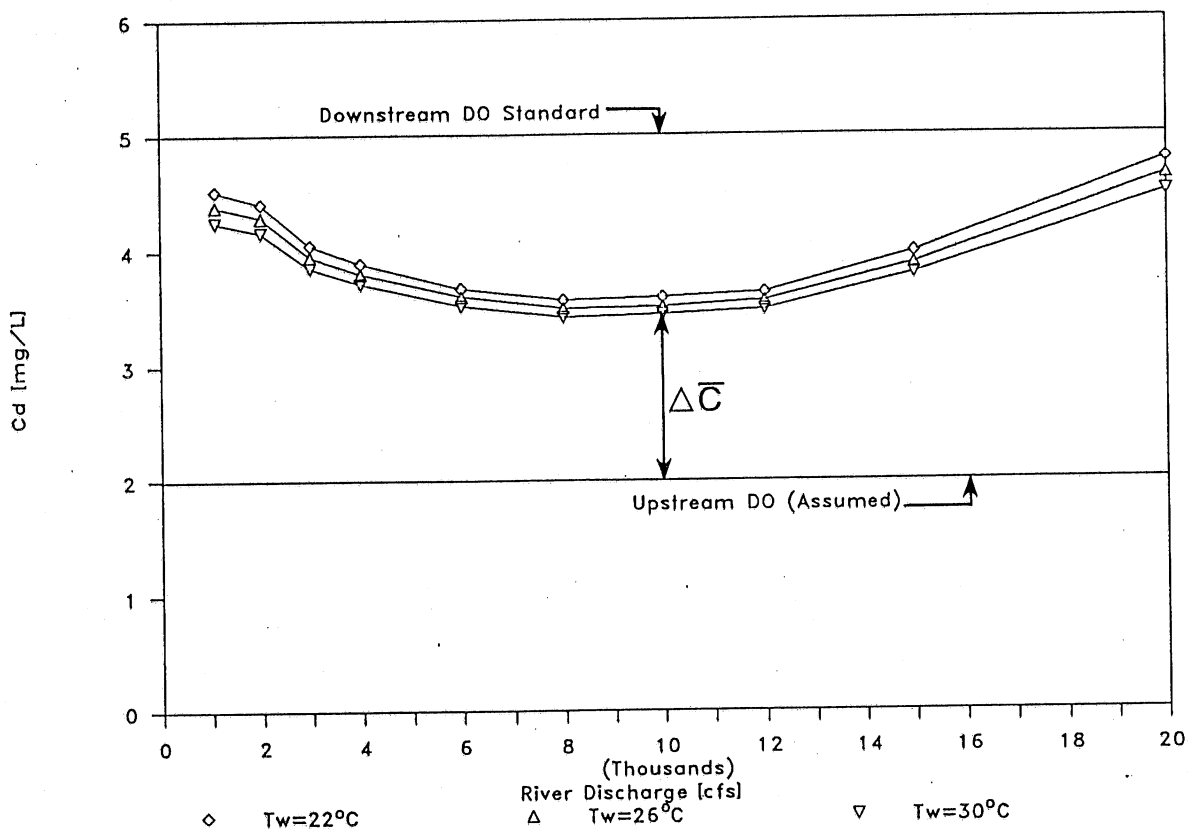


Fig. VI–1. Change in concentration, $\Delta\bar{C}$, for conditions before hydropower installation.

Table VI–4. Modeled Hydropower Impact at 26° C (Unmitigated)

Q (cfs)	1100	2000	3000	4000	6000	8000	10000	12000	15000	20000
C_u = 4.5 mg/l										
C_d Before Hydro	5.9	5.8	5.6	5.5	5.4	5.4	5.4	5.4	5.6	6.0
C_d After Hydro	4.6	4.5	4.5	4.5	4.6	4.7	4.8	4.9	5.0	5.4
Impact	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.1	0.0	0.0
C_u = 4 mg/l										
C_u Before Hydro	5.6	5.5	5.3	5.2	5.1	5.0	5.0	5.0	5.2	5.7
C_d After Hydro	4.1	4.0	4.0	4.0	4.1	4.3	4.4	4.5	4.6	5.0
Impact	0.9	1.0	1.0	1.0	0.9	0.7	0.6	0.5	0.4	0.0
C_u = 3 mg/l										
C_d Before Hydro	5.0	4.9	4.6	4.5	4.3	4.2	4.3	4.3	4.6	5.2
C_d After Hydro	3.1	3.1	3.0	3.0	3.1	3.3	3.5	3.6	3.7	4.2
Impact	1.9	1.8	1.6	1.5	1.2	0.9	0.8	0.7	0.8	0.8
C_u = 2 mg/l										
C_d Before Hydro	4.4	4.3	4.0	3.8	3.6	3.5	3.5	3.6	3.9	4.6
C_d After Hydro	2.1	2.1	2.0	2.0	2.1	2.4	2.6	2.7	2.9	3.5
Impact	2.3	2.2	1.9	1.8	1.5	1.1	0.9	0.9	1.0	1.1

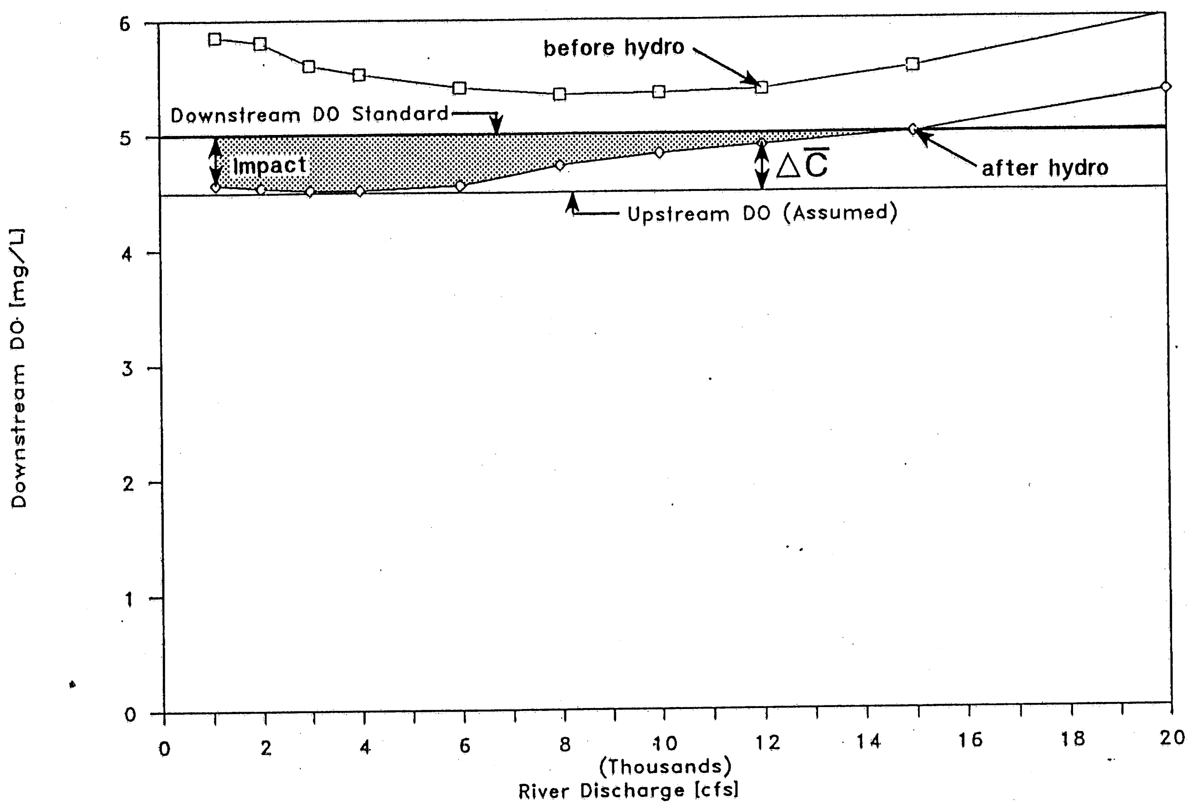


Fig. VI–2. Modeled impact of hydropower operation, $C_u = 4.5$ mg/ℓ, $T_w = 26°$ C.

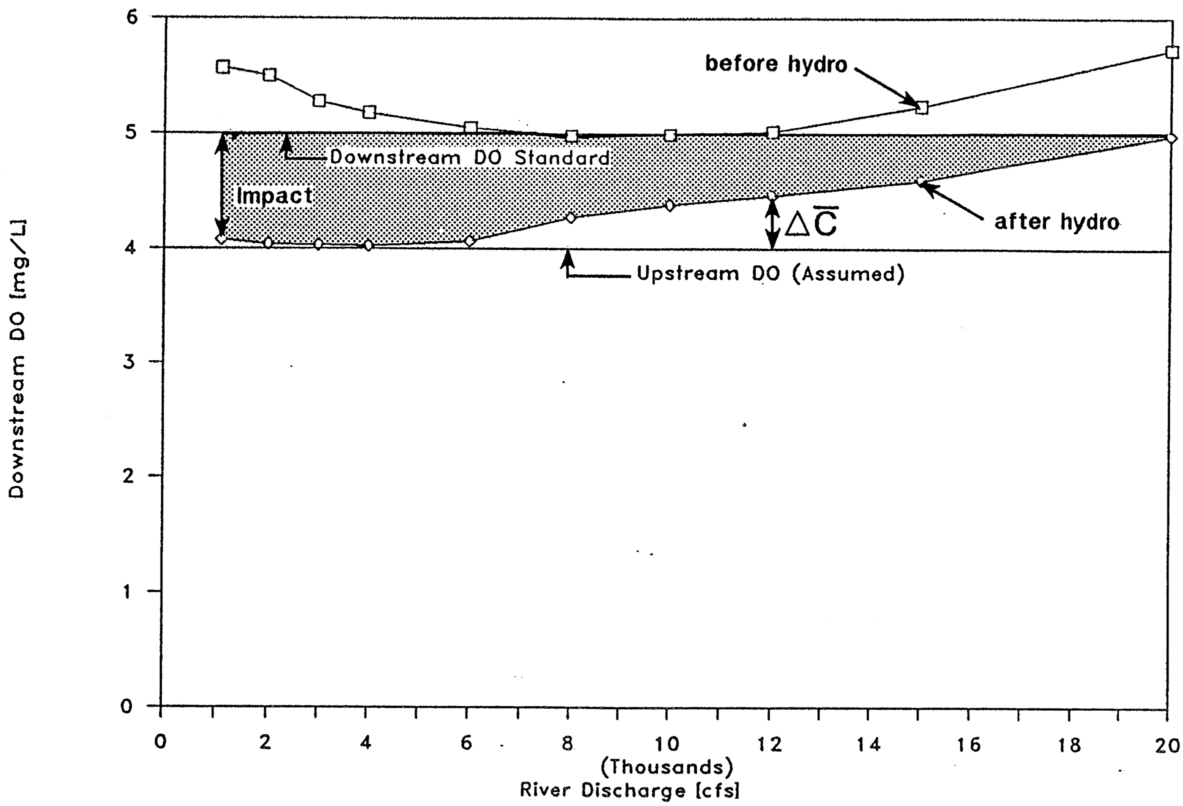


Fig. VI–3. Modeled impact of hydropower operation, $C_u = 4.0$ mg/ℓ, $T_w = 26°C$.

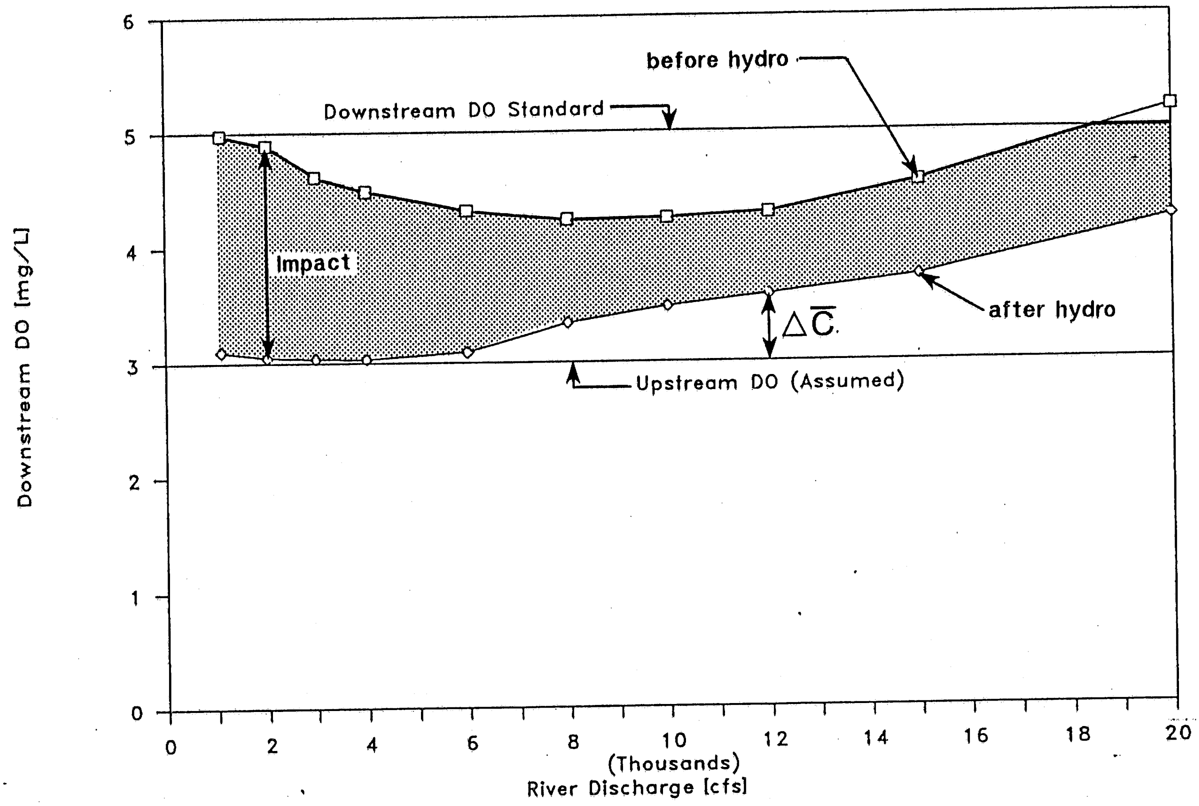


Fig. VI–4. Modeled impact of hydropower operation, $C_u = 3.0$ mg/ℓ, $T_w = 26°$C.

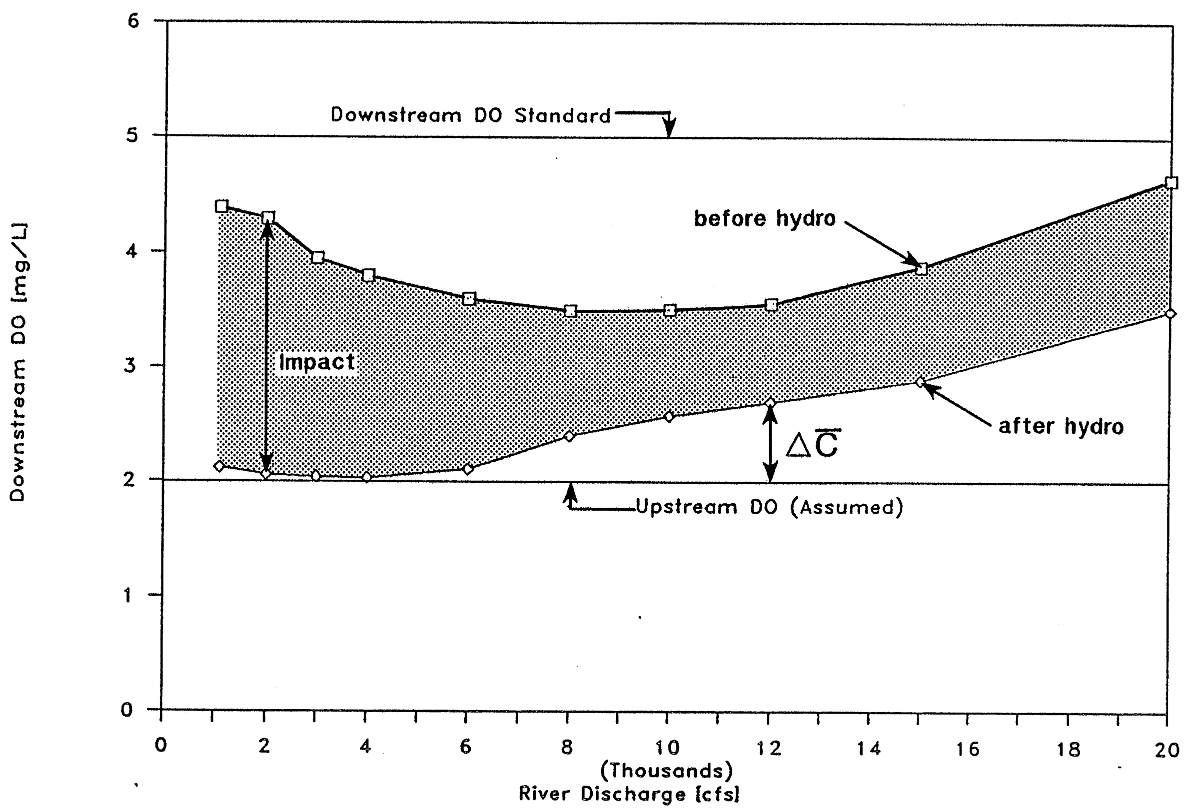


Fig. VI–5. Modeled impact of hydropower operation, C_u = 2.0 mg/ℓ, T_w = 26° C.

Figs. VI–2 through VI–5 should be used (except when it is greater than 5.0 mg/ℓ and 5.0 mg/ℓ should be used).

From Table VI–4, it can be seen that for most of the flows and concentrations tested, there appears to be a significant impact due to hydropower operation. However, the analysis of Westermeier and Stefan [1988] has shown that historically there is little risk of low D.O. for flows over 14,000 cfs, and D.O. of less than 2.0 mg/ℓ should not be expected. Other than the preceding generalizations and that low D.O. is a higher risk at higher water temperatures, little can be done to predict the risk of low D.O.

B. MITIGATION OF LOW DISSOLVED OXYGEN SITUATIONS

It was necessary to explore several mitigation procedures in order to meet the downstream D.O. standard at Lock and Dam No. 2. The standard, which was stated in Section I, can be summarized as non–degradation for downstream concentrations less than 5.0 mg/ℓ prior to development, or 5.0 mg/ℓ when downstream concentrations were 5.0 mg/ℓ or greater prior to development.

As seen in Section VI–A (Figs. VI–2 to VI–5 and Table VI–4), the hydroplant operation has a significant impact on downstream D.O. concentrations. Three possible means are generally available to mitigate these impacts and still allow for the operation of the hydropower plant. The simplest means of mitigation is to spill water over or under the release structures with the highest reaeration capacities while reducing the hydropower discharge. Thus, with proper operation, the water which is spilled will have a D.O. above the standard while the water from the power plant will dilute that water, so that the average D.O. of the water released will meet the standard. A second means is that of aerating the powerplant discharge using a system of bubble aerators in the tailrace of the powerplant. A third mitigation measure is called turbine or draft tube aspiration. This technique involves the injection or venting of air directly into the turbine, downstream of the runner where pressures are low. All three of these measures would require continuous monitoring of D.O. and water temperature.

Of the three options listed, only the use of gates and bulkheads to spill water along with hydropower plant discharge reduction was examined to mitigate low D.O. concentrations. At this time, when the risk of low D.O. is still uncertain, the capital costs of the other two systems are not justified. If after several seasons of monitoring, it is found that low D.O. concentrations lead to problems, causing significant reductions in power output, an economic analysis of the other two systems may be required to determine their feasibilities.

For each of the D.O. and discharge scenarios given in Table VI–4, it was necessary to determine if mitigation is possible and if so, what new discharge scheme (combination of spilling water and reduction of hydropower discharge) would mitigate the problem. The best aerators at the dam are flow over the bulkheaded gates, and discharge under the gate at the 1.5 foot opening (Table V–1). The bulkheads are best at low discharges, but their efficiency decreases with increasing discharge as:

$$\ln r_{20} = 5.2\ Q_b^{-.36} \qquad \text{(VI–3)}$$

where Q_b is the discharge over a single bulkhead (cfs) and Eq. VI–3 is taken from Eq. B–3 (Appendix B). In order to find the discharge at which the bulkheads and gates (at 1.5' opening) are equivalent aerators, Eq. VI–3 is solved at the gate value of 1/r, or 1/r = 0.57 at 20°C:

$$\ln(1/0.57) = 5.2\ Q_b^{-.36} \qquad \text{(VI–4)}$$

which is satisfied at Q_b = 490 cfs. Thus for Q_b < 490 cfs, the bulkheads should be more efficient aerators than the gates at 1.5 ft openings.

The bulkhead crests have been set at elevation 685.35 ft [Summer, 1988] and elevation 683.15 ft [Corps of Engineers, 1973]. Of these two elevations, combined with the normal pool elevations, only the former can discharge less than 490 cfs. The Corps of Engineers [1973] have enough bulkheads to make four bulkheaded gates available for aeration. Thus, combinations of 0 to 4 bulkheads (with crest elevations of 685.35 ft) and any number of gates open 1.5 ft, were used to mitigate low dissolved oxygen concentrations.

The results given in Table VI–5 are, like the modeled impact in Table VI–4, given at a single water temperature of 26°C. The mitigation is tested at several concentrations and discharges. Therefore, for other specific conditions, mitigation may need to be retested or interpolated. The mitigation measures given in Table VI–5 were determined by first applying the model with the hydropower plant running at full capacity or, when the total river discharge was less than 5,400 cfs, at the river discharge less the lock discharge. Subsequently, the model was applied with any excess discharge over the bulkheads and through the gates at the 1.5 ft gate opening. If the model did not predict that the standard was met at this point, the powerplant discharge was decreased and the flow over the bulkheads and through gates were increased until the downstream D.O. predicted by the model met the standard. The flow conditions at that point are presented in Table VI–5. For each combination of river discharge and upstream concentration, the number of bulkheads and gates (with the corresponding crest elevations and gate openings, respectively), and the powerplant discharge are given, which result in a downstream D.O. concentration which will meet the standard.

Mitigation was not explored for flows over 15,000, where low D.O. has not been found to occur [Westermeier and Stefan, 1989]. Where the modeled $\bar{C}_d$ after hydro development was at or above 5.0 mg/ℓ, no mitigation measures were tested. In some cases of low river discharge and low D.O.

Table VI–5. Modeled Hydropower Mitigation at 26° C

Q (cfs)	1100	2000	3000	4000	6000	8000	10000	12000	[b]15000	[b]20000
C_u = 4.5 mg/l										
Bulkheads, No.	2	2	3	4	2	1	4	0	4	
Crest elev.	85.35	85.35	85.35	85.35	85.35	85.35	85.35	–	85.35	
Gates, No.	0	0	0	0	1	2	1 3	1 5	1 8	
Opening	0	0	0	0	1.5	1.5	0.5 1.5	1.3 1.5	0.5 1.5	
Q, turbines	900	1300	2100	2900	4200	5400	5400	5400	5400	
Q, total	[c]1603	1987	3006	4026	5987	8055	9947	12015	15043	
Required C_d	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Predicted C_d	5.1	5.0	5.0	5.0	5.0	5.0	5.2	5.3	5.5	[d]5.4
C_u = 4 mg/l										
Bulkheads, No.	a	4	2	4	4	4	4	1	4	
Crest elev.		85.35	85.35	85.35	85.35	85.35	85.35	85.35	85.35	
Gates, No.		0	1	1	2	3	4	6	1 8	
Opening		0	1.5	1.5	1.5	1.5	1.6	1.5	0.5 1.8	
Q, turbines		900	1200	1700	2700	3700	4400	5100	5400	
Q, total		2074	3042	3993	6073	8041	9989	11984	15043	
Required C_d	[a]5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Predicted C_d		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.1	[d]5.0
C_u = 3 mg/l										
Bulkheads, No.	[a]Shutdown or artificial aeration in draft tube or downstream from plant		4	1	4	4	4	2	4	
Crest elev.			85.35	85.35	85.35	85.35	85.35	85.35	85.35	
Gates, No.			1	2	2	3	4	6	9	
Opening			1.5	1.5	1.5	1.5	1.6	1.5	1.5	
Q, turbines			900	1250	2600	3700	4400	5000	4600	
Q, total			[c]3213	4016	5973	8041	9989	12008	14959	
Required C_d	[a]5.0	[a]4.9	4.6	4.5	4.3	4.2	4.3	4.3	4.6	5.0
Predicted C_d			4.6	4.5	4.3	4.2	4.3	4.3	4.6	
C_u = 2 mg/l										
Bulkheads, No.			4	1	4	4	4	2	4	
Crest elev.			85.35	85.35	85.35	85.35	85.35	85.35	85.35	
Gates, No.			1	2	2	3	4	6	9	
Opening			1.5	1.5	1.5	1.5	1.6	1.5	1.5	
Q, turbines			900	1250	2600	3700	4400	5000	4600	
Q, total			[c]3213	4016	5973	8041	9989	12008	14959	
Required C_d	[a]4.4	[a]4.3	4.0	3.8	3.6	3.5	3.5	3.6	3.9	4.6
Predicted C_d			4.0	3.8	3.6	3.5	3.5	3.6	3.9	

a: Mitigation is not possible under these circumstances
b: For Q > 14,000 cfs, low D.O. is not of concern [Westermeier and Stefan, 1988]
c: River discharge increased to allow hydro operation at Q_{min} = 900 cfs
d: Mitigation is not required

(denoted by "a" in Table VI–5) mitigation was not possible. This was due to high concentrations before hydro development caused by bulkhead operation. In those cases, the hydro discharge was set at Q_{min} = 900 cfs and the river discharge was increased to the point where the standard was met (denoted by "c" in Table VI–5). Artificial aeration would have to be used in these cases. (It should be noted that artificial aeration would be beneficial in all cases where low D.O. would cause reduced hydro discharges.)

The results of the mitigation given in Table VI–4 are represented graphically in Fig. VI–6a. Figure VI–6a shows the modeled hydropower discharge for a given upstream concentration and total river discharge. Contours of constant hydropower discharge are added for clarification.

For comparison, the historical record of D.O. at Lock and Dam No. 2 [Westermeier and Stefan, 1989] is plotted at the same scale in Fig. VI–6b. Occurances of low D.O. at Lock and Dam No. 2 can be seen from Fig. VI–6b and Fig. VI–7 where the entire record is given. The risk appears to be limited to river discharges of less than 14,000 cfs.

C. FUTURE OPERATION AND MITIGATION

The model results given in Section VI–B were computed for the analysis of the measures for mitigation of low downstream D.O. levels caused by hydropower operation. Those results may, however, be used as an operational guide for the hydropower plant.

When the river discharge and dissolved oxygen are the same as one of the cases given in Table VI–5, the mitigation measures given there can be employed. For other cases, Fig. VI–6a must be used. The hydropower plant discharge for the ambient upstream concentration can be determined from Fig. VI–6a by interpolating between the discharge contours and/or specific model results. With that, the excess discharge (the total river discharge less the hydropower plant discharge and 200 cfs for the lock) may be discharged using gates set at 1.5 foot openings and over the bulkheads. At low flows, the bulkheaded gates should be used preferrentially, while at higher flows they can be used to balance the flow not delivered by an integer number of gates at 1.5 foot openings. The mitigation measures given in Table VI–5 can serve as a guide in determining the dam settings when interpolation is necessary.

An example of the use of Fig. VI–6 is given below:

$$Q_{river} = 9{,}500 \text{ cfs}$$

$$C_u = 3.4 \text{ mg}/\ell$$

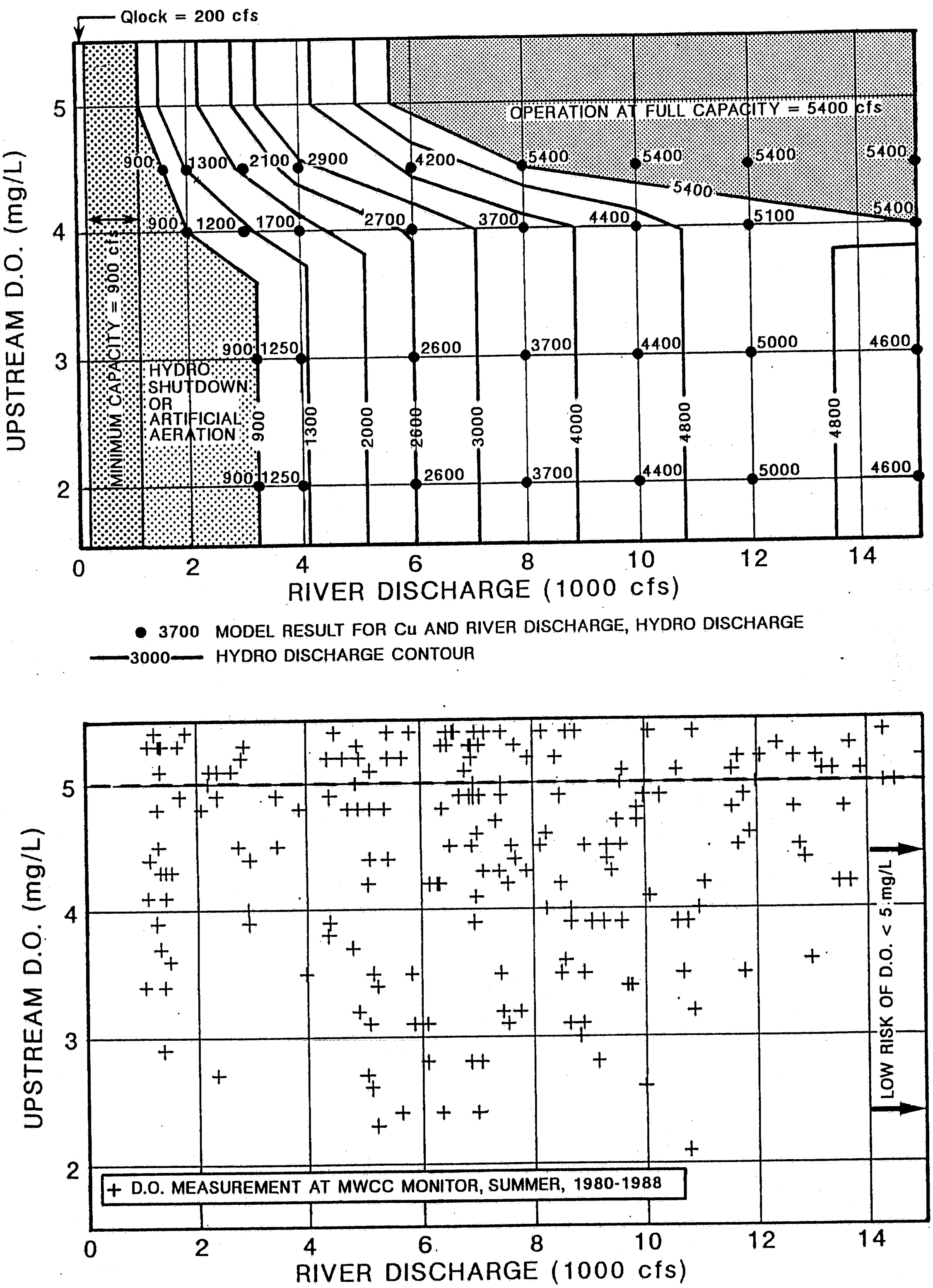


Fig. VI–6. a) Hydropower plant discharge that will result in 5 mg/ℓ downstream D.O. as a function of upstream D.O. and total river discharge, T = 26°C.

b) Historical upstream D.O. (June–Sept. 1980–1988) as a function of total river discharge [Westermeier and Stefan, 1989].

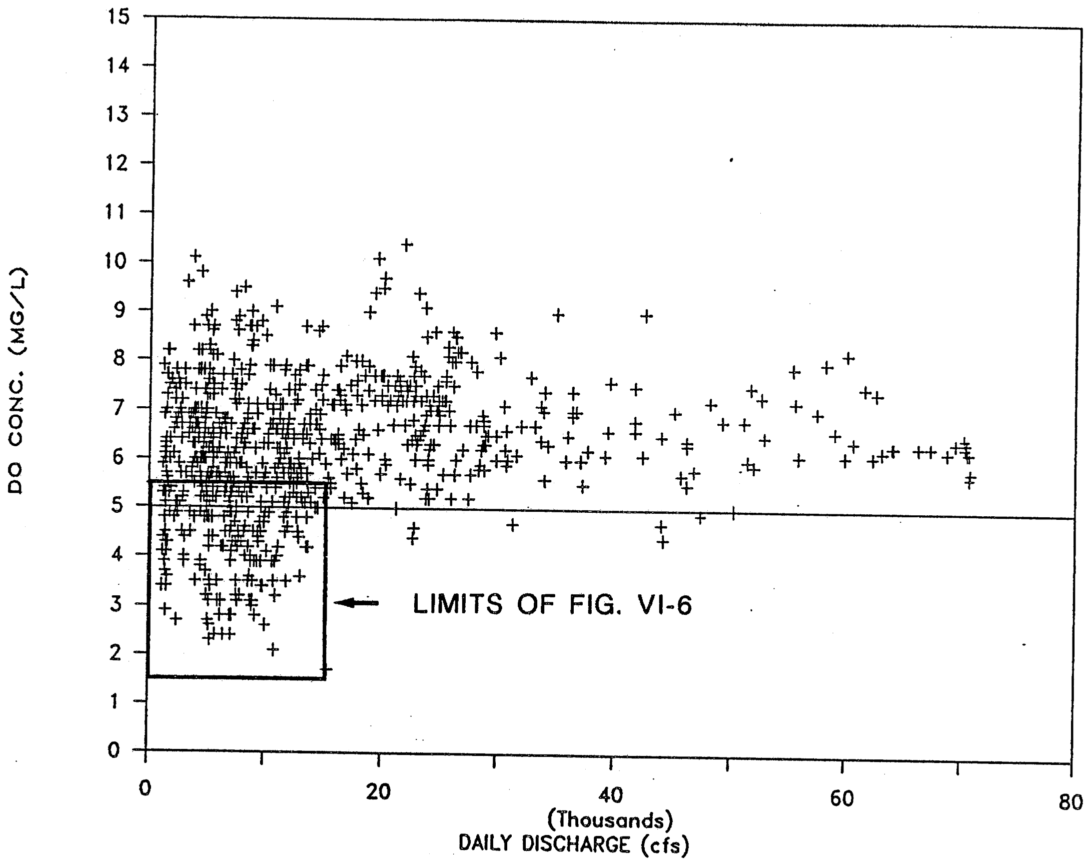


Fig. VI–7. Minimum daily D.O. is river discharge, June–September 1980–1988.

By interpolating between the 4000 cfs contour and the 4400 cfs results at Q_{river} = 10,000 cfs, the hydro discharge is found to be 4200 cfs for Q_{river} = 9,500 cfs. Then

$$Q_{excess} = Q_{river} - Q_{hydro} - Q_{lock}$$
$$= 9{,}500 - 4{,}200 - 200$$
$$= 5{,}100 \text{ cfs}$$

When Q_{river} = 9,500, the pool and tailwater elevations are (Table II–1):

Pool elevation = 686.74

T.W. elevation = 675.62

Head 11.12 ft.

Therefore, the tainter gate discharge per foot opening is

$$Q/ft = 748 \text{ cfs/ft},$$
$$Q = (748 \text{ cfs/ft})(1.5 \text{ ft}) = 1{,}122 \text{ cfs/gate at 1.5 ft opening.}$$

And the discharge per bulkheaded gate at elev. 685.35 is:

$$Q_b = 100\,(686.74 - 685.35)^{1.5} = 164 \text{ cfs} \qquad \text{(VI–2)}$$

The number of gates is determined as:

$$N_g = \frac{Q_{excess}}{Q/gate} = \frac{5{,}100}{1{,}122} = 4.54 \Rightarrow N_g = 4$$

The number of gates must be rounded down to a whole number. Then the remaining excess flow is:

$$Q'_{excess} = Q_{river} - Q_{hydro} - Q_{gates} - Q_{lock}$$
$$= 9{,}500 - 4{,}200 - 4(1{,}122) - 200$$
$$= 612 \text{ cfs}$$

Finally, the number of bulkheaded gates is:

$$N_b = \frac{612 \text{ cfs}}{164 \text{ cfs/bulkhead}} = 3.7 \Rightarrow N_b = 4$$

If the number of bulkheads is not sufficient to balance the flow, the gates can be opened to 1.6 feet (and even 1.7 feet) with little loss in reaeration (Table V–1).

Figure VI–6a was developed for a single water temperature of 26°C. However, it is applicable for the water temperatures of concern. When the standard for dissolved oxygen is below 5.0 mg/ℓ (i.e. when the standard is non–degradation based on previous operations), the net reaeration capacity for the mitigated case is the same as that for the "before hydro" case. Therefore, whatever the temperature, the net reaeration will be the same with mitigations as it was before hydro development. In cases when the standard is the 5.0 mg/ℓ limit (generally when $C_u \geq 4.0$ mg/ℓ), the $\Delta\bar{C}$, as determined for 26°C, is slightly less than that at 22°C and just slightly more than that at 30°C. For these reasons, one operational guide (Fig. VI–6a) at 26°C should prove to be sufficient and useful for mitigating low D.O. at Lock and Dam No. 2.

VII. SUMMARY AND CONCLUSIONS

1. An analysis of the summer D.O. record from the MWCC monitor at Lock and Dam No. 2 indicates that low dissolved oxygen concentrations (less than 5 mg/ℓ) occur infrequently (Table IV–7). Uncertainties exist, however, in the record, as evidenced by large calibration deviations and periods of missing data. Low D.O. is most frequently associated with water temperatures above 22°C and river discharges below 14,000 cfs.

2. Measurements made by the St. Anthony Falls Hydraulic Laboratory (SAFHL) during Summer 1988 (extreme low flow period) indicated no significant problems in dissolved oxygen at Lock and Dam No. 2. Only one upstream and one downstream depth–averaged D.O. value were lower than the 5 mg/ℓ standard (Figs. IV–9 and IV–10). Both of these values were observed on July 15, 1988, but the cross–sectional average was higher than 5 mg/ℓ as for all other surveys. The cooperative MWCC/MPCA low flow survey (Appendix A–3) also did not detect any low dissolved oxygen concentration (min recorded value 6.9 mg/ℓ). Some SAFHL measurements in Pool No. 2, 250 m upstream from the dam, indicated low D.O. values in the lower layer (Fig. IV–7). However, this low D.O. does not reach the powerhouse intakes, probably because of a rip–rap berm (remaining after construction) extending from the dam across the intakes. During another low flow summer in 1976, some measurements were taken in Pool No. 2 by Stefan and Wood [1976]. Again, D.O. levels in the "lower" pool (downstream from river mile 820) were generally above 5 mg/ℓ. On sunny afternoons, supersaturated water was found in some portions of the lower pool. Based on these two low flow survey periods, low dissolved oxygen concentrations do not appear to be associated with very low river flows.

3. A dissolved oxygen transport model has been developed for Lock and Dam No. 2 (Chapter III). It was applied to conditions before and after hydropower development. An impact of the hydropower development was found to exist for flows less than 14,000 cfs and upstream concentrations of less than 5 mg/ℓ. Under these conditions, changes in operation of the structure can be recommended to meet the D.O. standard (Chapter VI).

4. Because the D.O. data from the MWCC continuous monitor at Lock and Dam No. 2 is presently not of sufficient accuracy and not readily available, it is recommended that the City of Hastings measures D.O. and water temperature during the period of concern.

Because the D.O. of water discharged by the hydropower facility is of main concern, sampling (monitoring) should occur in the tailrace of the facility. This is representative of the average upstream D.O. since discharge through the powerhouse is well–mixed and is not aerated.

5. For a given river flow and measured D.O., the D.O. model can be used to determine how much of the total discharge can be used in the hydropower plant and how the remaining flow can be discharged through the existing bulkheads and the tainter gates at the dam so that the D.O. standard is still met. Results of such model applications are shown in Fig. VI–6a and Table VI–5 and can be used to provide guidance for plant operation.

6. For discharges, temperatures, and D.O. conditions other than those reported herein, the model can be used to determine appropriate operation of the dam and hydropower facility.

7. Because the bulkheads are efficient aerators and four have been available in the past, four gates, bulkheaded to an elevation of 685.35 ft (6–30" bulkheads and 1–16" bulkhead) should be kept available for use during the low flow summer season. Excess discharge may be released from the tainter gates which are also good aerators at the 1.5 foot opening.

8. Given the average diurnal fluctuation of D.O. of 2 mg/ℓ [Westermeier and Stefan, 1989] full capacity plant operation during low flow and low D.O. periods may still be possible from noon to midnight.

9. An artificial aerator system in the hydro facility was not investigated, only the use of existing structures was analyzed.

10. Consideration should be given to alternative monitoring of D.O. during plant shutdown, e.g. a small flow release through the turbine past the monitoring device.

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APPENDIX A

SUMMER 1988 DATA

1. St. Anthony Falls Hydraulic Laboratory Surveys Data
2. Conventional MWCC Monitoring Data
3. MWCC/MPCA Low Flow Survey Data – June 1988
4. Correction Factors Used in SAFHL Summer 1988 Survey Data
5. MWCC Continuous Monitoring Data – D.O. and Temperature

Appendix A.1

St. Anthony Falls Hydraulic Laboratory Survey Data

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN

Date: June 29, 1988

Weather: 8:00 a.m: 60 F, overcast, windy
Pressure: 736.2 mm Hg @ SAFHL @ 15:08
Discharge, gates: 375 cfs, #7
power: approx. 1000 cfs

Other notes: Only left unit is operating

Location:A Time: 9:30
Notes: Current dragging probe towards powerhouse

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	24.0	6.66
0.5	24.2	6.45
1.0	24.2	6.34
2.0	24.2	6.24
3.0	24.2	6.40
4.0	24.2	6.24
5.0	24.2	6.19

Location:B Time: 10:00
Notes: Profile taken in eddy to get vertical profile

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	24.0	6.40
1.0	24.0	6.43
2.0	24.0	6.34
3.0	24.0	6.29
4.0	24.0	6.34
5.0	24.0	6.24
6.0	24.0	6.14
7.0	24.0	6.14
8.3	24.0	6.14

Location:C Time: 10:25
Notes: Slow currents towards intakes

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	24.0	6.66
1.0	24.2	6.50
2.0	24.2	6.34
3.0	24.2	6.19
4.0	24.2	6.22
5.0	24.2	6.22
6.0	24.2	6.34
7.0	24.2	6.29
8.0	24.2	6.26
8.7	24.2	6.26

HASTINGS JUNE 26, 1988 D.O. SURVEY

Location:D Time: 10:42
Notes: 3m downstream from MWCC monitoring point

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	24.0	6.19
1.0	24.0	6.22
2.0	24.0	6.16
3.0	24.0	6.14
4.0	24.0	6.08
5.0	24.1	5.98
6.0	24.1	6.03
6.3	24.1	6.03

Location:E (DPH) Time: 10:55
Notes: Probe, ctr rt gate, left unit

Depth [m]	Temp [C]	D.O.
Surface	24.0	6.66

Location: F(DPH) Time: 10:57
Notes: 10:57 Probe, 11:13, 11:30 winklers

Depth [m]	Temp [C]	D.O. [mg/l]	
Surface (all samples)			
Probe:			
Center:	24.0	6.66	
Side:	24.2	6.24	
Winkler:		6.12	6.13
		6.10	6.13

Location: G Time: 11:00
Notes: In still water beside diffuser

Depth [m]	Temp [C]	D.O.
Surface	24.2	6.12

Location: UG7 Time: 11:50
Notes: Current pulling on probe

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	23.8	6.55
1.0	23.8	6.45
2.0	23.9	6.29
3.0	23.8	6.45
4.0	23.8	6.34

Location:H(DG7L) Time: 12:00
Notes: Left side gate #7

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	24.0	6.60

Location:I(DG7R) Time: 12:05
Notes: Right side gate #7

Depth [m]	Temp [C]	D.O. [mg/l]
Surface (all samples)		
Probe:	23.8	6.60
Winkler:	24.2	6.33
		6.28

JUNE 29, 1988 DATA

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN

Date: July 5, 1988

Weather: @ 7:40 wind upstream, T=76 F
Day before: windy, high T=95 F
Discharge, gates: 375 cfs (Gate #7)
power: 1025 cfs

Other notes:

Location: B Time: 7:45
Notes: secchi depth 0.3m

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	24.8	8.60
1.0	24.9	8.61
2.0	24.9	8.65
3.0	24.9	8.81
4.0	24.9	8.76
5.0	24.9	8.76
6.0	24.9	8.49
7.0	24.9	8.12
8.2	24.8	7.81

Location: D Time: 8:15
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	24.9	8.70
1.0	24.9	8.87
2.0	24.9	8.76
3.0	24.9	8.88
4.0	24.9	8.76
5.0	24.9	8.81
6.0	24.9	8.76

Location: C Time: 8:30
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	24.9	8.70
1.0	24.9	8.91
2.0	24.9	9.02
3.0	24.9	8.86
4.0	24.9	8.97
5.0	24.9	8.70
6.0	24.9	8.76
7.0	24.9	8.97
8.0	24.9	8.86
8.8	24.9	8.76

Location: F(DPH) Time: 8:45
Notes: Winklers @ 9:05
Depth [m] Temp [C] D.O.[mg/l]
Surface (all samples)

	Temp [C]	D.O.[mg/l]	
Probe:	24.8	9.02	(right)
	-	8.44	(left, mixing with surrounding waters?)
	24.9	8.97	(center)
Winklers:		8.53	
		8.43 (?)	

Location:UG7 Time: 9:36
Notes: Submerged hydraulic jump

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	24.8	9.07
1.0	24.8	8.97
2.0	24.8	8.97
3.0	24.8	9.50
4.0	24.8	8.97

Location:H(DG7L) Time: 9:45
Notes:

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	24.8	8.86

Location:I(DG7R) Time: 9:52
Notes:
Depth [m] Temp [C] D.O. [mg/l]
Surface Winklers:
8.22
8.14

Location:UG3 Time: 10:10
Notes:

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	25	8.76
1.0	24.9	8.49
2.0	24.9	8.36
3.0	24.8	8.28
4.0	24.8	8.23
5.0	24.7	8.02
5.5	24.7	8.02

Location:DG2 Time: 10:25
Notes:

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	24.8	8.12
1.0	24.8	7.99
2.2	24.8	7.93

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN

Date: 7/15/88

Weather: Wind out of east, sunny
T=83 F @ 7:00, high 102 F
Press.= 733.1 mm Hg @ 5:30 pm @ SAFHL
Note that temp. may not have fallen enough
to destratify pool

Discharge, gates: 375 cfs
power: 1225 cfs

Other notes: All titrations failed, no correction

Location: DG7 Time: 9:08 am
Notes: Winklers, titrations failed

Depth [m]	Temp [C]	D.O.[mg/l]	
Surface	27.5	-	*

Location:DPH Time:
Notes: Winkler titrations failed

Depth [m]	Temp [C]	D.O.[mg/l]	
Surface	27.6	-	*

Location: DG3 Time: ~9:30 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	26.2	5.00
0.5	26.2	4.90
1.0	26.2	4.80
2.0	26.2	4.80
2.5	26.1	4.75

Location: XD4 Time: 9:42 am
Notes: X-S XD is approx 1200 ft DS of structure

Depth [m]	Temp [C]	D.O.[mg/l]
0.5	26.2	4.90
1.0	26.2	4.90
2.0	26.1	4.80
3.0	26.1	4.80
4.2	26.0	4.65

Location:XD3 Time: 9.50 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
0.5	26.2	5.15
1.0	26.1	4.95
2.0	26.1	4.80
3.0	26.0	4.75
4.0	26.0	4.70
4.4	26.0	4.60

Location:XD2 Time: 10:00 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
0.5	26.2	5.30
1.0	26.1	4.90
2.0	26.1	4.95
3.0	26.1	4.90
4.0	26.0	4.70
5.0	26.0	4.80
5.7	26.0	4.80

Location:XD1 Time: 10:10 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
0.5	26.2	5.50
1.0	26.2	5.45
1.7	26.2	5.20

Location:DPH Time: ~10:20 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]	
Surface	26.2	6.00	(5.9-6.1)

Location:DG7 Time: ~10:30 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]	
Surface	26.2	5.40	(5.2)

Location: DG4 Time: ~10:40 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	26.2	4.70
0.5	26.2	4.50
1.0	26.1	4.50
2.0	26.1	4.60
3.0	26.1	4.55
3.5	26.1	4.50

Location: D Time: 11:45 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	27.0	6.70
1.0	26.5	5.50
2.0	26.2	5.10
3.0	26.1	4.70
4.0	26.0	4.30
5.0	26.0	3.90
5.1	26.0	3.80

HASTINGS D.O. DATA - JULY 15, 88

Location: C Time: ~11:50 am
Notes: Profile between two waters mixing

Depth [m]	Temp [C]	D.O. [mg/l]	
Surface	27.0	6.60	(+/- 0.2)
1.0	27.0	7.70	(+/- 0.3)
2.0	26.2	6.20	(+/- 0.4)
3.0	26.2	5.20	(+/- 0.1)
4.0	26.2	5.30	(+/- 0.2)
5.0	26.1	5.00	
6.0	26.1	4.70	
7.0	26.1	4.60	
8.0	26.1	4.60	
8.5	26.0	4.20	

Location: B2 Time: 11:55 am
Notes:

Depth [m]	Temp [C]	D.O. [mg/l]	
Surface	27.0	8.70	(+/- 0.2)
1.0	27.0	7.60	(+/- 0.1)
2.0	26.5	5.50	
3.0	26.1	4.90	
4.0	26.1	4.50	(+/- 0.3)
5.0	26.0	4.30	(+/- 0.3)
6.0	26.0	4.00	
7.0	25.9	3.80	
8.0	25.9	3.80	
8.5	25.9	3.80	

Location: UG3 Time: ~12:10
Notes:

Depth [m]	Temp [C]	D.O. [mg/l]	
Surface	28.0	11.50	(+/- 0.5)
0.5	27.5	10.00	
1.0	27.0	6.70	(+/- 1.2)
2.0	26.0	4.20	
3.0	26.0	4.10	
4.0	26.0	4.10	
5.0	26.0	3.90	
5.5	26.0	3.85	

Location: UG7 Time: 12:25 pm
Notes:

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	28.2	13.40
1.0	28.5	13.50
2.0	26.8	6.10
3.0	26.2	4.80
4.0	26.1	4.45
5.0	26.0	3.80
5.5	26.0	3.60

JULY 15, 1988 SURVEY

HASTINGS D.O. DATA - JULY 15, 88

Location: XU1 Time: ~12:55
Notes: From boat upstream
Ctr of old lock, 1300 ft upstream

Depth [m]	Temp [C]	D.O. [mg/l]	
0.5	28.0	10.80	
1.0	27.3	8.90	(+/- 0.1)
2.0	27.0	6.70	
3.0	26.2	5.60	
3.5	26.1	5.40	

Location: XU2 Time: 1:05 pm

Depth [m]	Temp [C]	D.O. [mg/l]
0.5	28.2	11.40
1.0	27.6	9.20
2.0	27.0	7.65
3.0	26.2	4.60
4.0	26.0	4.65
5.0	26.0	4.60
6.0	26.0	4.40
6.4	26.0	3.90

Location: XU3 Time: 1:15 pm

Depth [m]	Temp [C]	D.O. [mg/l]
0.5	28.2	12.40
1.0	28.0	11.60
2.0	27.0	7.20
3.0	26.2	4.90
4.0	26.0	4.30
5.0	26.0	4.20
6.0	26.0	3.80
7.0	25.9	3.20
8.0	25.5	2.30
9.0	25.1	0.40

Location: XU4 Time: 1:25 pm
Notes:

Depth [m]	Temp [C]	D.O. [mg/l]
0.5	28.8	13.00
1.0	28.8	12.70
2.0	27.0	7.10
3.0	26.3	5.10
4.0	26.1	4.60
5.0	26.0	3.80
6.0	25.9	3.80
7.0	25.9	3.20

Location: UG7 Time: 1:45 pm

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	28.0	10.80
1.0	27.5	8.70
2.0	27.3	8.20
3.0	27.0	6.60
4.0	26.1	4.60
5.0	26.0	3.80
5.5	26.0	3.50

JULY 15, 1988 SURVEY

HASTINGS D.O. DATA - JULY 15, 88

Location: UG3 Time: 1:53 pm

Notes:

Depth [m]	Temp [C]	D.O. [mg/l]
Surface	27.0	7.90
1.0	27.0	7.70
2.0	27.0	7.10
3.0	26.2	4.80
4.0	26.0	4.70
5.0	26.0	4.45
5.5	26.0	4.45

Location: B2 Time: ~2:02 pm

Notes:

Depth [m]	Temp [C]	D.O. [mg/l]	
Surface	27.2	8.20	
1.0	27.5	8.00	(+/- 0.5)
2.0	26.5	6.10	(+/- 0.2)
3.0	26.0	5.50	(+/- 0.6)
4.0	26.0	5.00	(+/- 0.1)
5.0	26.0	4.70	
6.0	26.0	4.70	(+/- 0.1)
7.0	25.9	3.70	(+/- 0.2)
8.0	25.9	3.60	
8.5	25.9	3.60	

Location: D Time: 2:12 pm

Notes:

Depth [m]	Temp [C]	D.O. [mg/l]	
Surface	26.8	7.10	
1.0	26.8	6.50	(+/- 0.1)
2.0	26.2	5.30	
3.0	26.1	4.80	
4.0	26.1	4.60	
5.0	26.0	4.45	
6.0	26.0	4.20	

* thermometer readings, with thermometer with +/- 1 C tolerance giving higher readings than the probe

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN

Date: 07/22/88

Weather: 8:00 am: Air temp= 70 F
9:40 Air T= 23.2 clear
Slight breeze out of south
Pressure at SAFHL 4.25= 721.5 mm Hg

Discharge, gates: 391 cfs
power: 2209 cfs

Other notes: Check probe T vs. thermometer

Location: D Time: 9:45 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	24.8	7.46
1.0	24.8	7.51
2.0	24.6	7.25
3.0	24.5	7.09
4.0	24.5	6.83
5.0	24.4	6.72
6.1	24.4	6.41

Location: C Time: 10:15 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]	
Surface	24.8	7.98	(+/- 0.4)
1.0	24.9	8.82	
2.0	24.9	8.61	(+/- 0.2)
3.0	24.9	8.09	(+/- 0.2)
4.0	24.7	7.35	
5.0	24.3	7.35	(+/- 0.2)
6.0	24.2	7.04	(+/- 0.1)
7.0	24.2	6.83	(+/- 0.1)
8.0	24.0	5.46	(+/- 0.3)
8.5	24.0	5.04	(+/- 0.1)

Location: C2 Time: 10:30 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]	
Surface	24.5	7.88	(+/- 0.2)
1.0	24.5	7.98	(+/- 0.1)
2.0	24.8	8.51	(+/- 0.1)
3.0	24.4	7.56	
4.0	24.6	7.72	
5.0	24.2	6.93	(+/- 0.1)
6.0	24.2	6.09	(+/- 0.3)
7.0	24.0	5.25	(+/- 0.5)
8.0	24.0	4.94	(+/- 0.1)
8.5	24.0	4.73	(+/- 0.1)

HASTINGS D.O. DATA - JULY 22, 88

Location: B2 Time: 10:45 am
Notes: In "cloudy" region

Depth [m]	Temp [C]	D.O.[mg/l]	
Surface	24.2	6.72	
1.0	24.2	7.14	
2.0	24.2	6.93	(+/- 0.1)
3.0	24.3	7.04	(+/- 0.1)
4.0	24.2	7.04	(+/- 0.1)
5.0	24.0	5.57	(+/- 0.4)
6.0	24.1	5.35	(+/- 0.1)
7.0	24.0	4.52	(+/- 0.3)
8.0	23.9	4.31	(+/- 0.2)
8.5	23.9	4.10	

Location: H Time: 11:00 am
Winkler grab sample - thermometer reading(*)

Temp [C]	D.O.[mg/l]	
25.2	6.50	*
	6.42	

Time: 11:05 am

Temp [C]	D.O.[mg/l]
25.2	6.30
	6.37

Location: UG3 Time: 11:30 am
Notes: Light wind from the north

Depth [m]	Temp [C]	D.O.[mg/l]	
Surface	25.8	9.24	(+/- 0.1)
1.0	24.8	6.62	
2.0	24.3	6.51	
3.0	24.2	6.41	
4.0	24.2	6.20	
5.0	24.1	6.25	
5.5	24.1	6.20	

Location: DG3 Time: 11:40 am
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	24.5	5.99
1.0	24.5	5.99
2.0	24.6	5.88
2.2	24.5	5.88

Location: UG7 Time: 12:00 noon
Notes:

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	26.9	11.55
1.0	26.9	11.03
2.0	24.9	7.88
3.0	24.3	5.99
4.0	24.2	6.20
5.0	24.0	6.09
5.5	24.0	4.83

JULY 22, 1988 SURVEY

HASTINGS D.O. DATA - JULY 22, 88

Location: DG7 Time: 12:10 pm

Depth [m]	Temp [C]	D.O.[mg/l]
Probe (left):		
Surface	24.3	6.41
Deeper	24.5	6.30

Grab smpl. (rt): Time: 12:20 pm

Temp [C	D.O.[mg/l]
25.7	6.05
	6.25

Location:Full lock Time: 2:20 pm

Notes: Upstream from lower gate

Depth [m]	Temp [C]	D.O.[mg/l]
Surface	24.8	6.88
1.0	24.8	6.83
2.0	24.8	6.83
3.0	24.8	6.83
4.0	24.8	6.83
6.0	24.8	6.77
8.0	24.8	6.72

Location:Downstream from lock outfall

Notes: Beginning

time	Temp[C]	D.O.[mg/l]
pre-opn	24.8	6.88
2:29	24.8	7.14
2:30	24.8	7.14
2.31	24.8	7.04
Grab:	24.8	6.90
Grab:	24.8	6.80
2:32	24.8	7.09
2:33	24.8	6.93
2:34	24.8	6.93
2:35	24.8	6.83

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN

Date: July 29, 1988

Weather: Cloudy to partly cloudy, T=76 F at 7:10
T=24 C at 9:25
Pressure: 727.6 mm @ time: 16:00

Discharge, total:	1100	cfs	
-gates:	389	cfs	(Gate 7)
-bulkH:			
=powerH:	711	cfs	

Other notes: Plant was shut down app. 14:00, bulkheads at gates 12 and 18 started

Location:D Time: 9:30
Notes: Air calibration, T=24 C, Cs=8.1 ppm

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.4	7.00
1.0	26.5	6.75
2.0	26.3	5.95
3.0	26.3	5.80
4.0	26.3	5.70
5.0	26.2	5.50
6.0	26.3	5.60

Location: C Time: 9:50
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.7	7.40
1.0	26.8	7.00
2.0	26.8	7.40
3.0	26.8	7.00
4.0	26.8	7.10
5.0	26.8	6.70
6.0	26.3	6.20 (+/- 0.2)
7.0	26.3	5.60
8.0	26.2	5.80 (+/- 0.2)
8.5	26.3	6.00

Location:C2 Time: 10:00
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.5	6.70
1.0	26.6	6.70
2.0	26.7	6.60
3.0	26.6	6.40
4.0	26.4	6.20
5.0	26.2	5.30
6.0	26.2	4.80
7.0	26.2	4.70
8.0	26.1	4.75
8.5	26.1	4.30

HASTINGS D. O. DATA - JULY 29, 88

Location: UG3 Time: 10:10
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.6	6.40
1.0	26.6	6.30
2.0	26.5	6.30
3.0	26.5	6.30
4.0	26.5	6.20
5.0	26.5	6.30
5.5	26.5	6.10

Location: UG7 Time: 10:20
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.4	6.55
1.0	26.5	6.60
2.0	26.6	6.50
3.0	26.6	6.50
4.0	26.5	6.40
5.0	26.3	5.80
5.5	26.3	5.70

Location: XU1 Time: 10:45
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.7	6.90
1.0	26.5	6.80
2.0	26.3	6.70
3.0	26.2	6.40
3.5	26.1	6.30

Location: XU2 Time: 10:55
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.5	6.95
1.0	26.4	6.80
2.0	26.4	6.70
3.0	26.3	6.50
4.0	26.2	6.80
5.0	26.1	6.30
6.0	26.0	5.20
6.8	26.0	4.30

Location: XU3 Time: 11:05
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.8	6.95
1.0	26.8	6.80
2.0	26.7	6.65
3.0	26.7	6.15 (+/- 0.15)
4.0	26.5	6.30
5.0	26.2	6.30 (+/- 0.1)
6.0	26.1	4.60 (+/- 0.4)
7.0	26.0	3.40
8.0	25.9	0.80
9.1	25.1	0.15

JULY 29, 1988 SURVEY

HASTINGS D. O. DATA - JULY 29, 88

Location: XU4 Time: 11:15
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.9	7.65
1.0	26.9	7.45
2.0	26.8	7.00
3.0	26.8	6.90
4.0	26.8	6.85
5.0	26.6	6.00
6.0	26.1	3.50
7.0	26.0	1.60
7.3	26.0	1.20

Location: UG7 Time: 11:35
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.8	6.20
1.0	26.8	6.20
2.0	26.3	6.00
3.0	26.2	5.90
4.0	26.2	5.50
5.0	26.2	5.10 (+/- 0.2)
5.5	26.1	4.50

Location: UG3 Time: 11:50
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	26.4	5.60	5.6
1.0	26.2	5.50	
2.0	26.2	5.50	
3.0	26.2	5.90 (+/- 0.1)	
4.0	26.1	5.60	
5.0	26.1	5.30	
5.5	26.1	5.30	

Location: C2 Time: 12:00
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.2	6.20
1.0	26.2	6.10
2.0	26.2	6.30
3.0	26.5	6.50
4.0	26.6	6.50
5.0	26.2	6.35
6.0	26.1	5.50
7.0	26.1	5.30
8.0	26.1	5.30
8.5	26.1	5.30

JULY 29, 1988 SURVEY

HASTINGS D. O. DATA - JULY 29, 88

Location: C Time: 12:20
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.2	6.60
1.0	26.3	6.60 (+/- 0.1)
2.0	26.3	6.60
3.0	26.2	6.60 (+/- 0.1)
4.0	26.1	6.60
5.0	26.1	6.50
6.0	26.1	5.40 (+/- 0.2)
7.0	26.1	5.80
8.0	26.1	5.90
8.5	26.1	5.85

Location: D Time: 12:30
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.2	6.55
1.0	26.2	6.50
2.0	26.2	6.40
3.0	26.2	6.40
4.0	26.2	6.40
5.0	26.2	6.30
6.0	26.2	5.70

Location: DG3 Time: 13:20
Notes: All downstream measurements from boat

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	5.50
1.0	26.9	5.45
2.0	26.9	5.50
3.0	26.8	5.40
3.3	26.8	5.40

Location: DG7 Time: 13:30
Notes: Gates 12 and 18 opening bulkheads app. now

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	26.2	5.80

Location: DG12 Time: 13:32
Notes: Readings are all near surface as boat approached gate

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	26.8	6.80
"	26.5	7.10
"	26.5	7.20

Location: DG18 Time: 13:35
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	26.5	6.70

Location: DPH Time: 13:40
Notes: Taken just before shutdown

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	26.2	6.10

JULY 29, 1988 SURVEY

HASTINGS D. O. DATA - JULY 29, 88

Location: XD1 Time: 13:45
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	26.8	6.15
1.0	26.5	5.80
1.7	26.4	5.80

Location: XD2 Time: 13:50
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	5.80
1.0	26.9	5.70
2.0	26.8	5.60
3.0	26.8	5.60
4.0	26.7	5.60
5.0	26.5	5.65
5.7	26.6	5.65

Location: XD3 Time: 13:55
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.2	8.00
1.0	27.1	7.40
2.0	26.9	5.65
3.0	26.7	5.40
4.0	26.7	5.40
5.0	26.4	5.50
5.4	26.4	5.50

Location: XD4 Time: 14:00
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.4	8.90
1.0	27.2	8.30
2.0	27.0	6.50
3.0	26.7	5.20
4.0	26.7	5.25
5.0	26.6	5.05
5.5	26.6	5.00

Location: DG18 Time: 14:10
Notes: At 'Danger' sign

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	26.5	6.70

Location: DG12 Time: 14:15
Notes: At RR culvert

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	26.4	7.00

Location: DG(11-8)Time: 14:16
Notes: Surface, taken en route from DG12 to DG7

Depth [m]	Temp [C]	D.O. [mg/L]
DG10		6.20
DG9		6.30

JULY 29, 1988 SURVEY

HASTINGS D. O. DATA - JULY 29, 88

Location: DG7 Time: 14:18
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	26.8	6.80
"	26.5	6.30 (+/- 0.1)

Location: DG3 Time: 14:20
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	6.80
1.0	27.0	6.60
2.0	27.0	6.60
3.0	27.0	6.55
3.3	27.0	6.55

Location: DPH Time: 14:30
Notes: Powerhouse is now shutdown

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	6.60
1.0	26.9	6.30
2.0	26.9	6.05
3.0	26.9	6.00
4.0	26.8	5.95
5.0	26.8	6.00
6.0	26.8	6.00
8.1	26.8	5.80

Location: BL Time: 14:40
Notes: At public boat launch, ~center channel

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.1	7.90
1.0	27.1	7.90
2.0	27.0	7.40
3.0	26.9	7.40

JULY 29, 1988 SURVEY

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN

Date: August 4,1988

Weather: cloudy, light rain
Night of Aug 3,88 1-2"rain-thunderstorm
Flow may be changing rapidly
93% relative humidity at 6:15am-21.5[C] air temp.

Pressure: 738.1 @ time: 6:30 am

	4:00	6:00	8:00
Discharge, total:	1100	1100	~2700 CFS
-gates:	394	395	
-bulkH:	663	711	
=powerH:			2100

Other notes:
Right unit of the powerhouse is running in full capacity-Left unit has an oil leak-not running

Location:UG11 Time 8:22am
Notes: Air calibration T=24.2 C, set Cs=8.1ppm

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	27.2	6.45 (+/- 0.15)		
1.0	27.2	6.40		
2.0	27.2	6.50 (+/- 0.10)		
3.0	27.2	6.40		
4.0	27.2	6.10		
5.0	27.2	6.00		
5.8	27.2	5.90		
				Grab samples
0.5	27.2	6.3		6.56
				6.40
			Ave	6.48

Location:UG13 Time: 8:43am

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.1	6.40
1.0	27.2	6.05
2.0	27.2	6.00
3.0	27.2	5.90
4.0	27.2	6.00
5.0	27.2	6.00
5.8	27.2	6.20

Location:UG17 Time: 8:50am

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.1	5.95
1.0	27.2	5.90
2.0	27.2	5.95
3.0	27.2	5.90
4.0	27.2	5.90
5.0	27.2	5.80
5.8	27.2	5.70

HASTINGS D.O. DATA - August 4, 1988

Location:UG19 Time: 8:55am
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.2	5.70
1.0	27.2	5.70
2.0	27.2	5.85
3.0	27.2	5.90
4.0	27.2	5.75
5.0	27.2	5.80
5.8	27.2	5.70

Location:UG8 Time: 9:07am
Notes: Gate 8 is open today- previously gate 7 was open

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	6.20
1.0	27.1	6.00
2.0	27.1	5.85 (+/- 0.05)
3.0	27.2	5.80
4.0	27.2	5.65
5.0	27.2	5.40
5.8	27.2	5.60

Location:UG17 Time: 9:15am
Notes: Grab samples (Winkler)in current to gate 18

Depth [m]	Temp [C]	D.O. [mg/L]
0.5	27.5	5.74
		5.71
	Ave	5.73

Location:UG11 Time: 9:21am
Notes: Grab samples (Winkler)in current to gate 12

Depth [m]	Temp [C]	D.O. [mg/L]
0.5	27.9	5.86
		5.75
	Ave	5.81

Location:DG18 Time: 9:43am
Notes: sampling near the surface with the probe

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.2	6.60 values
		6.70 increasing
		6.75 near the gate

Location:DG18 Time: 9:45am
Notes: Grab samples near the surface(Winkler)

Depth [m]	Temp [C]	D.O. [mg/L]
	27.2	6.62
		6.52
	Ave	6.57
	27.2	6.44
		6.55
	Ave	6.50

AUGUST 4, 1988 SURVEY

HASTINGS D.O. DATA - August 4, 1988

Location:DG12 Time: 9:55am
Notes: Meter (probe) readings near the surface approaching the gate from downstream

Depth [m]	Temp [C]	D.O. [mg/L]	
	27.2	6.50	cross section near culvert outlet
		6.60	
		6.40	
		6.50	
		6.60	cross section near "Danger" sign
		6.70	
		6.80	
Grab samples		6.53	
		6.48	
	Ave	6.51	

Location:DG12 Time: 10:00am
Notes: Grab samples near the surface

Depth [m]	Temp [C]	D.O. [mg/L]
	27.2	6.46
		6.52
	Ave	6.49

Location:DG8 Time: 10:06am
Notes: Gate 8 is open

Depth [m]	Temp [C]	D.O. [mg/L]		Grab samples
0.1	27.2	5.4		5.12
				5.22
			Ave	5.17

Location:UG19 Time: 10:30am
Notes: Towards gate 18

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.1	5.00
1.0	27.1	5.00
2.0	27.1	5.10
3.0	27.1	5.00
4.0	27.1	5.00
5.0	27.1	5.00
5.8	27.1	4.95

Location:UG17 Time: 10:38am
Notes: Towards gate 18

Depth [m]	Temp [C]	D.O. [mg/L]		Grab samples
0.1	27.1	5.30		
1.0	27.1	5.35		
2.0	27.1	5.30		
3.0	27.1	5.25		
4.0	27.1	5.10 (+/-0.10)		
5.0	27.1	5.10 (+/-0.05)		
5.8	27.1	5.20		
0.5	27.1	5.25 (+/-0.05)		5.16
				5.12
			Ave	5.14

AUGUST 4, 1988 SURVEY

HASTINGS D.O. DATA - August 4, 1988

Location:UG13 Time: 10:55am
Notes: In current to gate 12

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.1	6.30
1.0	27.1	5.40
2.0	27.1	5.40
3.0	27.1	5.40 (+/-0.20)
4.0	27.1	5.70 (+/-0.20)
5.0	27.1	5.10
5.8	27.0	3.80

Location:UG13 Time: 11:05am
Notes: Checking high surface value

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.2	6.50 (+/-0.30)
0.2	27.2	5.60
0.5	27.2	5.20

Location:UG11 Time: 11:12am
Notes: In current to gate 12

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	5.20
1.0	27.1	5.20
2.0	27.1	5.20
3.0	27.0	5.10
4.0	27.0	4.60 (4.5-4.9)
5.0	27.0	4.70
5.8	27.0	4.70

Location:UG8 Time: 11:30am
Notes: Sampling in front of gate with weights

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	5.50
1.0	27.0	5.40 (+/-0.10)
2.0	27.1	5.30
3.0	27.1	5.20
4.0	27.1	5.20
5.0	27.0	4.35 (+/-0.50)
5.8	27.0	4.35

Location:C2 Time: 11:42am
Notes: Water surface wavy in front of the intake
Cable angled 30 degrees to the vertical
(depths are not adjusted for the angle)
Wind blowing in the downstream direction
Increased flow does not allow sampling to the bottom since probe might be swept away

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	5.90
1.0	27.0	5.45
2.0	27.0	5.40
3.0	27.0	5.30
4.0	27.0	5.00 (+/-0.10)
5.0	27.0	4.90
6.0	27.0	5.00

AUGUST 4, 1988 SURVEY

HASTINGS D.O. DATA - August 4, 1988

Location:D Time: 11:56am
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	26.9	5.10		
1.0	27.0	5.02		
2.0	27.0	5.02		
3.0	27.0	4.95		
4.0	27.0	5.00		
5.0	27.0	5.00		
6.1	27.0	4.97		
				Grab samples
0.5	27.0	4.90		4.90
				4.81
			Ave	4.86

Location:XD1 Time: 12:18pm
Notes: Strong current-weights necessary for sampling

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	5.40
1.0	27.0	5.35
2.0	27.1	5.30

Location:XD2 Time: 12:25pm
Notes: Strong current-weights necessary for sampling

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	27.0	5.65
1.0	27.1	5.50
2.0	27.1	5.30
3.0	27.1	5.30
4.0	27.1	5.30
5.0	27.1	5.25
5.5	27.1	5.25

Location:XD3 Time: 12:31pm

Depth [m]	Temp [C]	D.O. [mg/l]
0.1	27.1	5.75
1.0	27.1	5.80
2.0	27.1	5.75
3.0	27.1	5.65
4.0	27.1	5.70
5.0	27.1	5.65
5.2	27.1	5.65

Location:XD4 Time: 12:37pm

Depth [m]	Temp [C]	D.O. [mg/l]
0.1	27.1	5.90
1.0	27.1	5.80
2.0	27.1	5.80
3.0	27.1	5.80
4.0	27.1	5.83
5.0	27.1	5.80
5.5	27.1	5.75

Pressure 738.8 @ 2:30pm

AUGUST 4, 1988 SURVEY

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN

Date: August 11, 1988

Weather: cloudy 8:00 am, storm front approached,
heavy rain (8:15-8:30)~0.3"
and clearing up from north(upstream)

Pressure:741.4 mmHg @ time: 6:30 am

Time	4:00 am	6:00 am	9:00 am
Discharge, total:	1600	1600	
-gates:	0	0	
-bulkH:	429	425	0
=powerH:	1145	1133	
Power(kW)	910	900	(910-940)
Air Temp.(F)	74.0	71.0	68.0
" (C)	23.3	21.7	20.0
Wind	15 SE		
Elevations			
Pool	87.00	86.99	
Tailwater	75.28	75.28	
Prescott		75.26	

Other notes:
All measurements are from Winkler titrations
Only grab samples were taken near the surface
or 0.5 m below the water for upstream samples

Bulkheads were in the process of shutting
down at the beginning of the survey and were
closed by the time the upstream samples were
taken

Location:DG18 Time: 7:45 am
Notes: Bulkheads operating (limited aerated flow)

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
surface	27.0	7.78	7.80	7.76

Location:DG12 Time: 7:50 am
Notes: Bulkheads operating (limited aerated flow)

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
surface	26.5	7.84	7.77	7.91

Aug 11, 1988

Hastings D.O. survey -August 11, 1988

Location:DPH Time: 7:55 am
Notes: Sample from the boat-
Dark storm front approaching

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
surface	26.3	8.87	8.86	8.88

Location:UG18 8:15 am
Notes: Gate closed completely
Sample center of the gate-Heavy rain

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
0.5		7.41	7.40	7.42

Location:UG12 Time: 8:20 am
Notes: Gate closed completely
Sample center of the gate-Heavy rain

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
0.5		8.06	8.12	8.00

Location:C2 Time: 8:25 am
Notes: Right unit operating only-heavy rain
Rough water surface ~20cm high waves

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
0.5		8.68	8.70	8.65

Location:D Time: 8:35 am
Notes: Almost stopped raining
We were told there was ~0.3" rainfall

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
0.5		8.17	8.20	8.14

Location:DPH Time: 9:30 am
Notes: sample from the boat
windy, clearing up from upstream(north)

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
surface	26.0	7.63	7.66	7.60

Location:BL Time: 9:35 am
Notes: near boat launch-center of the river

Depth [m]	Temp. [C]	D.O. [mg/L]	sample 1 [mg/L]	sample 2 [mg/L]
surface	27.0	7.20	7.16	7.24

NOTE: All temperature readings are with a thermometer having a (+/- 1C) tolerance, and generally gives higher readings than the probe used for profiles.

Aug 11, 1988

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN

Date: 8/18/88

Weather: Today: Overcast Wind from S-SE ~10-15 mph
T=24 C @ 10:04
T=24 C @ 13:25

Yesterday: Sky clear
Overnight low 66 F
High 97 F

Pressure:Morning 740.1 mm Hg atm. pressure 8:30
Evening 739.9 mm Hg atm. pressure 15:00

Discharge Lockmaster

time	04:00	06:00	12:00
Total	1800 cfs	1700 cfs	1300 cfs
-gates:	0 cfs	0 cfs	0 cfs
-bulkH:	444 cfs	436 cfs	430 cfs
=powerH:	1356 cfs	1264 cfs	870 cfs
Pool elevation	87.04	87.02	87

Other notes:

Location:D Time: 10:11 am
Notes: Secchi depth .49 m

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	28.2	8.47	
0.5	28.2	8.57	(10:20 am)
1.0	28.2	8.57	
2.0	28.3	8.57	
3.0	28.3	8.47	
4.0	28.2	7.82	
5.0	28.2	7.45	
6.1	28.1	7.19	

Location:B2 Time: 10:38 am
Notes: Left unit operating

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	28.2	8.82	(+/- .05)
1.0	28.2	8.82	
2.0	28.2	8.87	
3.0	28.2	8.57	
4.0	28.2	8.16	
5.0	28.0	7.96	
6.0	28.0	7.96	
7.0	28.0	7.65	
8.5	28.0	7.85	

HASTINGS D.O. DATA - August 18, 1988

Location:B Time: 10:50 am
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	28.1	8.44
1.0	28.1	8.47
2.0	28.2	8.67
3.0	28.1	8.26
4.0	28.1	8.16
5.0	28.1	7.85
6.0	28.1	8.01
7.0	28.1	7.96
8.0	28.0	7.75

Location:H Time: 11:00
Notes: Grab Sample
Temp: 27.8 C D.O. [mg/l]
8.02
8.01

Location:UG7 Time: 11:12
Notes: Gate 7 is closed.

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	28.0	8.06
1.0	28.0	8.08
2.0	28.1	7.91
3.0	28.1	7.85
4.0	28.1	7.75
5.0	28.1	7.36
5.5	28.1	7.24

Location:DG7 Time: 11:22
Notes: Left side

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	28.1	6.78
1.0	28.2	6.85
2.0	28.3	6.83
2.5	28.3	6.73

Location:UG11 Time: 11:30
Notes: Near 12

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	28.0	7.50
0.5	28.1	7.45
1.0	28.1	7.45
2.0	28.1	7.50
3.0	28.1	7.47
4.0	28.1	7.19
5.0	28.1	7.16
5.5	28.1	7.16

Location:DG12 Time: 11:45
Notes: Grab Sample

Temp[C]	D.O. [mg/l]
28.0	7.53
	7.58

HASTINGS D.O. DATA - August 18, 1988

Location:UG17 Time: 11:53 am
Notes: Towards G18, G18 Bulkhead operating

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	28.0	8.11	
1.0	28.1	7.96	
2.0	28.1	7.85	(+/- .1)
3.0	28.1	7.19	(+/- .05)
4.0	28.2	7.24	
5.0	28.2	7.45	
5.5	28.2	7.34	

Location:DG18 Time: 12:05
Notes: right side

Depth [m]	Temp [C]	D.O. [mg/L]	
Surface	28.1	7.803-7.956	In the jet
Below surface		6.83	Out of the jet

Location:DG17 Time: 12:08
Notes: left side, small leakage thru gate

Depth [m]	Temp[C]	D.O. [mg/L]
0.1	28.2	6.73
1.0	28.2	6.83
1.3	28.2	6.83

Location:UG18 Time: 12:15
Notes: Probe held u.s. by log

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	28.2	8.42 (+/- .05)

Reading stable, did not change for 5 minutes.

HASTINGS D.O. DATA - August 18, 1988

Location:DPH Time: 12:40
Notes: Left unit in jet, Probe cable not verticle
Weights were used, could not be lowered deeper
Depths are approximate, angle approx. 30 deg.

Depth [m]	Temp [C]	D.O. [mg/L]	Corrected depth [m]
0.1	28.0	7.80	-0.09
1.0	28.0	7.96	-0.87
2.0	28.1	7.85 (+/- .05)	-1.73
3.0	28.1	7.75	-2.60
4.0	28.1	7.75	-3.46
5.0	28.1	7.75	-4.33
6.0	28.1	7.75	-5.20

Location:DPHRB Time: 13:00
Notes: Downstream powerhouse, right bank
Not in main part of jet

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	28.1	7.34
1.0	28.1	7.29
2.0	28.1	7.36
3.0	28.1	7.45
4.0	28.1	7.40
5.0	28.1	7.34
6.0	28.1	7.24
7.0	28.1	7.24
8.5	28.1	7.04

Location: D Time: 13:13
Notes: Check change in time

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	28.0	7.55
0.5	28.1	7.45 (13:17)
1.0	28.0	7.50
2.0	28.0	7.34
3.0	28.0	7.45
4.0	28.0	7.36
5.0	28.1	7.34
6.0	28.1	7.19

AUGUST 18, 1988 SURVEY

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN
DIURNAL SURVEY - NINE DATA SETS

Date: August 24 & 25, 1988

Weather:

Date	Time	Temp	Sky	Wind [mph]	Atmos. Pressure [mmHg] (SAFHL)
Yesterday		78-80 F	Clear	W @25, gusts 40 mp	
8/24/88	05:00	64 F	Clear	NW	
	05:36		Sun coming up		
	06:22		Sun is up		
	08:07	22.2 C			
	08:49			Very high N/NW, Breaking waves	
	11:09	21.4 C			
	11:13			Few scattered clouds	
	11:40	26 C			738.1 mmHg
	14:00	78 F	Pt. Cldy	N/NW 15-30	
	16:00				737.0 mmHg
	16:55	76 F	Pt. Cldy	Not strong	
	19:00	74 F	Almost clear		
	20:00			Almost died out	
	20:15	19.2 C			
	23:03	17.3 C			
8/25/88	Morning	28 C			735 mmHg
	04:43	19.8 C	Mostly cldy, clr from NE		
	06:26		Sunrise		
	07:30	64 F	Clear	N/NW	
	08:14		Clear	More from N/NW	
	08:52			Some white caps	
	09:16	20.8 C			
	14:30	27 C			735.8 mmHg
	20:06		Sunset		

Discharge and Power:

Date	Time	Pool	Tailwater	Power KW	BulkH cfs	Hydro cfs	Gates cfs	Total cfs
8/24/88	04:00	87.24	75.62	4060	517	5153	1529	7200
	06:00	28.18	75.60	4060	495	5171	1526	7200
	12:00	87.25	75.51	4150	521	5214		5700
	16:00	87.21	75.51	4120	506	5194		5700
	20:00	87.10	75.50	4050	466	5149		5600
	24:00	87.05	75.45	3750	447	4768		5200
8/25/88	04:00	87.03	75.48	3720	440	4750		5200
	06:00	87.05	75.45	3740	447	4755		5200

Set 1 Corr. Factor 0.96

Location:D Time: 5:12
Notes: New membrane 5:00

Depth [m]	Temp [C]	D.O. [mg/L]	
0.0	22.9	6.16	
0.5	22.9	6.15	
1.0	22.9	6.15	
2.0	22.9	6.19	
3.0	22.9	6.22	AVERAGE
4.0	22.9	6.23	
5.0	22.9	6.19	
6.0	22.9	6.25	6.19

Location:C Time: 5:36
Notes: Velocities extremely high, sun starting to come up
Depths are approx. (30-45 degrees)

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.8	6.53
1.0	23.0	6.44
2.0	22.9	6.43
3.0	23.0	6.35
4.0	23.0	6.34

Location:B Time: 5:43
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	6.36	
1.0	22.9	6.44	
1.4	23.0	6.36	45 degrees
2.1	23.0	6.38	(+/- .02)

Location:DPH Time: 5:53
Notes: Right unit

Depth [m]	Temp [C]	D.O. [mg/L]
	22.4	6.35
		6.35

Location:UG3 Time: 5:58
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	AVERAGES
0.1	22.4	6.23	6.01
1.0	22.8	6.00	
2.0	22.8	5.90	
3.0	22.8	5.97	
4.0	22.9	6.05	
5.0	22.9	5.86	
5.5	22.9	6.06	

HASTINGS D.O. DIURNAL SURVEY

Location:DG3 Time: 6:05
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	6.33	6.25
1.0	23.0	6.25	
2.0	23.1	6.23	
2.5	23.1	6.19	

Location:UG11 Time: 6:12
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	6.63	6.29
1.0	22.7	6.24	
2.0	22.8	6.22	
3.0	22.8	6.25	
4.0	22.8	6.23	
5.0	22.8	6.22	
5.3	22.9	6.24	

Location:DG11 Time: 6:22
Notes: Gates 8-11e open 1/2, foot- still submerged, but less
aerated more, sun is up.

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.7	7.20	6.87
Bottom?	22.8	6.62	
In between		6.82	
		6.84	

Location:DG12 Time: 6:29
Notes: On wall, water flowing G12-G11
On side of wall, at end of bubbles

Depth [m]	Temp [C]	D.O. [mg/L]	
All @	22.9	7.88	
Surface	22.9	7.68	
	22.9	7.92	(+/- .05)

Location:DG18 Time: 6:41
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.8	8.21 (+/- .05)
		7.97 Somewhat further down

Location:DG17 Time: 6:47
Notes: Some leakage thru gate
Sunlight just reaching top of trees on right bank

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	23.0	6.67
1.0	23.0	6.70
2.0	23.0	6.46
2.5	23.0	6.62

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HASTINGS D.O. DIURNAL SURVEY

Location:UG17 Time: 6:53
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.5	6.13
0.5	22.8	6.05
1.0	22.7	6.07
2.0	22.7	6.10
3.0	22.8	6.06
4.0	22.8	6.05
5.0	22.8	6.12
5.5	22.7	5.97

6.07

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HASTINGS D.O. DIURNAL SURVEY

Set 2 Corr. Factor 1.028

Location:D Time: 8:14
Notes: Set 2

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.9	6.49
0.5	22.8	6.10
1.0	22.8	6.17
2.0	22.8	6.26
3.0	22.8	6.16
4.0	22.7	6.10
5.0	22.7	6.18
6.0	22.7	6.09

6.19

Location:C Time: 8:26
Notes: Power plant shut down

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.5	6.38
1.0	22.7	6.10
2.0	22.8	6.07
3.0	22.8	6.07
4.0	22.8	6.03
5.0	22.9	5.97
6.0	22.9	5.96
7.0	22.9	5.96
8	22.9	5.95
8.5	22.9	5.87

Location:B Time: 8:33
Notes: Power house should be back up @ 9:45
Will take grab sample after it is running

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.8	6.49
1.0	22.9	6.27
2.0	22.9	6.16
3.0	22.9	6.08
4.0	22.9	6.07
5.0	22.9	6.02
6.0	22.9	5.87
7.0	22.9	5.86
8	22.9	5.77
8.5	22.9	5.76

Location:UG3 Time: 8:43
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.6	6.38
1.0	22.7	6.18
2.0	22.8	6.16
3.0	22.8	6.08
4.0	22.8	6.08
5.0	22.8	6.18
5.5	22.8	6.17

6.17

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Location:DG3 Time: 8:49
Notes: Very high winds from N-NW, breaking waves

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	6.16	6.09
1	22.9	6.07	
2.0	22.9	6.05	
2.2	22.9	6.07	

Location:DPH Time: 8:58
Notes: Powerhouse running

Depth [m]	Temp [C]	D.O. [mg/L]
	22.4	6.28
		6.33
	Ave.	6.31

Location:UG11 Time: 9:07
Notes: Gates 8-11 have been closed

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	6.39	
1.0	22.6	6.20	
2.0	22.7	6.16	
3.0	22.7	6.12	
4.0	22.7	6.16	
5.0	22.7	6.16	
5.5	22.7	6.19	6.20

Location:DG11 Time: 9:13
Notes: A lot of leakage

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.6	6.44	
1.0	22.8	6.43	
2.0	22.8	6.45	6.44

Location:DG12 Time: 9:16
Notes: Near end of bubbles

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.7	8.02

Location:UG17 Time: 9:22
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	6.07	
1.0	22.5	6.05	
2.0	22.6	6.02	
3.0	22.6	6.07	
4.0	22.7	6.09	
5.0	22.8	6.05	
5.5	22.8	6.07	6.06

HASTINGS D.O. DIURNAL SURVEY

Location:DG18 Time: 9:28
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.8	8.02	7.6-7.9

Location:UG7 Time: 9:39
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	6.61	
1.0	22.5	6.48	
2.0	22.6	6.30	
3.0	22.6	6.27	
4.0	22.6	6.27	
5.0	22.7	6.31	
5.5	22.7	6.36	6.37

Location:DG7 Time: 9:45
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.8	6.13	
0.5	22.8	5.95	
1.0	22.8	6.05	
2.0	22.8	6.07	
2.4	22.8	5.98	6.04

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HASTINGS D.O. DIURNAL SURVEY

Set 3 Corr. Factor 0.994

Location:D Time: 11:13
Notes: Set #3 Few scattered clouds.

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	22.1	7.21		
0.5	22.3	6.81	(+/- .05)	
1.0	22.2	7.05		
2.0	22.3	6.96		
3.0	22.3	6.95		
4.0	22.2	6.95		
5.0	22.3	6.86		
5.7	22.3	6.80		
				6.95

Location:C Time:
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.5	7.36	
1.0	22.4	7.16	
2.0	22.4	7.06	
3.0	22.4	7.03	
2.8	22.4	7.07	45 degrees

Location:B Time: 11:36
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	7.46	
0.7	22.3	7.08	45 degrees
1.4	22.3	7.05	"
2.1	22.2	6.95	"
2.8	22.2	6.95	"

Location:DPH Time: 11:50
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
	22.3	6.92
		6.88
	Average	6.90

Location:UG3 Time: 11:54
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	7.06	
1.0	22.4	6.86	
2.0	22.4	6.76	
3.0	22.3	6.76	
4.0	22.5	6.76	
5.0	22.5	6.81	
5.5	22.4	6.97	6.85

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HASTINGS D.O. DIURNAL SURVEY

Location:DG3 Time: 12:01
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.6	6.46	
1.0	22.8	6.35	
2.0	22.8	6.21	
2.3	22.8	6.27	6.32

Location:UG11 Time: 12:08
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.3	6.57	
1.0	22.3	6.45	
2.0	22.4	6.36	
3.0	22.4	6.35	
4.0	22.4	6.35	
5.0	22.5	6.36	
5.5	22.5	6.45	6.41

Location:DG11 Time: 12:15
Notes: Leakage @ gate 11

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.6	6.61	
1.0	22.7	6.56	
2.0	22.6	6.57	
3.0	22.7	6.56 Current sweeping probe downstream	
			6.58

Location:DG12 Time: 12:18
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	22.5	7.85 up to 8.3 in jet w/ bubbles
Surface	22.5	7.85 in flow over wall w/o bubbles
		8.3 may be due to bubbles at prob

Location:UG17 Time: 12:26
Notes: Barges in front of gates 15-19

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.5	6.16	
1.0	22.5	6.15	
2.0	22.5	6.14	
3.0	22.5	6.15	
4.0	22.5	6.06	
5.0	22.5	6.07	
5.5	22.5	6.08	6.12

Location:DG18 Time: 12:32
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.5	7.70 7.5-8.0 (+/- .25)
1.0	22.5	6.76 Sidewater still

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Location:DG7 Time: 12:40
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.5	6.41	
1.0	22.7	6.35	
2.0	22.8	6.35	
2.3	22.8	6.41	5.62

Location:UG7 Time: 12:44
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	7.21	
0.5	22.5	7.05	
1.0	22.5	7.05	
2.0	22.5	6.95	
3.0	22.5	6.98	
4.0	22.5	6.97	
5.0	22.5	7.04	
5.5	22.5	6.98	7.03

HASTINGS D.O. DIURNAL SURVEY

Set 4 Corr. Factor 1.073

Location:D Time: 14:00
Notes: Secchi ~0.5 too hard to read because of winds and waves. Probe at about 30 degree angle

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.8	8.42	
0.5	22.8	8.34	
1.0	22.8	8.32	
2.0	22.8	8.37	
3.0	22.8	8.26	
4.0	22.8	8.21	
5.0	22.7	8.18	
5.5	22.7	8.15	8.28

Location:C Time: 14:25
Notes: Depths adjusted for angle

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	23.0	8.53	45 degrees	(+/- .05
0.7	22.9	8.10	45 degrees	
1.4	22.9	8.05	45 degrees	
2.1	22.9	8.10	45 degrees	

Rest was impossible, very strond winds.

Location:B Time: 14:30
Notes: Depths adjusted for angle

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.58	45 degrees
0.7	22.9	8.32	45 degrees
1.4	22.9	8.42	45 degrees
2.1	22.9	8.37	45 degrees

Location:DPH Time: 14:45
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.5	23.1	7.95
		8.12
	Average	8.04

Location:UG3 Time: 14:54
Notes: Strong wind, Probe swept against the gate from the win

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	8.48	
1.0	23.0	8.32	
2.0	23.0	8.37	
3.0	23.0	8.34	
4.0	23.0	8.32	
5.0	23.0	8.37	
5.5	23.0	8.32	8.36

HASTINGS D.O. DIURNAL SURVEY

Location:DG3 Time: 15:05
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.8	7.30	
1.0	22.9	7.24	
2.0	22.9	7.24	
2.3	22.9	7.19	7.24

Location:UG11 Time: 15:15
Notes: Strong wind

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.8	7.73	
1.0	22.9	7.62	
2.0	22.9	7.48	
3.0	22.9	7.46	
4.0	22.9	7.43	
5.0	22.9	7.40	
5.5	22.9	7.62	7.53

Location:DG11 Time: 15:22
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	7.46	
1.0	22.9	7.40	
2.0	22.9	7.48	
-	22.9	7.51	Drifted downstream
-	22.9	7.51	Prob. near outflow of G12
			7.47

Location:DG12 Time: 15:28
Notes: In middle of outflow

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.48	
		8.42	7.7-8.0 Over the wall

Location:UG17 Time: 15:35
Notes: Barge next to pier

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	7.51	
1.0	22.9	7.51	
2.0	22.9	7.40	
3.0	22.9	7.48	
4.0	22.9	7.40	
5.0	22.9	7.40	
5.5	22.9	7.30	7.43

Location:DG18 Time: 15:40
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.9	7.30
Instream of 18		8.37

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HASTINGS D.O. DIURNAL SURVEY

Location:DG7 Time: 15:50
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	7.30	
1.0	22.9	7.19	
2.0	22.9	7.08	
2.3	22.9	7.08	
-	22.9	7.03	7.14

Location:UG7 Time: 15:55
Notes: Strong wind

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.58	
0.5	23.0	8.32	(+/- 0.05)
1.0	23.0	8.53	
2.0	23.0	8.37	
3.0	23.0	8.26	
4.0	23.0	8.32	
5.0	23.0	8.26	
5.5		8.37	8.38

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Set 5 Corr. Factor 1.056

Location:D Time: 17:00
Notes: Set #5 Secchi depth 0.5m
Air check: 22 C/ 8 mg/l

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.1	8.87	
0.5	23.1	8.71	
1.0	23.1	8.82	
2.0	23.1	8.76	
3.0	23.1	8.76	
4.0	23.1	8.76	
5.0	23.1	8.76	8.78

Location:C Time: 17:15
Notes: Strong wind to D/S - Depths adjusted for angle

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.1	8.45	
0.9	23.0	7.92	30-45 degree angle
1.4	23.0	7.76	
2.1	23.0	7.76	

Location:B Time: 17:25
Notes: 45-60 degree angles - Depths adjusted for angle

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.50	(+/- .1)
0.7	23.0	8.29	
1.4	23.0	8.45	(+/- .1)
1.5	23.0	8.45	60 degree angle

Location:DPH Time: 17:30

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	23.3	7.96
		8.22
	Average	8.09

Location:UG3 Time: 17:42

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.1	8.45	
1.0	23.1	8.31	
2.0	23.1	8.24	
3.0	23.1	8.13	
4.0	23.1	8.13	
5.0	23.1	8.31	
5.5	23.1	8.45	8.29

Location:DG3 Time: 17:47
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.7	7.39	
1.0	22.9	7.39	
2.0	22.9	7.39	
2.3	22.9	7.29	7.37

HASTINGS D.O. DIURNAL SURVEY

Location:UG11 Time: 17:53
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.76	
1.0	23.0	8.45	
2.0	23.0	8.34	
3.0	23.0	8.26	
4.0	23.0	8.29	
5.0	23.0	8.24	
5.5	23.0	8.52	8.41

Location:DG11 Time: 17:53
Notes: Drift to x ds

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	7.92	
1	23.0	7.81	
2.0	23.0	7.92	
3.0	23.0	7.92 Swept ds by underflow	
			7.89

Location:DG18 Time: 17:55
Notes: Left edge of wall to G18 side

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	23.0	8.34 (+/- .1)

Location:UG17 Time: 18:05
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.55	
1.0	23.0	8.50	
2.0	23.0	8.45	
3.0	23.1	8.36	
4.0	23.1	8.34	
5.0	23.1	8.34	
5.5	23.1	8.24	8.40

Location:DG17 Time: 18:10
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.9	3.70 Right side
0.1	23.0	8.61 Left side (in flow) (+/- .05)

Location:DG7 Time: 18:20
Notes: right side

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	7.29	
1.0	22.9	7.50	
2.0	23.0	7.50	
2.3	23.0	7.44	7.43

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Location:UG7 Time: 18:26
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.1	8.42	
0.05	23.1	8.34	
1.0	23.1	8.31	
2.0	23.1	8.29	
3.0	23.1	8.24	
4.0	23.1	8.24	
5.0	23.1	8.26	
5.5	23.1	8.24	8.29

HASTINGS D.O. DIURNAL SURVEY

Set 6 Corr. Factor 1.057

Location:D Time: 20:15
Notes: Set #6 Wind has died out, twilight

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	8.46	
0.5	23.2	8.46	
1.0	23.0	8.56	
2.0	23.0	8.56	
3.0	23.0	8.51	
4.0	23.0	8.51	
5.0	23.0	8.35	
5.5	23.0	8.35	8.47

Location:C Time: 20:25
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.42	
0.7	23.0	8.14	(+/- .2) 45 degrees
1.4	23.0	8.14	"
2.1	23.0	7.98	"

Location:B Time: 20:30
Notes: angle is about 60 degrees.

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	23.0	8.35
0.5	23.0	8.14
1.0	23.0	8.03
1.5	23.0	8.14

Location:DPH Time: 20:40
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.9	7.58
		7.56
	Average	7.57

Location:UG3 Time: 20:48
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	7.74	
1.0	23.0	7.72	
2.0	23.1	7.72	
3.0	23.1	7.72	
4.0	23.0	7.72	
5.0	23.0	7.77	7.73

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HASTINGS D.O. DIURNAL SURVEY

Location:DG3 Time: 20:55
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	22.9	7.26		
1	22.9	7.50		
2.0	22.9	7.45		
2.3	23.0	7.40		7.40

Location:UG11 Time: 21:02
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	23.0	8.35		
1.0	23.0	7.77		
2.0	23.0	7.68		
3.0	23.0	7.72		
4.0	23.0	7.74		
5.0	23.1	7.82		7.85

Location:DG11 Time: 21:09
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	23.0	7.56		
1	23.0	7.56		
2.0	23.0	7.66		
	23.0	7.66	Swept ds by underflow	
				7.61

Location:DG12 Time: 21:09
Notes: In middle of outflow

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.35	(+/- .1)

Location:UG17 Time: 21:15
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	23.0	7.77		
1.0	23.1	7.72		
2.0	23.1	7.68		
3.0	23.1	7.72		7.72

Location:DG17 Time: 21:20
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	23.0	7.42
1.0	23.0	7.42
2.0	23.0	7.35
2.5	23.0	7.29

Location:DG18 Time: 21:23
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	7.72	In stream to the right

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HASTINGS D.O. DIURNAL SURVEY

Location:DG7 Time: 21:30
Notes: right side

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	7.00	
1.0	22.9	7.08	
2.0	23.0	7.08	
2.3	23.0	7.08	
			7.06

Location:UG7 Time: 21:35
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	7.56	
0.5	23.0	7.50	
1.0	23.0	7.61	
2.0	23.1	7.63	
3.0	23.1	7.56	
4.0	23.1	7.50	
5.0	23.1	7.50	7.55

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Set 7 Corr. Factor 1.087

Location:D Time: 23:05
Notes: Set #7

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	22.8	7.72		
0.5	23.0	7.45		
1.0	22.8	7.61		
2.0	22.9	7.58		
3.0	22.9	7.50		
4.0	22.9	7.45		
5.0	22.9	7.50		
5.2	22.9	7.39	20 degree angle	7.52

Location:C Time: 23:16
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	7.45	
0.9	22.9	7.23	30 degrees
1.4	22.9	7.17	45 degrees
2.1	22.9	7.07	

Location:B Time: 23:22
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	7.47	
0.9	23.0	7.45	30 degrees
1.7	23.0	7.39	
2.1	23.0	7.34	45 degrees

Location:DPH Time: 23:30
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.5	7.11
		7.13
	Average	7.12

Location:UG3 Time: 23:40
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	7.14	
1.0	23.0	6.98	
2.0	23.0	7.03	
3.0	23.0	7.07	
4.0	23.0	7.07	
5.0	23.0	7.07	
			7.06

HASTINGS D.O. DIURNAL SURVEY

Location:DG3 Time: 23:46
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	7.03	
1.0	22.9	7.03	
2.0	22.9	7.07	
2.3	22.9	7.07	7.05

Location:UG11 Time: 23:51
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	7.12	
1.0	23.0	7.01	
2.0	23.0	7.03	
3.0	23.0	7.03	
4.0	23.0	7.07	
5.0	23.0	7.03	7.05

Location:DG11 Time: 23:58
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]		
0.1	22.9	7.20		
1	22.9	7.17		
2.0	23.0	7.28		
	23.0	7.28	Swept ds by underflow	
				7.23

Location:DG12 Time:
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1		8.10	(+/- .05) Near edge of the wall, in outflow of G12

Location:UG17 Time: 00:04
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.9	6.96	
1.0	23.0	6.92	
2.0	23.0	6.92	
3.0	23.0	6.96	
4.0	23.0	6.96	
5.0	23.0	6.90	6.94

Location:DG17 Time: 11:10
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.9	7.17
1.0	23.0	7.20
2.0	23.0	7.17
2.5	23.0	7.12

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Location:DG18 Time: 00:13
Notes: Foot to center from edge of pier

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	8.15	

Location:DG7 Time: 00:19
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.8	6.74	
1.0	22.9	6.74	
2.0	22.9	6.85	
2.3	22.9	6.87	6.80

Location:UG7 Time: 00:25
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	23.0	7.01	
0.5	23.0	6.98	
1.0	23.0	7.07	
2.0	23.0	6.92	
3.0	23.0	6.87	
4.0	23.0	6.96	
5.0	23.0	6.90	6.96

Location:D Time: 00:41
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	22.9	7.03
1.0	22.9	7.03
2.0	22.9	7.03
3.0	22.9	7.09
4.0	22.9	7.09
5.0	22.9	7.07
5.5	22.9	7.03

HASTINGS D.O. DIURNAL SURVEY

Set 8 Corr. Factor 1.023

Location:D Time: 4:45
Notes: Set #8 :mostly cloudy, clearing from NE

Depth [m]	Temp [C]	D.O. [mg/l]	
0.1	22.8	7.09	
0.5	22.8	7.00	
1.0	22.9	7.14	
2.0	22.8	7.14	
3.0	22.9	7.14	
4.0	22.8	7.07	
5.0	22.8	6.98	
5.7	22.8	6.97	7.07

Location:C Time: 5:00
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.5	7.17	
0.9	22.6	7.17	30 degrees
1.7	22.7	7.17	30 degrees
2.6	22.7	7.17	30 degrees
2.8	22.8	7.16	45 degrees

Location:B Time: 5:07
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.7	7.25	
0.9	22.7	7.17	30 degrees
1.4	22.6	7.17	45 degrees
2.1	22.6	7.17	45 degrees
3.0	22.6	7.17	60 degrees

Location:DPH Time: 5:16
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
	22.7	6.87
		6.91
	Average	6.89

Location:UG3 Time: 5:23
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.5	6.75	
1.0	22.5	6.74	
2.0	22.5	6.74	
3.0	22.6	6.67	
4.0	22.6	6.74	
5.0	22.5	6.73	
5.5	22.6	6.74	6.73

HASTINGS D.O. DIURNAL SURVEY

Location:DG3 Time: 5:29
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.5	6.46	
1.0	22.7	6.47	
2.0	22.8	6.52	
2.3	22.8	6.49	6.48

Location:UG11 Time: 5:36
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	6.80	
1.0	22.5	6.73	
2.0	22.6	6.68	
3.0	22.6	6.66	
4.0	22.6	6.66	
5.0	22.6	6.65	
5.5	22.6	6.69	6.70

Location:DG11 Time: 5:42
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.5	6.65	
1.0	22.7	6.61	
2.0	22.7	6.70	
-	22.8	6.66 Swept d.s. by underflow	
			6.65

Location:DG12 Time: 5:46
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	22.5	8.03 (+/- .05)

Location:UG17 Time: 5:51
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.3	6.54	
1.0	22.5	6.54	
2.0	22.6	6.54	
3.0	22.6	6.47	
4.0	22.7	6.55	
5.0	22.6	6.53	
5.5	22.6	6.54	6.53

Location:DG18 Time: 5:58
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
Surface	22.6	7.67 (+/- 0.1)

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HASTINGS D.O. DIURNAL SURVEY

Location:DG7 Time: 6:06
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	6.16	
1.0	22.4	6.16	
2.0	22.6	6.24	
2.4	22.6	6.22	6.19

Location:UG7 Time: 6:11
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	6.64	
0.5	22.5	6.54	
1.0	22.5	6.55	
2.0	22.6	6.53	
3.0	22.6	6.48	
4.0	22.6	6.46	
5.0	22.6	6.53	
5.5	22.7	6.54	
			6.53

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Set 9 Corr. Factor .989

Location:D Time: 8:14
Notes: Set #9 Sky has cleared, more wind from N-NW
Secchi .49m

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	6.74	
0.5	22.3	6.62	
1.0	22.3	6.72	
2.0	22.3	6.72	
3.0	22.3	6.64	
4.0	22.3	6.61	
5.0	22.3	6.58	
6.0	22.3	6.54	6.64

Location:C Time: 8:30
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	7.04	
0.5	22.3	6.93	30 degrees
1.0	22.3	6.92	30 degrees
1.5	22.3	6.82	30 degrees
2.8	22.3	6.82	45 degrees

Location:B Time: 8:36
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	7.17	(+/- 0.05)
0.5	22.3	6.91	30 degrees
1.0	22.3	6.83	30 degrees
2.1	22.3	6.79	45 degrees
2.8	22.4	6.77	45 degrees

Location:DPH Time: 8:45
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
	22.1	6.67
		6.67

Location:UG3 Time: 8:52
Notes: Wind picked up, some white caps

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	6.91	
1.0	22.3	6.67	
2.0	22.3	6.63	
3.0	22.3	6.54	
4.0	22.3	6.54	
5.0	22.3	6.60	
5.5	22.4	6.73	6.66

HASTINGS D.O. DIURNAL SURVEY

Location:DG3 Time: 8:58
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	6.53	
1.0	22.4	6.28	
2.0	22.5	6.28	
2.2	22.5	6.31	6.35

Location:UG11 Time: 9:05
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	6.82	
1.0	22.3	6.61	
2.0	22.4	6.52	
3.0	22.4	6.52	
4.0	22.4	6.54	
5.0	22.5	6.54	
5.5	22.5	6.63	6.60

Location:DG11 Time: 9:12
Notes: Leakage in gate 11

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.4	6.72	
1.0	22.5	6.63	
2.0	22.5	6.72	
3.0	22.5	6.72	In under current 6.69

Location:DG12 Time: 9:16
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.5	8.06 (+/- 0.05)	
In air		8.31	In air T(air)=20.8

Location:UG17 Time: 9:21
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	6.42	
1.0	22.3	6.39	
2.0	22.3	6.43	
3.0	22.3	6.34	
4.0	22.4	6.31	
5.0	22.4	6.35	
5.5	22.4	6.33	6.37

Location:DG18 Time: 9:27
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	7.91	(+/- .1)

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Location:DG7 Time: 9:33
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	6.38	
1.0	22.3	6.34	
2.0	22.4	6.33	
2.3	22.5	6.33	6.34

Location:UG7 Time: 9:41
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	22.2	6.91	
0.5	22.3	6.71	
1.0	22.3	6.72	
2.0	22.3	6.64	
3.0	22.3	6.62	
4.0	22.3	6.62	
5.0	22.3	6.54	
5.5	22.4	6.62	6.67

Location:DG12 Time: 9:57
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
	22.1	7.85
		7.82
	Average	7.84

St. Anthony Falls Hydraulic Laboratory
Dissolved Oxygen Study for City of Hastings, MN
Oxygen transfer study at gate 8

Date: September 9, 1988

Weather: Clear, calm during sampling

Pressure: 738.7 @ time: 6:45
738.7 13:00

		04:00	06:00	11:00
Discharge:	total:	2300	2300	
	-gates:			
	-bulkH:	510	510	
	=powerH:	1770	1763	
Elevation:				
	Pool:	87.22	87.22	87.2
	TW:	75.22	75.22	75.22

Location:D Time: 8:15 am
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	18.7	7.12
0.5	18.8	7.02
1.0	18.9	6.94
2.0	18.9	6.94
3.0	18.9	6.92
4.0	18.9	6.90
5.0	18.9	6.89
6.0	18.9	6.89
6.1	18.9	6.82

Location:UG8 Time: 8:28 am
Notes: Gate 8 closed.

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	18.1	6.82
1.0	18.8	6.82
2.0	18.8	6.82
3.0	18.8	6.77
4.0	18.9	6.73
5.0	18.9	6.68
5.5	18.9	6.68

HASTINGS D.O. DATA - September 9, 1988

Location:UG7L Time: 8:34 am
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	18.9	6.79
1.0	18.9	6.94
2.0	18.9	6.94
3.0	18.9	6.73
4.0	18.9	6.73
5.0	18.9	6.68
5.5	18.9	6.68

Location:UG9R Time: 8:41
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	18.9	6.82
1.0	18.9	6.82
2.0	18.9	6.79
3.0	18.9	6.79
4.0	18.9	6.73
5.0	18.9	6.73
5.5B	18.9	6.74

Measurements taken from the boat with the probe mounted a "fish" and without the stirrer. This arrangement results i higher velocities past the probe and a different correction factor
P: Probe readings, W: Grab samples for Winkler titrations

Location:DG8 Time: 9:10
Notes: Gate opening: 0.5 ft
1) Check variation with depth
2) Set probe at 1.5 m for rest of readings.

Depth [m]	Temp [C]	D.O. [mg/L]	Notes
0.5	18.9	7.29 P	C.L. of flow
		7.19 P	Toward gate 9
4.0	18.9	7.29 P	C.L. of flow
		7.26 P	Transverse variation
		7.24 P	Minimum rdg.
1.5	18.9	7.29 P	
Surface		7.18 W	C.L., near surface
		7.27 W	C.L., near surface
		7.225	Average

HASTINGS D.O. DATA - September 9, 1988

Location:DG8 Time: 9:30
Notes: Gate Opening: 1.0 ft

Depth [m]	Temp [C]	D.O. [mg/L]	
1.5	18.9	7.38 P	D.S. Gate 8
1.5	18.9	7.43 P	Closer, ~110 ft. C.L.
1.5		7.39 P	D.S. right wall
1.5		7.36 P	D.S. left wall
1.5		7.40 P	C.L.
Surface		7.42 W	C.L.
Surface		7.45 W	C.L.
		7.435	Average

Location:DG8 Time: 9:40
Notes: Gate Opening: 1.5 ft

Depth [m]	Temp [C]	D.O. [mg/L]	
1.5	18.9	7.73 P	C.L., moving upstream
		7.85 P	C.L., D.S. of culvert
		7.71 P	Rt. 1/4 pt.
		7.66 P	Further rt.
		7.61 P	Furhter rt.
		7.77 P	Lt. 1/4 pt.
		7.68 P	Further lt.
		7.80 P	C.L.
Surface		7.80 W	C.L.
Surface		7.83 W	C.L.
		7.815	Average

Location:DG8 Time: 9:50
Notes: Gate Opening: 2.0 ft.

Depth [m]	Temp [C]	D.O. [mg/L]	
1.5	18.9	7.75 P	C.L., approaching gate
		7.85 P	C.L., closer to gate
		7.80 P	D.S. left wall
		7.71 P	D.S. right wall
		7.80 P	C.L.
		7.85 P	C.L., closer to gate
Surface		7.76 W	C.L.
		7.78 W	C.L.
		7.77	Average

Location:DG8 Time: 9:55
Notes: Gate Opening: 0.5 ft

Depth [m]	Temp [C]	D.O. [mg/L]	
1.5	18.9	7.47 P	C.L., D.S. 2/3 way to culvert
Surface		7.47 W	C.L.,"
		7.50 W	C.L.,"
		7.485	

SEPTEMBER 9, 1988 SURVEY - GATE AERATION

HASTINGS D.O. DATA - September 9, 1988

Location:DG3,1,2 Time: 10:00
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
1.5	18.9	7.61 P	DG3
		7.29 P	DG1
		7.38 P	DG2

Location:UG7L Time: 10:10
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	18.9	7.42
0.5	18.9	7.32
1.0	18.9	7.27
2.0	18.9	7.12
3.0	18.9	7.12
4.0	18.9	7.12
5.0	18.9	7.07
Bottom	18.9	7.12

Location:UG9R Time: 10:20
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]
0.1	19.0	7.81
1.0	19.0	7.71
2.0	19.0	7.24
3.0	18.9	7.32
4.0	18.9	7.12
5.0	18.9	6.99
5.5B	18.9	6.97

Location:UG8 Time: 10:30
Notes:

Depth [m]	Temp [C]	D.O. [mg/L]	
0.1	19.1	8.26	
0.5	19.0	7.62	
1.0	18.9	7.42	
2.0	18.9	7.12	
3.0	18.9	7.04	Gate closed here.
4.0	18.9	7.09	
5.0	18.9	7.02	
B5.5	18.9	7.07	

SEPTEMBER 9, 1988 SURVEY - GATE AERATION

Appendix A.2

Conventional MWCC Monitoring Data

MWCC CONVENTIONAL MONITORING DATA FOR SUMMER 1988

Location: UM 815.6 – all samples 1 m below surface

Date	Hour	D.O. (mg/l)	Temperature (°C)
June 02	1032	3.7	26.4
June 07	1051	7.2	26.9
June 21	736	7.4	25.5
June 28	706	10.6	23.5
July 06	1045	8.7	26.3
July 12	1052	6.9	25.1
July 22	1033	10.5	25.0
July 26	1038	9.1	25.3
Aug 02	1137	8.5	28.1
Aug 09	1050	6.0	25.4
Aug 18	1059	7.0	27.4
Aug 24	1115	7.3	22.6

APPENDIX A.3

MWCC/MPCA Low Flow Survey Data – June 1988

COOPERATIVE MWCC/MPCA LOW FLOW SURVEY DATA

Note: all samples taken at 1 m depth.

Date	Shift	Flow (cfs)	D.O. (mg/l)	Temperature (°C)
June 17	1	1946	6.87	23.2
presurvey	2		8	23.2
June 18	1	1852	8.67	25.2
	2		10.2	25
June 19	1	1763	7.03	24.4
presurvey	2		12.8	26.5
June 20	1	1563	8.64	27
	2		cancelled	
June 21	1	1763	7.42	25.5
	2		7.8	26.5
June 22	1	2120	8	25.7
	2		9.8	27
June 23	1	2020	7.7	25.8
	2		7	25.5
June 24	1	1520	5.89	24.5
	2		7	25.5
June 25	1	1470	7.41	25.4
	2		9.4	26.5
June 26	1	1570	6.55	24.5
	2		7	25.5
June 27	1	2246	7.71	24.3
	2		20	28
June 28	1	1396	10.58	23.5
	2		12.3	26
June 29	1	1298	7.11	22.7
	2		9.2	24
June 30	1	1139	7.54	21.8
	2		10.2	23
July 1	1	1103	8.8	22.6
	2		No shift 2 on July 1	

Shift 1 Time 0600–1430, Shift 2 Time 1300 – 1930

APPENDIX A.4

Correction Factors Used in SAFHL Summer 1988 Survey Data

CORRECTION FACTORS (CF) USED IN

SAFHL SUMMER 1988 SURVEY DATA

Date	CF range	CF uanation	CF used
June 29	1.039–1.044	0.005	1.04
July 5	1.053–1.058	0.005	1.055
July 22	1.035–1.064	0.029	1.05
July 29	0.987–1.015	0.028	1.00
August 4	0.979–1.029	0.050	1.00
August 18	1.008–1.032	0.024	1.02
August 24			
set #1	0.938–0.982	0.044	0.960
set #2	1.023–1.032	0.009	1.028
set #3	0.983–1.005	0.022	0.994
set #4	1.064–1.081	0.017	1.073
set #5	1.032–1.080	0.048	1.056
set #6	1.026–1.087	0.061	1.057
set #7	1.067–1.106	0.039	1.087
August 25			
set #8	0.996–1.049	0.053	1.023
set #9	0.988–0.990	0.002	0.989
September 9			
upstream	0.986–0.989	0.003	0.989
downstream	0.926–0.939	0.013	0.934

APPENDIX A.5

MWCC Continuous Monitoring Data – D.O. and Temperature

AUTOMATIC MONITOR MONTHLY RIVER QUALITY SUMMARY

JUNE ,1988

PRELIMINARY DATA
SUBJECT TO REVIS'^ '

MISSISSIPPI RIVER AT LOCK AND DAM #2 (UM 815.3)

DAILY VALUES DISSOLVED OXYGEN(MG/L) DAY	MEAN	MIN	MAX	CLEANING/ CALIBRATION TIME	CALIBRATION INITIAL/CALIBRATED	DEVIATION	PERCENT ERROR
1	6.4	5.2	7.8				
2	5.8	3.7	7.1				
3	6.2	5.0	7.6	1045			
4	6.6	5.7	8.2				
5	6.8	5.8	7.4				
6	6.2	4.9	7.4				
7	6.1	4.0	7.7	1045	4.8/ 4.8	0.0	0.0
8	5.6	4.4	6.9				
9	5.0	4.5	6.2	1600			
10	5.3	3.9	7.0				
11	5.8	5.1	6.5				
12	5.6	4.9	6.3				
13	5.6	5.0	6.7	1600			
14	5.7	5.1	6.1				
15	6.6	4.8	7.8	810	4.8/ 6.2	-1.4	22.6
16	7.5	6.8	8.4				
17	7.9	6.8	9.0	810	7.2/ 8.2	-1.0	12.2
18	8.1	7.2	8.7	800	8.2/ 7.3	0.9	12.3
19	8.4	7.6	9.1				
20	7.9	7.5	8.5	800	7.8/ 7.6	0.2	2.6
21	8.5	6.9	10.3	800	7.5/ 6.8	0.7	10.3
22	9.6	7.8	10.6	800	9.8/ 7.6	2.2	28.9
23	6.7	5.3	9.3	800	7.4/ 6.8	0.6	8.8
24	6.4	5.3	8.4	500	5.8/ 5.8	0.0	0.0
25	7.1	6.1	7.8	700	6.5/ 7.2	-0.7	9.7
26	7.4	5.5	10.7	740	5.8/ 6.8	-1.0	14.7
27	7.4	6.0	13.9	1010	7.4/ 8.0	-0.6	7.5
28	9.8	8.2	13.7	745	10.4/ 10.4	0.0	0.0
29	6.9	5.6	8.6	800	6.5/ 7.2	-0.7	9.7
30	7.5	6.1	9.3	745	6.4/ 7.4	-1.0	13.5

METROPOLITAN WASTE CONTROL COMMISSION
AUTOMATIC MONITOR MONTHLY RIVER QUALITY SUMMARY

JULY ,1988

PRELIMINARY DATA
SUBJECT TO REVISIONS

MISSISSIPPI RIVER AT LOCK AND DAM #2 (UM 815.3)

DAILY VALUES DISSOLVED OXYGEN(MG/L) DAY	MEAN	MIN	MAX	CLEANING/ CALIBRATION TIME	CALIBRATION INITIAL/CALIBRATED	DEVIATION	PERCENT ERROR
1	8.6	7.5	10.5	800	8.7/ 8.4	0.3	3.6
2	9.7	7.6	10.9				
3	10.6	7.7	13.4				
4	10.1	8.2	13.1	800			
5	9.2	7.3	11.0	815	9.5/ 9.4	0.1	1.1
6	8.8	7.7	10.2				
7	7.6	6.4	9.1				
8	8.8	6.0	13.8	1600			
9	7.0	5.1	10.1				
10	6.9	5.7	8.2				
11	7.5	5.3	9.9	1600			
12	7.0	5.3	9.6	815	5.5/ 6.0	-0.5	8.3
13	10.2	7.0	14.4				
14	8.2	6.1	12.0	1600			
15	7.8	5.4	11.1				
16	7.8	5.7	10.2				
17	5.4	3.6	8.2				
18	4.7	3.7	5.9	1600			
19	5.4	3.9	6.6	830	3.6/ 6.8	-3.2	47.1
20	5.1	4.3	5.6				
21	6.1	4.1	10.3				
22	7.4	4.8	12.0				
23	8.0	6.3	11.2				
24	8.7	6.9	11.0				
25	8.1	5.9	11.2	1600			
26	8.1	5.3	12.7	820	5.2/ 8.0	-2.8	35.0
27	10.2	7.9	12.9				
28	7.1	4.4	11.2				
29	-	-	-				
30	- Dirty Probe	-	-				
31	-	-	-				

PRELIMINARY DATA
SUBJECT TO REVISIONS

METROPOLITAN WASTE CONTROL COMMISSION
AUTOMATIC MONITOR MONTHLY RIVER QUALITY SUMMARY

AUGUST ,1988

MISSISSIPPI RIVER AT LOCK AND DAM #2 (UM 815.3)

DAILY VALUES DISSOLVED OXYGEN(MG/L) DAY	MEAN	MIN	MAX	CLEANING/ CALIBRATION TIME	CALIBRATION INITIAL/CALIBRATED	DEVIATION	PERCENT ERROR
1	4.7	3.4	8.0	1600			
2	5.8	4.1	7.6	800	4.4/ 6.2	-1.8	29.0
3	-	-	-				
4	5.9	4.9	7.3				
5	5.2	4.3	6.8	1600			
6	4.5	2.9	7.1				
7	4.5	3.4	6.6				
8	-	-	-	1600			
9	9.2	4.3	14.4	800	5.0/ 6.6	-1.6	24.2
10	8.1	6.3	10.4				
11	7.7	6.2	9.9				
12	6.8	4.5	10.2	920	4.6/ 7.4	-2.8	37.8
13	7.5	6.4	9.5				
14	7.8	5.4	12.5				
15	6.2	4.5	9.0	1600			
16	8.9	5.3	13.2	825	5.8/ 8.0	-2.2	27.5
17	-	-	-				
18	-	-	-				
19	4.1	2.7	5.3	855	2.8/ 4.2	-1.4	33.3
20	5.8	4.8	9.8				
21	6.2	5.5	6.7				
22	5.4	4.8	6.2				
23	6.0	4.4	7.7	900	4.7/ 5.1	-0.4	7.8
24	7.3	6.2	8.5				
25	8.2	6.9	9.5				
26	8.9	7.4	12.0	855	8.2/ 7.7	0.5	6.5
27	8.9	8.2	9.7				
28	7.8	6.9	8.8				
29	10.1	6.7	15.1	850	7.0/ 8.8	-1.8	20.5
30	11.1	9.8	13.1				
31	10.1	9.3	11.6				

METROPOLITAN WASTE CONTROL COMMISSION
AUTOMATIC MONITOR MONTHLY RIVER QUALITY SUMMARY

SEPTEMBER, 1988

MISSISSIPPI RIVER AT LOCK AND DAM #2 (UM 815.3)

DAILY VALUES DISSOLVED OXYGEN(MG/L) DAY	MEAN	MIN	MAX	CLEANING/ CALIBRATION TIME	CALIBRATION INITIAL/CALIBRATED	DEVIATION	PERCENT ERROR
1	7.7	6.9	9.3				
2	7.7	5.9	11.0	1600			
3	7.4	6.9	8.4				
4	7.1	6.5	8.0				
5	6.4	5.7	7.2				
6	-	-	-	815	5.5/ 6.8	-1.3	19.1
7	8.2	7.6	10.0				
8	7.4	6.7	8.1				
9	7.4	5.7	9.5	1600			
10	8.0	7.5	8.5				
11	7.6	7.1	8.0				
12	7.2	6.7	7.6	1600			
13	7.7	6.4	9.1	815	6.4/ 7.4	-1.0	13.5
14	7.9	6.6	10.2				
15	6.3	5.9	7.0				
16	-	-	-	1600			
17	8.3	7.5	9.5				
18	7.6	6.9	9.2				
19	5.8	5.1	7.0				
20	7.0	5.2	8.2	810	5.6/ 7.6	-2.0	26.3
21	7.6	7.2	8.1				
22	7.9	7.5	8.3				
23	-	-	-				
24	7.6	7.0	8.6				
25	9.1	7.8	12.0				
26	9.0	7.8	10.8	1600			
27	9.9	8.9	11.2	800	9.2/ 9.0	0.2	2.2
28	8.7	7.8	9.9				
29	8.1	7.0	9.1				
30	8.2	6.9	9.6				

METROPOLITAN WASTE CONTROL COMMISSION
AUTOMATIC MONITOR MONTHLY RIVER QUALITY SUMMARY

JUNE , 1988

PRELIMINARY DATA SUBJECT TO REVISION

MISSISSIPPI RIVER AT LOCK AND DAM #2 (UM 815.3)

DAILY VALUES TEMPERATURE(C) DAY	MEAN	MIN	MAX	CLEANING/ CALIBRATION TIME	CALIBRATION INITIAL/CALIBRATED	DEVIATION	PERCENT ERROR
1	24.0	23.7	24.5				
2	24.0	23.9	24.3				
3	23.8	23.5	24.0	1045			
4	23.9	23.4	24.9				
5	24.4	24.0	25.0				
6	24.6	24.0	25.2				
7	25.9	24.4	27.9	1045	25.0/ 26.0	-1.0	3.8
8	26.5	26.0	27.0				
9	25.5	25.2	26.0	1600			
10	25.3	25.0	26.1				
11	25.5	25.2	25.7				
12	25.4	25.2	25.6				
13	25.5	25.3	26.0	1600			
14	25.7	25.6	25.9				
15	24.6	23.7	25.8	810	25.0/ 24.0	1.0	4.2
16	24.0	23.6	24.6				
17	23.7	23.5	24.0	810	24.0/ 24.0	0.0	0.0
18	23.8	23.5	24.1	800	24.0/ 24.0	0.0	0.0
19	24.2	23.9	24.7				
20	25.5	24.5	26.1	800	25.0/ 26.0	-1.0	3.8
21	26.0	25.8	26.1	800	26.0/ 26.0	0.0	0.0
22	26.2	26.0	26.8	800	26.0/ 26.0	0.0	0.0
23	25.9	25.7	26.2	800	26.0/ 26.0	0.0	0.0
24	25.7	25.4	26.1	500	25.5/ 25.5	0.0	0.0
25	26.0	25.8	26.2	700	26.0/ 26.0	0.0	0.0
26	25.4	25.0	26.0	740	26.0/ 25.0	1.0	4.0
27	25.1	24.9	25.9	1010	25.0/ 25.0	0.0	0.0
28	25.3	25.1	25.8	745	26.0/ 26.0	0.0	0.0
29	24.7	24.3	25.2	800	25.0/ 25.0	0.0	0.0
30	23.7	23.2	25.1	745	24.5/ 24.0	0.5	2.1

METROPOLITAN WASTE CONTROL COMMISSION
AUTOMATIC MONITOR MONTHLY RIVER QUALITY SUMMARY

PRELIMINARY DATA
SUBJECT TO REVISIONS

JULY ,1988

MISSISSIPPI RIVER AT LOCK AND DAM #2 (UM 815.3)

DAY	DAILY VALUES TEMPERATURE (C) MEAN	MIN	MAX	CLEANING/ CALIBRATION TIME	CALIBRATION INITIAL/CALIBRATED	DEVIATION	PERCENT ERROR
1	22.5	22.0	23.3	800	23.5/ 22.0	1.5	6.8
2	22.2	22.1	22.3				
3	22.5	22.2	23.1				
4	22.9	22.6	23.2	800			
5	23.2	23.0	23.6	815	24.0/ 25.0	-1.0	4.0
6	23.5	23.3	23.9				
7	23.8	23.6	24.2				
8	24.2	23.9	25.1	1600			
9	24.1	23.9	24.3				
10	24.0	23.9	24.2				
11	23.8	23.5	24.1	1600			
12	24.3	23.4	24.8	815	24.0/ 25.0	-1.0	4.0
13	25.0	24.6	25.6				
14	25.0	24.8	25.4	1600			
15	25.3	24.8	26.1				
16	25.7	25.3	26.1				
17	25.6	25.3	25.8				
18	25.4	25.2	25.6	1600			
19	25.5	25.1	25.9	830	25.0/ 26.0	-1.0	3.8
20	25.3	25.1	25.6				
21	25.2	24.9	26.3				
22	25.3	25.0	26.2				
23	25.6	25.4	26.1				
24	25.9	25.7	26.1				
25	25.8	25.5	26.1	1600			
26	25.7	25.3	26.0	820	25.5/ 25.5	0.0	0.0
27	26.0	25.6	26.4				
28	26.1	25.8	26.3				
29	-	-	-				
30	26.5	26.0	27.4				
31	26.3	26.0	26.7				

PRELIMINARY DATA
SUBJECT TO REVISIONS

METROPOLITAN WASTE CONTROL COMMISSION
AUTOMATIC MONITOR MONTHLY RIVER QUALITY SUMMARY

AUGUST ,1988

MISSISSIPPI RIVER AT LOCK AND DAM #2 (UM 815.3)

DAY	MEAN	MIN	MAX	CLEANING/ CALIBRATION TIME	CALIBRATION INITIAL/CALIBRATED	DEVIATION	PERCENT ERROR
	DAILY VALUES TEMPERATURE(C)						
1	26.3	26.2	26.7	1600			
2	26.8	26.5	26.9	800	26.5/ 27.5	-1.0	3.6
3	-	-	-				
4	26.7	26.6	26.8				
5	26.5	26.2	26.7	1600			
6	26.4	26.2	26.8				
7	26.5	26.2	26.7				
8	26.5	26.2	26.7 *	1600			
9	26.1	25.6	26.6	800	26.5/ 26.0	0.5	1.9
10	25.8	25.6	26.0				
11	25.9	25.7	26.5				
12	26.0	25.8	26.4	920	26.0/ 26.0	0.0	0.0
13	26.1	26.0	26.3				
14	26.2	25.8	26.7				
15	26.2	26.0	26.6	1600			
16	27.0	25.4	27.7	825	26.5/ 26.5	0.0	0.0
17	27.7	27.2	28.8				
18	27.1	25.9	27.8				
19	26.3	25.8	26.7	855	26.5/ 26.0	0.5	1.9
20	25.9	25.7	26.3				
21	25.7	25.6	25.9				
22	25.4	25.2	25.7				
23	23.8	22.7	25.2	900	25.0/ 23.0	2.0	8.7
24	22.7	22.4	22.9				
25	22.5	22.2	22.7				
26	22.1	21.8	22.4	855	22.5/ 22.0	0.5	2.3
27	21.8	21.6	22.1				
28	21.3	21.1	21.6				
29	20.5	19.7	21.3	850	21.0/ 20.0	1.0	5.0
30	20.1	19.9	20.5				
31	20.3	20.1	20.7				

METROPOLITAN WASTE CONTROL COMMISSION
AUTOMATIC MONITOR MONTHLY RIVER QUALITY SUMMARY

SEPTEMBER, 1988

MISSISSIPPI RIVER AT LOCK AND DAM #2 (UM 815.3)

DAILY VALUES TEMPERATURE (C) DAY	MEAN	MIN	MAX	CLEANING/ CALIBRATION TIME	CALIBRATION INITIAL/CALIBRATED	DEVIATION	PERCENT ERROR
1	20.3	20.2	20.6				
2	20.4	20.2	20.8	1600			
3	20.0	19.8	20.5				
4	19.7	19.6	19.9				
5	19.5	19.3	19.7				
6	19.4	19.0	20.3	815	19.0/ 19.0	0.0	0.0
7	19.5	19.4	19.7				
8	19.3	19.2	19.5				
9	19.3	19.1	19.5	1600			
10	19.3	19.1	20.1				
11	19.4	19.1	19.7				
12	19.5	19.2	19.7	1600			
13	18.7	18.2	19.3	815	19.0/ 18.0	1.0	5.6
14	18.6	18.3	19.2				
15	18.2	18.0	18.4				
16	18.0	17.9	19.7	1600			
17	18.4	18.1	18.9				
18	18.9	18.5	19.2				
19	19.2	18.8	19.3				
20	17.9	17.7	18.8	810	18.0/ 18.0	0.0	0.0
21	17.4	17.3	17.6				
22	17.6	17.5	17.7				
23	-	-	-				
24	17.5	17.4	17.6				
25	17.7	17.5	18.2				
26	17.8	17.6	18.2	1600			
27	18.1	17.8	18.4	800	18.0/ 18.0	0.0	0.0
28	17.7	17.0	18.1				
29	17.0	16.9	17.1				
30	17.4	17.0	17.9				

APPENDIX B

ANALYSIS OF REAERATION CAPACITIES

1. Reaeration of Flow Through Powerhouse.
2. Reaeration at Old Boulé Spillway.
3. Reaeration of Flow Through Lock.
4. Reaeration of Bulkheads
5. Reaeration of Flow Under Gates.

APPENDIX B.1

Reaeration of Flow Through Powerhouse

Reaeration of Flow Through Powerhouse

At first glance one would expect little or no significant reaeration of water as it passes through the powerhouse. One reason is that the water is not exposed to air as it passes through the turbines. Secondly, as the water exits the diffusers, only a small amount of air is entrained by upwelling and vortex action. Given the large depth (8.5 m) and discharge, the reaeration should be minimal. As an example of this, data from several surveys, taken upstream and, shortly afterwards, downstream of the powerhouse will be used.

For each set of measurements listed here, oxygen profiles were taken upstream of the powerhouse and grab samples were taken near the surface in the discharge of the plant.

	D.O. (mg/ℓ)	
Survey	U.S.	D.S.
6/29	6.3	6.1
7/29	6.1	6.1
8/18	8.2	8.0
8/24–1	6.4	6.35
8/24–3	7.1	6.9
8/24–7	7.3	7.1
8/24–8	7.2	6.9
8/24–9	6.9	6.7

For the first three surveys listed, the upstream concentration is the average of two full vertical profiles taken in the approach to the powerhouse. All downstream samples are the average of two grab samples taken approximately 0.5 m below the water surface. For the August 24 survey, the upstream concentrations are the average of two profiles consisting of four to five probe readings taken in the upper 2 to 3 meters of the flow. Higher velocities on that day prevented the measurement of full profiles.

Profiles were taken in the tailrace of the powerplant on two occasions. Those profiles are given in Figure B–1. The profile of 7/29/88 was taken just minutes after the hydroplant shut down on that date. Under other conditions, high velocities make it impossible to take a full profile. On August 18, 1988, weights were attached to the probe to obtain a profile in the discharge; however, only the upper 5 m could be sampled from the structure. Another profile was taken approximately 50 ft downstream from the cofferdam. All three of these profiles indicate well–mixed conditions, justifying the use of surface samples.

In the eight cases shown, none exhibits reaeration. In fact, a drop of 0.2 mg/ℓ appears typical. Because only surface values were used for August 24, and withdrawal may not be uniform from all depths, this "drop" is not

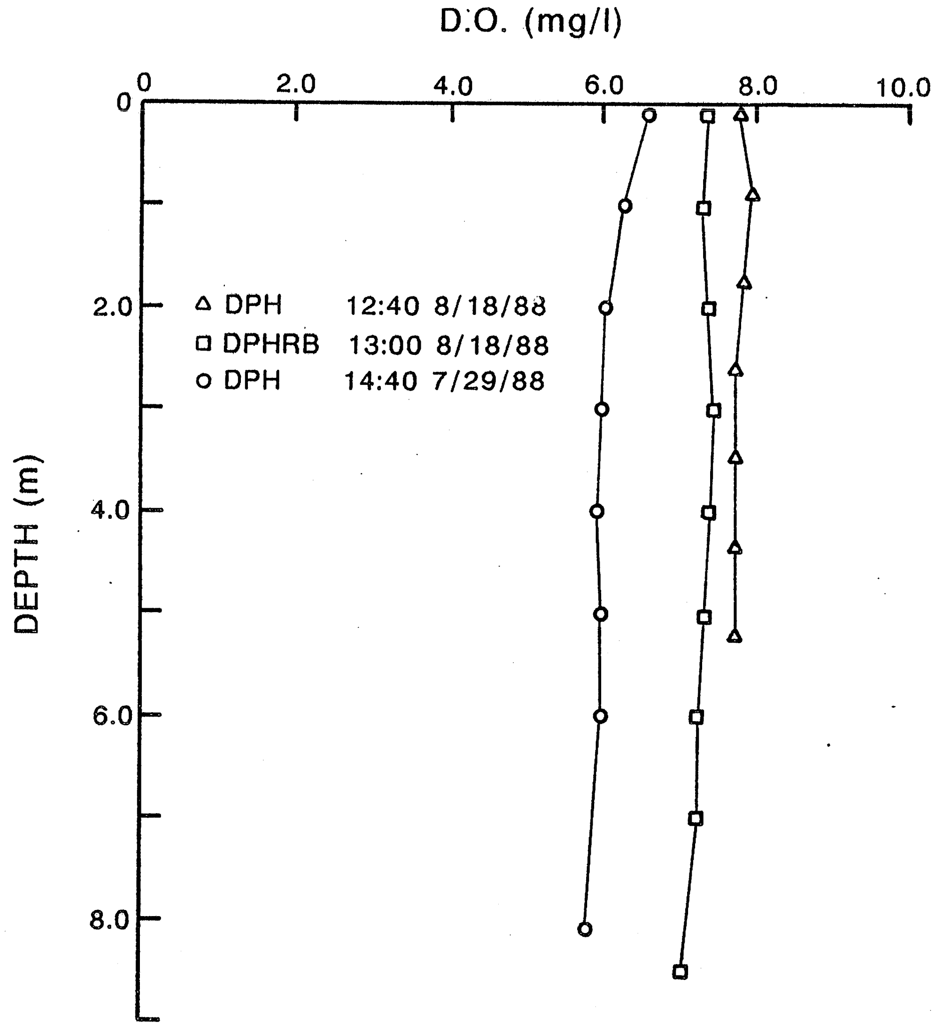

Fig. B–1. D.O. profiles in powerhouse discharge indicating well–mixed conditions.

seen to be real. Additionally a 0.2 mg/ℓ discrepancy between grab samples and probe readings is not significant. Furthermore, the upstream and downstream sampling was not done simultaneously.

For the above reasons, the powerhouse is believed to have no significant effect on the dissolved oxygen concentration of water passed through it, and the deficit ratio is given as $1/r = 1.0$.

APPENDIX B.2

Reaeration at Old Boulé Spillway

Reaeration at Old Boulé Spillway

The only reaeration data available for the Boulé spillway are those of Rindels [1986]. He took advantage of high winter oxygen deficits to measure oxygen transfer. The results are summarized below:

Q_s (cfs)	T_w (°C)	1/r (–)
157	0.5	0.66
157	0.5	0.55
208	0.5	0.40

The first result is preferred [Rindels, 1986] because the downstream sample was taken closer to the spillway. The other two results were computed from samples taken further downstream where mixing with other waters may have occurred. The first value, when adjusted to 20° C, becomes

$$\left.\frac{1}{r}\right|_{20^\circ} = 0.57$$

Tsivoglou and Neal [1976] give a relationship for deficit ratio dependent on fall height:

$$\left.\frac{1}{r}\right|_{20^\circ} = \exp(KH)$$

where H is the change in elevation (ft) and K is an empirical constant, –0.054 ft^{-1}. Wilhelms and Smith [1981] used that relation with K = 0.045 ft^{-1} for gated–conduit outlet works. For the design fall height of 12.2 ft, the equations give 1/r = 0.52 and 0.58 for K = – .054 and – .045 ft^{-1}, respectively. These results seem to verify the measurement of Rindels, therefore 1/r = 0.57 will be used.

It is important to note here, as well as for other structures to be analyzed subsequently, that the second digit in 1/r is not seen as significant. Furthermore it will not be very significant in predicting oxygen concentrations as well. However, because the 1/r values are adjusted for temperature (and in some cases discharge), the second digit is carried. If it were not carried, it would not be logical to adjust them.

APPENDIX B.3

Reaeration of Flow Through Lock

Reaeration of Flow Through Lock

When the lock is drained, the discharge is very turbulent; additionally some air is entrained by an air–core vortex in the lock. Because of these conditions, reaeration at the lock was measured during the July 7 survey. When the lock was full, one D.O. profile was taken in the full lock near the downstream end. As the lock discharged, the D.O. probe was placed in the plume and surface readings were taken while the lock discharged. The top to bottom variation in the lock was just 0.15 mg/ℓ with an average of 6.80 mg/ℓ. The increase in D.O. is plotted versus the time from the beginning of the drainage of the lock in Figure B–2. The average increase in probe readings over the seven minute draining of the lock was 0.2 mg/ℓ. With that increase in D.O., a water temperature of 24.8 and an initial D.O. of 6.8 mg/ℓ, the deficit ratio is given as

$$\frac{1}{r} = \frac{8.05 - 7.0}{8.05 - 6.8} = 0.84, \ \left(\frac{1}{r}\right)_{20^\circ} = 0.85$$

Because only one D.O. profile was taken in the lock before drainage, there is some uncertainty in the result. Dissolved oxygen in the lock had only a 0.15 mg/ℓ top to bottom variation, indicating that the lock was quite well mixed. It is evident that gas transfer does occur; however, a more conservative value of $1/r = 0.9$ will be used.

No reaeration was evident during the filling of the lock as no air was entrained. No measurements were made to verify this.

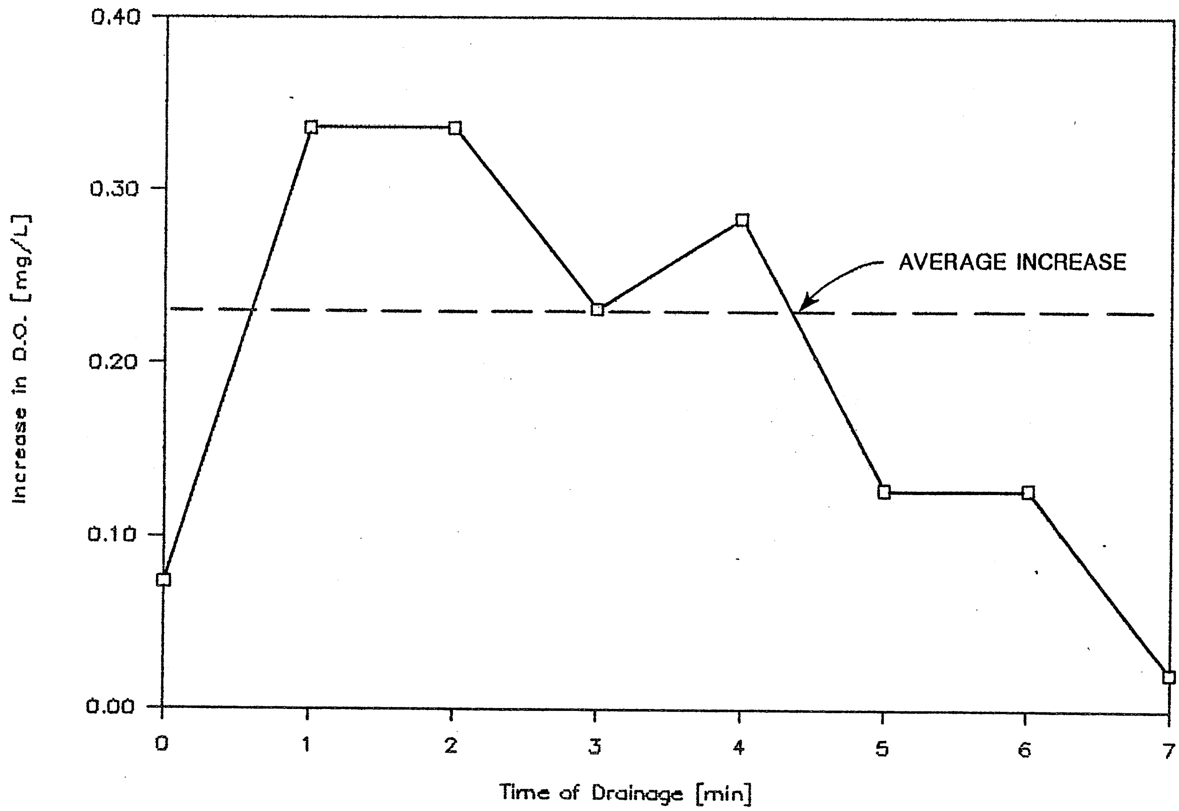

Fig. B–2. Increase in D.O. due to drainage from lock.

APPENDIX B.4

Reaeration of Bulkheads

Reaeration of Bulkheads

Several values for the deficit ratio of the bulkheads are available. The first value to be reported here is that obtained from the August 4, 1988, survey. That survey was designed to measure the reaeration at the bulkheaded tainter gate bays 12 and 18.

The measurements were made by taking vertical profiles upstream of the gates 11, 13, 17, and 19 close to gates 12 and 18 where lower velocities allowed use of the probe. Also one pair of grab samples was taken upstream of gates 17 and 11. Then the downstream sampling was done from a boat. The boat was pointed upstream and propelled into the existing jet as close to the structure as possible and where most of the bubbles had left the water. The dissolved oxygen probe was held in the water as the boat moved across the jet. The meter was read to find the location of the maximum D.O. concentration. At that point a pair of grab samples was taken. After that, profiles and grab samples were again taken upstream in order to account for temporal changes in the upstream D.O.

Because of the large variations in D.O. with depth near the surface at gate 12, there was a large uncertainty in the upstream concentration. Because of this and because the data at gate 18 was better, the data for gate 12 are not used.

Upstream of gate 18, the water column was well mixed from top to bottom. The average of all the upstream readings at 9:00 was 5.8 mg/ℓ. When sampled again at 10:35 the average of the upstream readings was 5.1 mg/ℓ. Sampling downstream of gate 18 occurred at 9:45. By using linear interpolation, the upstream concentration corresponding to the downstream measurement should be 5.5 mg/ℓ.

Downstream measurements using the D.O. probe gave a range of values from 6.6 to 6.75 mg/ℓ in the center of the plume. Four grab samples gave an average of 6.53 mg/ℓ, with a range of 6.44 to 6.62 mg/ℓ. The average result of the Winkler titrations and the maximum probe reading will be used to compute deficit ratios. The temperature was 27.2°C, and after correction for atmospheric pressure $C_s = 7.7$ mg/ℓ.

$$\frac{1}{r} = \frac{7.7-6.53}{7.7-5.5} = 0.53, \quad \frac{1}{r} = \frac{7.7-6.75}{7.7-5.5} = 0.43$$

As the best estimate for the deficit ratio, the average of these two results will be used or

$$\left.\frac{1}{r}\right|_{\text{bulkheads}} = 0.48$$

Again the second digit is carried for adjustments.

Rindels [1986] made three winter measurements of reaeration at the bulkheads. The samples taken at the best downstream sampling locations lead to 1/r values of 0.60 and 0.64 at 0.5°C and 465 cfs over each bulkhead. In order to compare this result with that of this study, we take the average result, 1/r = 0.62, convert it to 27.2°C, to obtain $(1/r)_{27.2} = 0.49$. This compares very well with the result of this survey, $(1/r)_{27.2} = 0.48$. Thus just one value of 1/r = .48 will be used for the bulkheads, at a temperature of 27.2°C.

Data from the August 24 and 25 diel survey (taken completely from the structure) were also used to determine deficit ratios at the bulkheads. Two significant problems with the data are evident. The first being that the downstream probe readings were taken where bubbles still existed in the flow. These bubbles might have the effects of increasing probe readings to near saturation. The second problem was that the downstream deficits were small so that the measurements are very uncertain. The "best" data indicate 1/r values from 0.3 to 0.4 at 22.5°C. For the above reasons, this data will not be used except to show that the 0.48 value may be conservative.

Presently there are two predictive equations available in the literature which take into account fall height and discharge. The first, that of Avery and Novak [1978] is given as

$$r_{15} - 1 = 0.245\, h^{1.34}\, q^{-.36} \tag{B.1}$$

where r_{15} is the deficit ratio at 15°C, h is the difference in elevations of the upstream and downstream pools (m) and q is the specific discharge (m^2/s).

Nakasone [1987] gives a set of four equations, the fourth of which is given here and is that which is said to apply for h > 1.2 m and q > .065 m^2/s:

$$\ln r_{20} = .303\, h^{.816}\, q^{-.363}\, H^{.310} \tag{B.2}$$

where H is the tailwater depth (m).

Both of the above relationships were developed from the results of measurements made on small laboratory weirs. Nakasone tested both of the equations using data from several prototype structures. Most of the data was taken for 4 m < h < 5.7 m, 0.2 m^2/s < q < 3.0 m^2/s and 0.2 m < H < 1.7 m. Both equations predicted r with similar accuracy, however, a large scatter resulted for both equations. For example, when the 1/r is computed as 0.33, the measured values might range from 0.25 to 0.50. The discharges computed for the bulkheads on days on which surveys were made and they were operated ranged from 210 cfs to 350 cfs per bulkheaded gate. This discharge range will be used to test the predictive equations. The design fall height of 12.2 ft (3.7 m) and the design tailwater depth of 6.1 ft (1.9 m) will be used.

Q (cfs)	q (m^2/s)	$1/r_{20}$, computed Eq. (B–1)	$1/r_{20}$, computed Eq. (B–2)	$(1/r)_{20}$,meas.	$(1/r)_{20,ADJ}$
210	.65	.35	.28		.47
250	.77	.36	.31		.49
300	.93	.38	.33		.51
350	1.08	.39	.35	.53 (this study)	.53
465	1.44	.42	.39	.54 (Rindels, 1985)	.57

Equations B–1 and B–2 predict higher transfer than that which was measured. This may be due to the problems in the equations which caused the large scatter observed in Nakasone [1987]. Another possible cause is that the back side of the nappe is not ventilated; the discharge from the bulkheads fills the entire width of the tainter gate bay. Equations B–1 and B–2 were developed for well–ventilated nappes. For these reasons, the measurement of reaeration is preferred over the predictive equations.

The measured value must be adjusted for varying discharge. For lack of a better method the Nakasone equation will be fit to the measurement. Because fall height and tailwater depth are relatively constant, they will be dropped from the equation, and it is written as:

$$\ln r_{20} = K\, q^{-.36} \qquad \text{(B.3)}$$

With the measured value of $1/r_{20}$ = 0.53, and q = 1.08 m^2/s, the equation is solved to give K = 0.65. The values listed under $(1/r)_{20,ADJ}$ are the measured values adjusted for discharge by Eq. B.3. These values may be conservative and are those which will be used in the model.

APPENDIX B.5

Reaeration of Flow Under Gates

Reaeration of Flow Under Gates

The aeration which occurs under the tainter gates of Lock and Dam No. 2 was measured on September 9, 1988. The measurements, which were made at gate 8, were accomplished by the following procedure:

From the structure:

1) D.O. and temperature profile and a pair of grab samples were taken at UG8.

2) Gate 8 was opened 0.5 ft.

3) D.O. and T. profiles were taken at UG7 and UG9, near gate 8.

Then using a boat downstream:

4) The D.O. probe was attached to a "fish" weight and hung from the front of the boat.

5) The boat was positioned in the plume as close to the structure as possible, but where few bubbles remained in the flow.

6) While maintaining that position, vertical variation in the plume was checked by taking readings at 0.5 m and 4.0 m depth. No variation was detected.

7) The probe was set at approximately 1.5 m depth for all subsequent readings.

8) Probe readings of D.O. were used to detect the center (maximum reading) of the plume.

9) At that point a pair of grab samples was taken.

10) The gate was adjusted to the next opening and steps 8 and 9 were repeated. Openings of 0.5, 1.0, 1.5, 2.0 and 0.5 ft were used.

Then from the structure:

11) Step 3 was repeated with an 0.5 ft gate opening.

12) Gate 8 was closed.

13) Step 1 was repeated.

14) Gate 8 was opened to take photographs at the gate openings tested.

The original data from that survey are compiled along with the rest of the surveys in Appendix A.

The upstream concentration varied during the measurements, and this must be accounted for. The first profiles taken in the morning showed little vertical change in D.O, however, the second set was slightly stratified in D.O. near the surface. In Fig. B–3 the total vertical average (over 5.5 m total depth), the average of the bottom 3.5 m, and 1.5 m are plotted versus time. There is little difference between the 3.5 m and 1.5 m bottom averages. Therefore, as an estimate of C_u versus time, a straight line was drawn through the bottom averages of the first and second sets. The upstream concentrations for each gate opening can be determined from this plot. These bottom averages are used because the sill of the tainter gate bay is at 5.5 m depth. Thus most of the water withdrawn by the gate should come from the lower layer.

For the downstream concentrations, only the average of the two Winkler samples was used. As shown in Fig. B–3, the probe generally read about 0.5 mg/ℓ more than the Winklers. However, the probe and Winkler samples gave good agreement during the upstream sampling. Additionally, the probe, as attached to the weight, had its membrane pointed into the flow. The stagnation pressure on the membrane may have caused the discrepancy. For these reasons, the Winkler results are preferred.

The deficit ratios for the tainter gates are determined below. The saturation concentration is adjusted for temperature and pressure

Gate Opening	Q	T	C_s	C_u	C_d	1/r
(ft)	(cfs)	(°C)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(–)
0.5	390	18.9	9.02	6.89	7.23	.84
1.0	780	18.9	9.02	6.93	7.44	.76
1.5	1170	18.9	9.02	6.96	7.82	.58
2.0	1560	18.9	9.02	6.99	7.77	.62
0.5	390	18.9	9.02	7.01	7.49	.76
0.5		Average of two measurements:				.80

There is only one predictive equation available for underflow gates such as these; Wilhelms [1988] measured the oxygen transfer at two low head dams similar to that at Hastings. The equation was developed for flows where the tailwater submerged the flow out of the gate:

$$\frac{1}{r} = \exp\left(-0.000797\,\frac{\Delta h\ q}{s} - 0.188\right) \qquad \text{(B.4)}$$

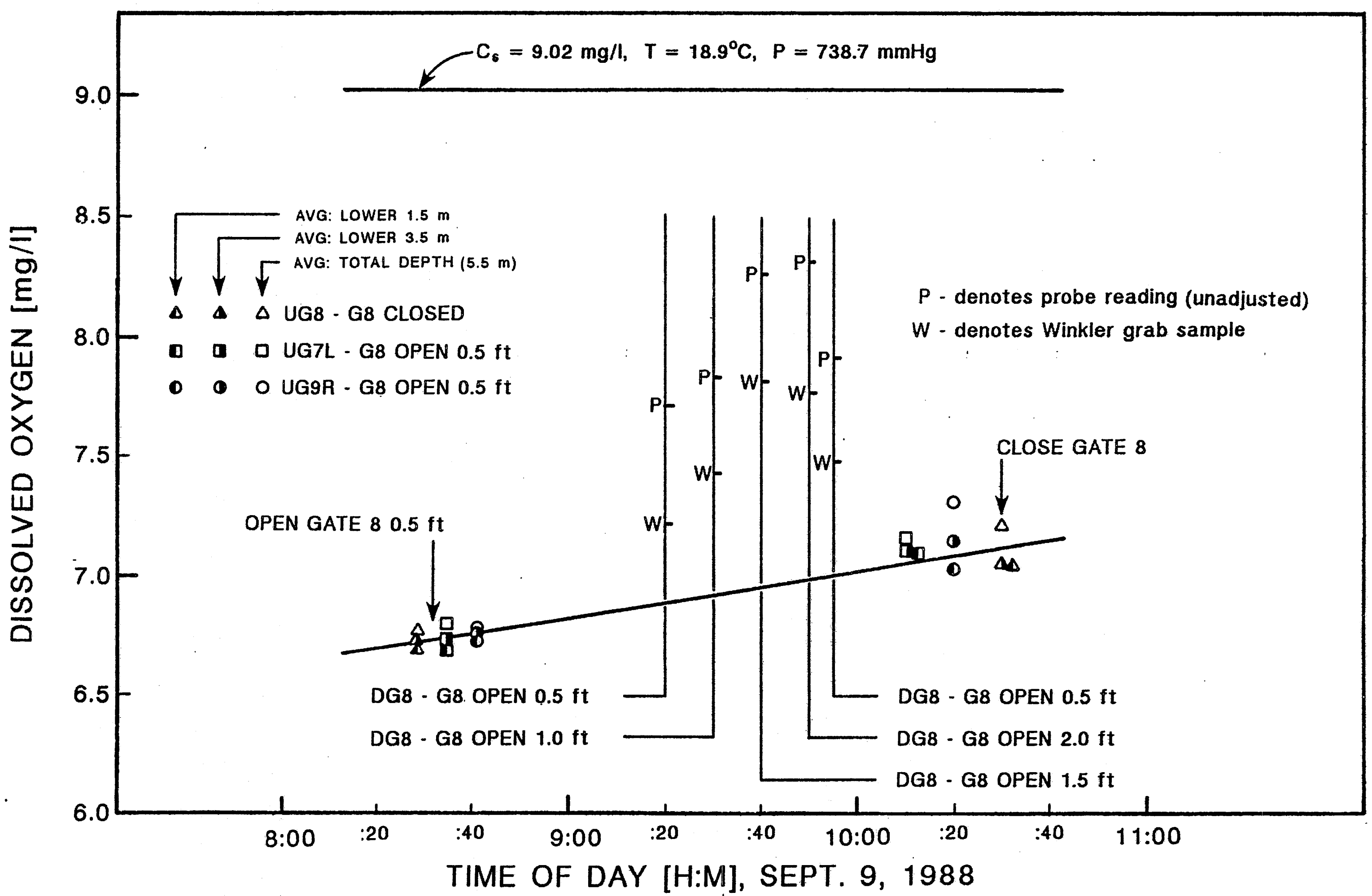

Fig. B–3. Reaeration measurements at gate 8, Lock and Dam No. 2, September 9, 1988.

where Δh is the difference in pool and tailwater elevations (ft), q is the specific discharge (ft^2/s), and s is the downstream submergence on the gate lip (ft).

On the day of the survey, the pool and tailwater elevations were 687.2 and 675.2 feet above sea level, respectively, while the floor of the tainter gate bay is at 669.1 ft. These elevations and the rating table for the gates [Corps of Engineers, 1973] are used to predict the deficit ratios from Eq. B–4.

Gate Opening	Q	q	Δh	s	$(1/r)_{20°C}$	
					Eq. B–4	Meas
(ft)	(cfs)	cfs/ft	(ft)	ft	—	—
0.5	390	13	12.0	5.6	.81	.80
1.0	780	26	12.0	5.1	.79	.76
1.5	1170	39	12.0	4.6	.76	.57
2.0	1560	52	12.0	4.1	.73	.61

The measurements which were made for submerged flow at the gates (gate openings 0.5 and 1.0 ft) show good agreement with Eq. B–4. However, at openings of 1.5 and greater, the agreement is not good, the reason for this being the non–submerged conditions at the gate lip. At these higher gate openings, the momentum of the flow forces the hydraulic jump downstream and the air entrainment increases as the jet becomes exposed. At the 1.5 ft gate opening, and the given pool elevations, this condition is imminent.

With no other information available, for gate openings other than those listed above, the corresponding 1/r value should be interpolated. The pool elevations for this survey were very close to the normal pool elevations. Therefore the 1/r values measured here should be generally applicable at the low flows of concern in this report. For gate openings less than 0.5 ft, the value will be interpolated from 1/r = 1.0 at 0.0 ft to 1/r = 0.80 at 0.5 ft.