APPENDIX F

CURRENT METER MEASUREMENTS OF DISCRETIONARY AND LEAKAGE FLOWS AT THE CHICAGO RIVER CONTROLLING WORKS, O'BRIEN LOCK AND DAM, AND THE WILMETTE CONTROLLING WORKS

OCTOBER 1990

CURRENT METER MEASUREMENTS OF DISCRETIONARY AND LEAKAGE FLOWS

TABLE OF CONTENTS

Subject	Page
BACKGROUND	1
PURPOSE	9
AUTHORITY	9
PROCEDURES	10
RESULTS	12
RECOMMENDATIONS/DISCUSSIONS	15
Options for Future Measurements	15
Applicability of Two-Point and Three-Point Methods for Future Current Meter Measurements	17
Probability of High Biased Measurements	20
Improving the Accuracy of Future Current Meter Measurements	22
Improving the Safety of Future Current Meter Measurements	24
Benefits of In-House Flow Measuring Equipment	24
CONCLUSIONS	25

LIST OF TABLES

Table	Subject	Page
1	WY84 Lake Michigan Diversion Accounting Report	2
2	WY85 Lake MIchigan Diversion Accounting Report	3
3	Water Budgets	5
4	WY84 Summary of Flow Components Above Romeoville	6
5	WY85 Summary of Flow Components Above Romeoville	7
6	MWRDGC Reported Flows vs. Corps' Measured Flows	14
7	Two-Point and Three-point Method Coefficients	19
F-1	Instantaneous MWRDGC Discretionary and Leakage Flows	F-1
F-2	Water Surface Elevations at CRCW	F-3
F-3	Water Surface Elevations at O'Brien Lock & Dam	F-4
F-4	Water Surface Elevations at Wilmette CW	F-5

LIST OF TABLES (Continued)

Table	Subject	Page
G-1	Two-Point and Three-Point Flows at CRCW	G-1
G-2	Two-Point and Three-Point Flows at O'Brien Lock and Dam	G-3
G-3	Two-Point and Three-Point Flows at Wilmette CW	G-5
G-4	Two-Point and Three-Point Coefficients at CRCW	G-7
G-5	Two-Point and Three-Point Coefficients at O'Brien Lock and Dam	G-8
G-6	Coefficient Summary Table	G-9

LIST OF FIGURES

Figure	Subject	Page
A-1	Navigation Notice (22 May 1990)	A-1
A-2	Navigation Notice (26 June 1990)	A-2
B-1	Chicago River Columbus Drive Bridge Section	B-1
B-2	Calumet River 130th Street Bridge Section	B-2
B-3	North Shore Channel Linden Avenue Section	B-3
C-1	Columbus Drive Bridge Section at Chicago River	C-1
C-2	Current Meter Measurements at Columbus Drive	C-1
C-3	130th Street Bridge at Calumet River	C-2
C-4	Current Meter Measurements at 130th Street	C-2
C-5	Linden Avenue Bridge at North Shore Channel	C-3
C-6	Current Meter Measurements at Linden Avenue	C-3
C-7	Price AA Current Meter	C-4
C-8	Pygmy-type Current Meter	C-4
C-9	Marsh-McBirney Electromagnetic Current Meter	C-5
C-10	Marsh-McBirney Analog Processor	C-5
C-11	Type A Four-Wheel Truck with Type A Crane	C-6
C-12	Current Meter Apparatus	C-6
C-13	Price AA Current Meter with Flagged Cable	C-7
D-1	LMO-6 for Chicago River Controlling Works	D-1
D-2	LMO-6 for O'Brien Lock and Dam	D-2
D-3	LMO-6 for Wilmette Controlling Works	D-3
E-1	Sluice Gate Rating Table for CRCW	E-1
E-2	Sluice Gate Rating Table For O'Brien Lock & Dam	E-2
E-3	Sluice Gate Rating Table for Wilmette CW	E-3
E-4	Upstream Water Surface Elevation Chart at CRCW	E-5
E-5	Downstream Water Surface Elevation Chart at	E-6
E-6	Upstream Elevation Chart at O'Brien Lock & Dam	E-7
E-7	Downstrean Elevation Chart at O'Brien Lock & Dam	E-8
E-8	Upstream Elevation Chart at Wilmette CW	E-9
E-9	Downstream Elevation Chart at Wilmette CW	E-10

APPENDICES

A. Navigation Notices for Current Meter Measurements

B. Flow Measurement Cross Sections

C. Photographs of Measurement Sites and Equipment

D. July 1990 LMO-6 Reports

E. MWRDGC Rating Tables, Leakage Equations, and Water Surface Elevation Charts

F. Calculations of Instantaneous MWRDGC Discretionary and Leakage Flows

G. Calculations of Coefficients for Two-Point and Three-Point Methods

BACKGROUND

1. The Army Corps of Engineers, Chicago District is responsible for the computation of diverted Lake Michigan flows accountable to the State of Illinois. The Corps' computation of the diversion is performed by deducting all flows not attributable to Lake Michigan from the flow measured by the Acoustical Velocity Meter (AVM) on the Chicago Sanitary and Ship Canal (CSSC) at Romeoville, Illinois and by adding all diverted Lake Michigan waters that bypass the AVM.

2. The diversion accounting computations are summarized as a series of flow columns. The annual summary tables of the diversion flows for Water Years 1984 and 1985 are shown in Table 1 and 2, respectively. Column 11 contains the official computed Lake Michigan diversion accountable to Illinois. As previously summarized, the official diversion contained in Column 11 is computed by first measuring the canal system flow at Romeoville. The flows at Romeoville are presently measured by the AVM and are contained in Column 1. The total flow through the canal system (Column 3) is calculated by adding any diversions (withdrawals) upstream of the AVM (Column 2). The small value contained in Column 2 during WY84 and WY85 is the withdrawal of water from the CSSC by Argonne National Labs. Some additions and subtractions to the flow of Column 3 must be made in order to arrive at Illinois' official diversion contained in Column 11. As shown in Tables 1 and 2, Column 11 equals Column 3 minus Column 8 plus Column 9 minus Column 10. Column 8 is the total deduction from the Romeoville gage record and is composed of the sum of Columns 4, 5, 6, and 7. Column 4 contains the effluent whose source is groundwater supply pumpage by Illinois' communities and industries as reported by the State. Column 5 contains the groundwater supply pumpage from the Des Plaines River watershed whose sanitary effluent reaches the canal. Column 6 contains the domestic pumpage from Indiana whose sanitary effluent reaches the canal. Column 7 contains the runoff from the Des Plaines River watershed that reaches the canal. Column 9 contains water supply pumpage from Lake Michigan, the effluent of which is not discharged to the canal. This constitutes an addition to the Romeoville gage record. Column 10 constitutes a deduction from the Romeoville gage record and is composed of withdrawals for federal use that enter the canal.

3. Columns 12, 13, and 14 are independent flow estimates for the three sources of diversion: water supply pumpage from Lake Michigan (Column 12), runoff from the diverted Lake Michigan watershed (Column 13), and direct diversion through the lakefront control structures (Column 14). Column 14 is made up of four components of flow: lockages, leakages through lock gates and sluice gates, navigational makeup flow (flows necessary to maintain minimum navigable depth), and discretionary flow (flows required to maintain water quality in the canal). Navigational make-up and discretionary flows are regulated by the Metropolitan Water Reclamation

TABLE 1

LAKE MICHIGAN DIVERSION ACCOUNTING - WATER YEAR 1984

SUMMARY OF DIVERSION FLOWS (cfs)

DATE	ROMEOVLL GAGE RECORD	DIVERSN ABOVE GAGE	TOTAL FLOW THRU CANAL	GRNDWTR PUMPAGE FROM LAKE MICH. WATRSHD IN ILLINOIS	GRNDWTR PUMPAGE FROM DES PLAINES WATRSHD	WATER SUPPLY PUMPAGE FROM INDIANA REACHNG CANAL	RUNOFF FROM DES PLAINES WATRSHD REACHNG CANAL	TOTAL DEDUCT. FROM ROMEOVLL GAGE RECORD	LAKE MICH. PUMPAGE NOT DISCHRG TO CANAL	FEDERAL LAKE MICH. WTHDRWL REACHNG CANAL	TOTAL DIVERSN	PUMPAGE FROM LAKE MICH. ACCT. TO ILLINOIS	RUNOFF FROM THE DIVERTD WATRSHD	DIRECT DIVERSN THRU LAKE CONTROL STRUCT.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
OCT, 1983	3428.3	0.4	3428.7	48.5	51.2	57.0	118.1	274.8	28.1	2.5	3179.4	1526.0	546.4	756.1
NOV, 1983	3379.5	0.2	3379.7	48.5	50.7	46.2	282.6	428.0	29.4	2.5	2978.6	1484.2	1099.8	254.9
DEC, 1983	3566.4	0.3	3566.7	48.5	51.0	37.7	216.1	353.2	27.1	2.0	3238.6	1510.6	986.6	116.7
JAN, 1984	2519.8	0.2	2520.0	48.5	51.0	31.0	116.8	247.3	28.5	1.1	2300.1	1584.2	341.9	138.8
FEB, 1984	3549.9	0.2	3550.1	48.5	50.7	36.0	340.1	475.4	29.7	1.2	3103.3	1556.1	1281.5	113.7
MAR, 1984	4120.4	0.2	4120.6	48.5	50.7	43.9	348.6	491.7	30.1	1.1	3658.0	1535.4	1654.0	119.8
APR, 1984	3870.0	0.3	3870.3	48.5	50.7	58.0	385.9	543.1	29.5	1.0	3355.7	1485.6	1422.9	215.4
MAY, 1984	4091.0	0.4	4091.4	48.5	50.8	66.1	223.6	389.0	30.0	1.1	3731.4	1539.5	1207.5	422.0
JUN, 1984	4230.0	0.6	4230.6	48.5	51.0	80.2	107.8	287.5	31.2	1.1	3973.2	1817.7	545.7	1070.4
JUL, 1984	4285.5	0.8	4286.3	48.5	51.0	98.0	47.4	244.8	34.3	1.3	4074.5	1992.7	247.6	1610.1
AUG, 1984	4202.6	0.8	4203.4	48.5	51.0	91.4	73.4	264.3	34.9	1.4	3972.7	2122.6	221.0	1391.2
SEP, 1984	4246.7	0.5	4247.2	48.5	50.9	69.6	109.9	278.9	29.5	401.1	3596.7	1658.2	427.9	978.5
WY 1984	3790.6	0.4	3791.0	48.5	50.9	59.7	196.5	355.5	30.2	34.2	3431.5	1652.0	829.0	601.3

COL#3 = COL#1 + COL#2   COL#8 = COL#4 + COL#5 + COL#6 + COL#7   COL#11 = COL#3 - COL#8 + COL#9 - COL#10
COL#14: DIRECT DIVERSIONS ACCOUNTABLE TO THE STATE OF ILLINOIS

STATUS OF ILLINOIS' LAKE MICHIGAN DIVERSION
UNDER 1980 AMENDED U.S. SUPREME COURT DECREE

Accounting year	Annual Diversion (% of 3200 cfs)	40 Year Running Average	Deviation from 3200 cfs Annual	Deviation from 3200 cfs Cumulative Sum (cfs-years)
1981	3106.0 cfs (97.1%)	3106.0	+ 94.0	+ 94.0
1982	3087.0 cfs (96.5%)	3096.5	+ 113.0	+ 207.0
1983	3613.1 cfs (112.9%)	3268.7	- 413.1	- 206.1
1984	3431.5 cfs (107.2%)	3309.4	- 231.5	- 437.6

TABLE 2

LAKE MICHIGAN DIVERSION ACCOUNTING - WATER YEAR 1985

SUMMARY OF DIVERSION FLOWS

DATE	ROMEOVLL GAGE RECORD	DIVERSN ABOVE GAGE	TOTAL FLOW THRU CANAL	GRNDWTR PUMPAGE FROM LAKE MICH. WATRSHD IN ILLINOIS	GRNDWTR PUMPAGE FROM DES PLAINES WATRSHD	WATER SUPPLY PUMPAGE FROM INDIANA REACHNG CANAL	RUNOFF FROM DES PLAINES WATRSHD REACHNG CANAL	TOTAL DEDUCT. FROM ROMEOVLL GAGE RECORD	LAKE MICH. PUMPAGE NOT DISCHRG TO CANAL	FEDERAL LAKE MICH. WTHDRWL REACHNG CANAL	TOTAL DIVERSN	PUMPAGE FROM LAKE MICH. ACCT. TO ILLINOIS	RUNOFF FROM THE DIVERTD WATRSHD	DIRECT DIVERSN THRU LAKE CONTROL STRUCT.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
OCT, 1984	3699.5	0.4	3700.0	27.7	46.7	66.6	124.5	265.5	33.1	2.0	3465.6	1556.7	423.2	986.4
NOV, 1984	2904.6	0.3	2904.9	27.7	46.7	73.8	225.2	373.4	32.9	2.1	2562.3	1498.0	735.6	135.9
DEC, 1984	3017.4	0.3	3017.6	27.7	46.6	73.6	304.1	452.0	33.8	1.8	2597.7	1503.4	982.1	134.3
JAN, 1985	3165.3	0.3	3165.6	27.7	46.8	76.4	230.9	381.8	33.7	2.2	2815.3	1548.2	703.9	130.3
FEB, 1985	4056.5	0.3	4056.7	27.7	46.4	79.2	354.5	507.8	36.3	2.1	3583.2	1574.6	1694.0	173.9
MAR, 1985	4690.1	0.3	4690.3	27.7	46.3	76.8	516.5	667.4	36.3	2.0	4057.3	1548.0	2082.5	141.9
APR, 1985	3682.4	0.3	3682.7	27.7	46.7	77.7	270.8	422.9	33.3	2.2	3290.9	1547.2	903.1	251.9
MAY, 1985	3165.9	0.4	3166.3	27.7	46.7	86.5	86.7	247.7	34.8	2.1	2951.3	1704.7	373.0	418.1
JUN, 1985	3695.7	0.4	3696.1	27.7	46.7	92.2	59.2	225.8	36.5	2.3	3504.4	1861.3	352.7	841.4
JUL, 1985	4442.8	0.6	4443.4	27.7	46.7	97.1	51.2	222.7	39.7	2.7	4257.7	2013.9	430.5	1332.3
AUG, 1985	4535.7	0.4	4536.1	27.7	46.7	85.2	70.7	230.3	36.7	2.0	4340.5	1819.0	501.4	1399.9
SEP, 1985	4428.3	0.4	4428.7	27.7	46.7	82.5	60.5	217.5	36.2	1.7	4245.7	1767.3	305.2	1580.3
WY 1985	3789.4	0.4	3789.8	27.7	46.7	80.6	195.4	350.4	35.3	2.1	3472.5	1662.5	785.5	630.1

COL#3 = COL#1 + COL#2   COL#8 = COL#4 + COL#5 + COL#6 + COL#7   COL#11 = COL#3 - COL#8 + COL#9 - COL#10

COL#14: DIRECT DIVERSIONS ACCOUNTABLE TO THE STATE OF ILLINOIS

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1982	3087.0 cfs (96.5%)	3096.5	+ 113.0	+ 207.0
1983	3613.1 cfs (112.9%)	3268.7	- 413.1	- 206.1
1984	3431.5 cfs (107.2%)	3309.4	- 231.5	- 437.6
1985	3472.5 cfs (108.5%)	3342.0	- 272.5	- 710.1

District of Greater Chicago (MWRDGC) through the opening and closing of sluice gates at the three lakefront control structures: Chicago River Controlling Works (CRCW), O'Brien Lock and Dam, and Wilmette Controlling Works.

4. In addition to the diversion calculations presented in the 14 columns, there exists 13 water budgets (Table 3) that serve as input to the diversion calculations and that verify the estimated flows that are determined through hydrologic and hydraulic simulation. The first three budgets are direct summations of water supply pumpage data used in the actual computation of Illinois' diversion. Budgets 5 through 8 and Budget 12 are budgets that compare the simulated flows to the measured inflows at four water reclamation plants and one pump station. The purpose of these budgets is to calibrate and verify the simulation models which estimate the three sanitary treatment plant influent components: infiltration, inflow, and sanitary flow. Budget 4 and budgets 9 through 11 are budgets of stream gage sites used to make estimates of runoff from portions of the diverted Lake Michigan watershed. Budget 13 compares the inflows and outflows to the canal system.

5. The budget of interest for the purpose of this report is Budget 13. In Budget 13, a comprehensive comparison of inflows to and outflows from the canal system is performed. Inflows to the canal system include direct diversion through the lakefront structures, stormwater runoff discharged to the canal system, and domestic water supply effluent that is discharged to the canal system. The outflows from the canal system include the discharge at Romeoville measured by the AVM, backflows through the three lakefront control structures, and the withdrawal upstream of Romeoville by Argonne National Labs. The comparison of canal inflows and outflows for WY84 and WY85 is presented in Table 4 and Table 5. Table 4 indicates that during WY84 the inflows are 431.1 cfs (11%) less than the outflows. Table 5 indicates that during WY85 the inflows are 508.3 cfs (13%) less than the outflows. Since almost 100% of the outflow is measured by the AVM, which has been verified to have an accuracy of approximately 2%, it appears that a significant portion of inflows are not being reported or that some inflows are being underreported.

6. Although Columns 12 through 14 are not used in the actual diversion calculation, they provide a verification of the diversion flow computed in Column 11. They also emphasize the existence of unreported and/or underreported flows found in Budget 13. Theoretically, the sum of Columns 12, 13, and 14 should equal the total diversion presented in Column 11. As shown in Tables 1 and 2, the difference between the flow of Column 11 and the sum of the flows for Columns 12 through 14 in Water Year 1984 and 1985 is 349.2 cfs and 394.4 cfs, respectively. The diversion estimate from Columns 12 through 14 is based on simulation, flow separation techniques, and rating tables for the three lakefront structures. Consequently, the diversion estimate derived from Columns 12 through 14 is

TABLE 3

WATER BUDGETS

Budget	Description
1	Lake Michigan Water Supply
2	Groundwater Supply Lake Michigan Watershed
3	Groundwater Supply Des Plaines Watershed
4	North Branch Chicago River at Touhy Avenue
5	Northside Water Reclamation Plant
6	Upper Des Plaines Pump Station
7	West - Southwest Water Reclamation Plant
8	Calumet Water Reclamation Plant
9	Little Calumet River at State Line
10	Thorn Creek at Thornton
11	Little Calumet River at South Holland
12	Lemont Water Reclamation Plant
13	Lockport Powerhouse and Controlling Works

TABLE 4

Water Year 1984
SUMMARY OF FLOW COMPONENTS ABOVE ROMEOVILLE (Budget 13)

INFLOWS TO THE CHICAGO SANITARY AND SHIP CANAL	
Lake Controlling Structures (Measured)	
Wilmette	38.8
CRCW	278.6
O'Brien	283.5
Streamflows (Measured)	
North Branch at Touhy	140.8
Little Calumet at South Holland	215.7
MSDGC Treatment Plants (Measured)	
Northside	420.2
West - Southwest	1162.7
Calumet	358.6
Adjustment for Interlake - Riverdale	-2.5
Lemont	2.0
Other Point Sources (Measured)	5.4
Summit Conduit (Estimated)	9.7
Grand Calumet Streamflow (Estimated)	61.3
Combined Sewer Overflows in Ungaged Watershed (Simulated)	212.3
Direct Runoff in Ungaged Watershed (Simulated)	140.5
COE Emergency Nav. Make - up (Estimated)	32.8
TOTAL	**3360.4**
OUTFLOWS FROM THE CHICAGO SANITARY AND SHIP CANAL	
Argonne Withdrawal (Measured)	0.4
AVM @ Romeoville Recorded Flow	3790.6
Lake Controlling Structures (Measured) Backflows	0.5
TOTAL	**3791.5**
DIFFERENCE BETWEEN INFLOWS AND OUTFLOWS	**-431.1**

TABLE 5

Water Year 1985
SUMMARY OF FLOW COMPONENTS ABOVE ROMEOVILLE (Budget 13)

INFLOWS TO THE CHICAGO SANITARY AND SHIP CANAL	
Lake Controlling Structures (Measured)	
Wilmette	26.8
CRCW	306.2
O'Brien	297.2
Streamflows (Measured)	
North Branch at Touhy	107.7
Little Calumet at South Holland	180.8
MSDGC Treatment Plants (Measured)	
Northside	438.8
West - Southwest	1115.9
Calumet	336.9
Adjustment for Interlake - Riverdale	-2.5
Lemont	1.8
Other Point Sources (Measured)	6.1
Summit Conduit (Estimated)	11.7
Grand Calumet Streamflow (Estimated)	105.3
Combined Sewer Overflows in Ungaged Watershed (Simulated)	209.3
Direct Runoff in Ungaged Watershed (Simulated)	145.1
TOTAL	**3287.1**

OUTFLOWS FROM THE CHICAGO SANITARY AND SHIP CANAL	
Argonne Withdrawal (Measured)	0.4
AVM @ Romeoville Recorded Flow	3789.6
Lake Controlling Structures (Measured) Backflows	0.9
TOTAL	**3790.9**

DIFFERENCE BETWEEN INFLOWS AND OUTFLOWS **-503.8**

not as accurate as the AVM based diversion estimate contained in Column 11. However, the differences of 10% and 11% for WY84 and WY85 are larger than would be anticipated. By comparing Column 1 (the AVM measured flow) with Column 11 (the total diversion) it becomes obvious that Column 11 is composed primarily of the flows measured by the AVM. Consequently, greater confidence is placed in the flow of Column 11 than in the sum of Columns 12 through 14. Additionally, the sum of Columns 12 through 14 was less than the flow in Column 11 for both water years. Therefore, it is probable that there exists flows that are not being reported and/or flows that are being underreported. This supports the conclusion drawn from Budget 13.

7. It is due to the discrepancy in inflows and outflows found in Budget 13 and the discrepancy between the flows of Column 11 and the sum of flows of Columns 12 through 14 that an investigation was deemed necessary to determine the reasons for the discrepancies. Flow discrepancies for both WY84 and WY85 are similar in magnitude and percentage of total flow. This implies that the sources of error are probably the same.

8. Possible sources of the canal flow imbalance found in Budget 13, and supported by the diversion flow estimate imbalance between Column 11 and Columns 12 through 14, include unreported discharges to the canal system, groundwater seepage into the canal system, and underreporting of inflows to the canal system. Unreported discharges include any point source discharges to the canal system that are unknown to the State of Illinois and the Army Corps of Engineers. If any unreported point source discharges are occurring, the magnitude is anticipated to be much smaller than the flow discrepancy previously discussed. The degree of groundwater seepage to and from the canal system is unknown. The estimation of groundwater seepage would require an extensive and costly effort that would include the drilling and monitoring of several observation wells in the vicinity of the canal and its tributaries. Underreporting of inflows to the canal system may include underreporting of the following: combined sewer overflows (CSO), direct runoff to the canal, and direct diversion flows through the three lakefront control structures. CSO's and direct runoff to the canal are simulated with models that have been reasonably calibrated and verified. Underreporting of flows through the lakefront control structures could be the result of both inaccurate rating tables and leakages through those structures.

9. Flow through the lakefront control structures is the most readily analyzed potential source of the canal system imbalance. The effort to check this possible source of error does not require as extensive an effort as compared to the effort involved in verifying all point source discharges, quantifying groundwater seepage, or further verifying the simulation techniques for determining CSO's and direct runoff. Therefore, it was determined that the lakefront control structures would be an appropriate starting point for an investigation into the flow imbalance.

10. It should be emphasized that the components of direct diversion do not enter directly into the diversion calculation. The direct diversion flows are already accounted for in the flows measured by the AVM. Although the canal system flow balance does not enter into the calculation of Illinois' diversion, identifying the sources of discrepancy of this flow balance improves the credibility of the Corps' modeling and accounting procedures by reducing the amount of uncertainty inherent with the nature and complexity of diversion accounting.

11. It is important to note that prior to WY87 a 1,100 foot section of the Chicago harbor wall was at 3.0 feet CCD and in need of repair. Because of this fact it is probable that a significant amount of unreported water overtopped the harbor wall as well as leaking through the wall. Analysis of the inflows and outflows for WY84 and WY85 showed that an increase in lake level resulted in an increase in the flow imbalance. However, it is difficult to determine how much of the flow imbalance was due to overtopping and leakage through the harbor wall because higher lake levels also tend to increase the leakage through the sluice gates and lock gates as well as increasing the discretionary and navigation make-up flow through open sluice gates.

PURPOSE

12. The flow measurements during the period of 23 through 27 July 1990 were conducted in order to assess the accuracy of the MWRDGC reported direct diversion flows. This was necessary to evaluate potential source(s) of the canal system flow imbalance detected in Budget 13 and suggested by the discrepancy between Column 11 and the sum of Columns 12 through 14 of the annual diversion reports for WY84 and WY85. It was anticipated that part of this flow imbalance could be explained through flow measurements, provided that the measured flows were greater than those reported by the MWRDGC. The purpose of this report is to present the results of these flow measurements and to make recommendations for future measurements of direct diversion flows.

AUTHORITY

13. Under the provisions of the U.S. Supreme Court Decree in Wisconsin, et al v. Illinois et al, 388 U.S. 426,87 S. Ct. 1774 (1967) as modified by 449 U.S. 48, 101 S. Ct. 557 (1980), the Corps is responsible for monitoring the measurement and computation of Lake Michigan water by the State of Illinois. The Water Resources Development Act of 1986 gives the Corps total responsibility for the computation of diversion flows as formerly done by the State of Illinois. This responsibility became effective 1 October 1987. The terms and conditions of the Supreme Court Decree specify that "all measurements and computations required by this decree shall be

made...using the best current engineering practice and scientific knowledge." In keeping with the terms of the decree, flow measurements were required in order to determine sources of the canal system flow imbalance.

PROCEDURES

14. A field survey was conducted on 7 March 1990 to determine possible locations for the flow measurements. A location at all three lakefront control structures was determined. The measurements were to be conducted from the Columbus Drive bridge approximately 2/3 mile downstream of the Chicago River Controlling Works, the 130th Street bridge approximately 1/2 mile upstream of O'Brien Lock and Dam, and the Linden Avenue bridge approximately 900 feet downstream of the Wilmette Pumping Station. Pictures were taken at each site for reference and are included in Appendix C.

15. The period of 23 July through 27 July 1990 was selected for the measurements. This period was selected since the sluice gate flows during that time of year represented an approximation of the average sluice gate flow during the discretionary period (mid-June through thru mid-November). An alternate measurement period was set in the event that inclement weather prohibited at least three measurements from being taken at each of the three sites. This alternate period was scheduled to be 20 August through 24 August 1990.

16. An initial navigation notice was sent out on 22 May 1990 to all appropriate parties. Since the locks would be closed while the measurements were taken, recent lockage data was used to determine the times of measurement best suited to avoiding periods of heavy river traffic. A second navigation notice containing the times of measurement was sent out on 26 June 1990 to all appropriate parties. Both navigation notices are contained in Appendix A. One complete measurement at each of the three sites was accomplished per day according to the schedule contained in the navigation notice. The measurement at Wilmette Pumping Station concluded the daily activities.

17. In addition to the navigation notices, the Coast Guard, Milwaukee group was informed of the proposed activities so that notices would be issued via marine radio one week prior to the measurements. Additionally, the Coast Guard issued daily notices during the period 23 - 27 July 1990 two hours prior to each measurement.

18. At the start of each day, the MWRDGC was called via mobile telephone to obtain the sluice gate settings at all three sites. The lock operator was contacted at least 15 minutes prior to the start of the discharge measurements as a reminder to keep the lock closed during the measurements occurring upstream or downstream of

the lock. This was necessary to avoid unsteady flow conditions during the measurements. Upon completion of each measurement the lock operators were informed to proceed with normal lock operations and the MWRDGC dispatcher was contacted in order to obtain upstream and downstream elevations at the control structure. These elevations were recorded at half-hour increments over the measurement period. The dispatcher was also asked to verify that the sluice gate settings remained constant during the measurement.

19. The flow measurements were accomplished by first sounding the river bottom to provide a profile of the channel section and to determine the depths at which each measurement would be taken. The metering locations were set at the center of each panel (partial cross section). Cross sections of the three sites are shown in Figures B-1, B-2, and B-3. The measurements on the Chicago River downstream of the Chicago River Controlling Works used 10 discharge panels each 20 feet wide. The measurements on the Calumet River upstream of the O'Brien Lock used 11 discharge panels each 20 feet wide. The measurements on the North Shore Channel downstream of the Wilmette Pumping Station used 5 discharge panels each 14 feet wide. Current meter readings were taken every one-tenth of the total depth at the metering location in accordance with the "Vertical-Velocity Method" contained in the U.S. Geological Survey's (USGS) "National Handbook of Recommended Methods for Water-Data Acquisition" Sec. 1.B.2.c. Due to time constraints for each measurement and in order to limit the length of time the locks were shut down, it was necessary to deviate from the 25 partial cross sections (panels) suggested by the USGS in Sec. 1.B.2.b.4 of the "National Handbook of Recommended Methods for Water-Data Acquisition." However, the USGS states that fewer partial cross sections can be used at a smooth cross section that has a good velocity distribution, a condition initially believed to exist at the three measurement sites. Even with fewer than the ideal number of partial cross sections, the USGS' recommendation that no partial cross section contain more than 10 percent of the total flow was nearly met at two of the sites, CRCW and O'Brien Lock and Dam.

20. The measuring rig was placed along the upstream face of the bridge from which the measurements were taken. Pictures of the three bridges from which the measurements were taken are shown in Figures C-4 through C-9. A Price AA current meter, as shown in Figure C-10, was lowered to the surface and the depth gage zeroed out. The meter was then lowered to the 9/10 depth location. Simultaneously the stop watch and counter box were started. After a duration of 40 or 60 seconds, both were shut off simultaneously and the number of counts (revolutions of the bucket wheel) were recorded. Sixty second durations were used on 23, 24, and 27 July while forty second durations were used on 25 and 26 July.

21. Three different Price AA meters were used to dampen out any minor errors attributable to one particular meter. The pygmy meter shown in Figure C-11 was not used as it appeared in need of cali-

bration. On Wednesday 25 July, an attempt was made at all three sites to use the Marsh-McBirney electromagnetic meter shown in Figures C-12 and C-13. However, the meter gave erroneous readings while remaining in a stationary position. The meter was in obvious need of recalibration.

22. The rig used in conjunction with the Price AA current meter is shown in Figure C-14. The meter was suspended by a cable from the bridges previously mentioned. The meter elevation was read from the depth gage pictured in Figure C-15. The counter used was an analog type and required a separate power source as shown in Figure C-14. To zero out the depth gage shown in Figure C-15 the current meter was lowered so that the bucket wheel centerline was at the water surface as shown in Figure C-16. The cable line was flagged with fluorescent tape to make it more visible to boaters. After the depth gage was zeroed out, the meter was lowered to nine-tenths the total depth at its particular station and the first reading was taken over a 40 or 60 second duration. Subsequent readings were taken by raising the meter at increments of one-tenth the total depth.

RESULTS

23. The measured flow included both flow through open sluice gates and leakage occurring through lock gates and any closed sluice gates. The sluice gate settings at all three sites remained unchanged during the flow measurements. At the CRCW, all four sluice gates (situated at the Columbia Yacht Club located approximately 1/4 mile southwest of the lock in the same harbor) were open 1.5 feet. The four gates situated at the lock remained closed and, since their repair approximately 2 years ago, have only been used during extreme flooding for reverse flows or to aid in ice removal. At O'Brien Lock and Dam, gates 1,2, and 3 remained closed while gate #4 was open 3 feet. The single sluice gate at Wilmette Controlling Works remained open 1.0 feet. According to MWRDGC, these gate settings reflect the predominant setting during the discretionary period.

24. A direct comparison of the measured flows against the MWRDGC flows recorded in the monthly LMO-6 reports would be incorrect since the flows contained in these reports are average daily flows. Copies of the July LMO-6 reports for the three lakefront control structures are contained in Appendix D. Instead of using the average daily flows recorded in these LMO-6 reports, instantaneous MWRDGC flows were calculated over the actual period of each individual measurement. This period normally spanned over one to three hours. The instantaneous MWRDGC discretionary flows were calculated by using the rating tables provided by the MWRDGC for the three lakefront control structures. The instantaneous leakage at each site was calculated from a single equation (one for each control structure) developed by the MWRDGC. The equation contains varia-

bles for both the head across the gates and the number of lockages occurring over one day. The latter term was not part of the leakage equation for the Wilmette CW since locks do not exist at this site. The head across the gates used in the leakage equation was determined from the circular water surface elevation charts that record real-time headwater (upstream) and tailwater (downstream) elevations at the three control structures.

25. The rating tables and leakage equations used to calculate instantaneous discretionary and leakage flows are the same as those used by the MWRDGC in calculating the daily average flows recorded in the monthly LMO-6 reports. Examples of the MWRDGC rating tables, leakage equations, and circular water surface elevation charts are included in Appendix E. Appendix F contains the calculations of the instantaneous MWRDGC flows that utilize the elements of Appendix E.

26. The actual comparison of the measured flows to the instantaneous MWRDGC flows appears in Table 6 on the following page. The results in Table 6, with full consideration of the accuracy problems which are discussed later in the report, show that during the week of 23 through 27 July 1990, lakefront direct diversions were underreported by an average of 352 cfs at CRCW, 398 cfs at O'Brien Lock and Dam, and 103 cfs at Wilmette Controlling Works.

27. There exists an unstable relationship between the reported and measured flows as evidenced by the wide variance in the U.S. Army Corps of Engineers (USACE)/MWRDGC flow ratios. Instability of the coefficients could be the result of inaccuracies of the actual gate openings, rating tables, leakage equations, and flow measurements.

28. The results presented thus far concerning the possible underreporting of flows require further verification through additional measurements. Although preliminary conclusions can be drawn from one week of measurements (five measurements at each site) it is inappropriate to place significant emphasis on the results without confirmation from a larger set of data. In order to improve the confidence and accuracy of the results, future measurements will be required so as to expand the size of the data set. Expansion of the data set would include a wider range of sluice gate settings and a wider range of upstream and downstream water surface elevations (head across the gates).

TABLE 6

MWRDGC Reported Flows vs. Corps' Measured Flows

CRCW

	MWRDGC Disc.	MWRDGC Leak.	MWRDGC Sum	USACE Sum	Diff.	USACE/MWRDGC Flow Ratio
7-23	426	30	456	907	-451	1.99
7-24	457	32	489	836	-347	1.71
7-25	452	32	484	933	-449	1.93
7-26	460	32	492	573	- 81	1.16
7-27	440	31	471	902	-431	1.92
		AVERAGE=	478	830	-352	

O'Brien

	MWRDGC Disc.	MWRDGC Leak.	MWRDGC Sum	USACE Sum	Diff.	USACE/MWRDGC Flow Ratio
7-23	283	20	303	540	-237	1.78
7-24	289	20	309	718	-409	2.32
7-25	301	21	322	951	-629	2.95
7-26	300	21	321	666	-345	2.07
7-27	287	20	305	673	-368	2.21
		AVERAGE=	312	709	-398	

Wilmette

	MWRDGC Disc.	MWRDGC Leak.	MWRDGC Sum	USACE Sum	Diff.	USACE/MWRDGC Flow Ratio
7-23	110	2	112	198	-86	1.77
7-24	121	3	124	246	-122	1.98
7-25	119	3	122	226	-104	1.85
7-26	124	3	127	237	-110	1.87
7-27	123	3	125	218	-93	1.74
		AVERAGE=	122	225	-103	

RECOMMENDATIONS/DISCUSSIONS

29. Improvements to the present reporting procedures of the direct diversion flows should be investigated to minimize error in the reported flows. Therefore, options for future measurements will be discussed. Since all of the options include or recommend current meter measurements, the applicability of the two-point and three-point methods will be discussed and recommendations will be made for improving the accuracy and safety of future current meter measurements. Finally, the benefits of having in-house current measuring capabilities will be presented.

OPTIONS FOR FUTURE MEASUREMENTS

30. Future measurements and analyses are required to determine accurately the amount of the flow imbalance attributable to the underreporting of direct diversion flows. The options for accurately estimating these direct diversion flows include a regression analysis, installation of gaging stations at the three lakefront control structures, and development of revised rating curves and/or tables.

31. The first option, a regression analysis, would require several more flow measurements at the three lakefront control structures to provide a reliable data base. This larger data set is necessary for regression analyses. It is necessary that this database include flows over a wide range of gate settings and various upstream and downstream water surface elevations. After a series of measurements have been collected, regression equations can be evaluated. Due to the dynamic condition of the sluice gates, ie. physical wear and maintenance, the leakage rates and accuracy of the rating tables are expected to change over time. It is probable that the changes in the leakage rates and accuracy of the rating tables will vary in relation to maintenance of the sluice gates. However, these changes are expected to be small due to the relatively small amount of leakage that occurs as compared to the total sluice gate flow. To account for any subtle changes in the leakage rate and changes in the accuracy of the rating tables, periodic current meter measurements are required to verify the regression equations. If necessary, the regression equations would be updated to reflect these changes.

32. The second option, installation of gaging stations, requires hardware purchase and installation of an AVM at each of the three lakefront control structures. Additionally this option also necessitates ongoing data collection, maintenance, and calibration as well as the annual costs associated with each task. Calibration of the gages is accomplished by periodic current meter measurements. This option also requires the development of regression equations in order to provide a backup system in the event one of the gages malfunctions or is damaged.

33. The third option is the development of new or revised rating curves and/or tables for the sluice gates. This would encompass a thorough evaluation of existing operational and hydraulic conditions with development of equations for the purpose of calculating sluice gate flow at various gate settings and water surface elevations. Like the option of gaging stations, calibration and verification of these equations is accomplished through current meter measurements. This option requires that daily records of the gate settings and upstream and downstream stages be obtained from MWRDGC. In order to estimate flows through the lock gates, revised estimating procedures would be required.

34. Determination of the appropriate method for future analyses of the sluice gate flow at the three lakefront control structures involves consideration of the cost, accuracy, and benefits/disadvantages of each of the three options. The cost of the first option, development of regression equations, depends on the desired size of the database. One week of flow measurements (5 measurements at each site) costs approximately $6,500 when accomplished through resources from the Detroit District. With in-house equipment and staffing, the cost for one week of measurements is reduced to approximately $5,000. Provided that the number of flow measurements at each site is less than 50, and provided that the Chicago District has in-house flow measuring capabilities, the total cost for this option will probably not exceed $75,000 ($50,000 for the measurements and $25,000 for the regression analysis). If the measurements are conducted by the Detroit District the total cost would rise to approximately $90,000 ($65,000 for the measurements). The accuracy of this option is difficult to determine at this point. However, this is probably the least accurate of the three options being evaluated. The accuracy of the developed regression equations is dependent on the accuracy achieved through the flow measurements. The accuracy may be limited by inconsistencies between the operation of the sluice gates and the reported sluice gate openings as well as inconsistencies of the recorded water surface elevations that determine the reported flows. Despite these accuracy limitations, the reliability of the regression equations can be improved by increasing the size of the database. While this option may yield the least accurate results, expanding the database allows greater estimating accuracy of the sluice gate and leakage flows than is currently possible through the MWRDGC reported flows. The disadvantage of this method is that traffic on the waterways is disrupted during the current meter measurements. Additionally, every measurement requires the cooperation of MWRDGC and the Coast Guard. Frequent measurements will require a significant amount of cooperation from these agencies.

35. Installation and hardware costs of the second option, gaging stations (AVM's) at each control structure, are estimated at approximately $250,000. Additional costs of this option include approximately $105,000 per year for data collection, maintenance,

and calibration. This option yields the most accurate results of the three options. The primary advantage of this option over the others is that the measured flows include all the components of direct diversion: discretionary and navigation makeup flows through the sluice gates, leakage through the lock gates and sluice gates, lockage flows, and flow reversals. The accounting of all the direct diversion components in one measurement results in more available time to investigate other potential source(s) of the flow imbalance.

36. The estimated cost for the third option, development of new or revised rating curves and/or tables, is approximately $100,000. The accuracy of this approach falls somewhere between the other two options. The estimated error for this option is expected to be under 10 percent. The disadvantage of this option is that leakage through the sluice gates is not accounted for.

37. The least costly option is a regression analysis. The total cost for 50 measurements at each site along with the development of regression equations is approximately $75,000 with in-house capabilities or $90,000 if conducted by the Detroit District. While this method is the least costly, it is probably also the least accurate. The most accurate option is the installation of gaging stations at each of the three control structures. This option is also the most comprehensive in that it accounts for all the direct diversion components. However, the installation cost of approximately $250,000 coupled with the annual cost of approximately $105,000 for data collection, maintenance, and calibration may make this option infeasible. The option of developing new or revised sluice gate rating curves and/or tables for the three control structures falls somewhere between the other two options in terms of cost and accuracy. The cost to develop new rating tables is approximately $100,000 while the estimated error is expected to be under 10 percent.

APPLICABILITY OF TWO-POINT AND THREE-POINT METHODS FOR FUTURE CURRENT METER MEASUREMENTS

38. Due to the fact that all three options for future analyses of the direct diversion flows include current meter measurements, consideration was given to shortening the amount of time necessary to conduct each measurement. Consequently, the applicability of the two-point and three-point methods for flow measurements was determined. The two-point, three-point, and vertical-velocity methods are outlined in Section 1.B.2.c.1.b.3, 4, and 5 of the USGS "National Handbook of Recommended Methods for Water-Data Acquisition." The accuracy of the vertical-velocity method is greater than any other current meter method according to the USGS. The accuracy of this method is realized by integrating the 10-point vertical velocity curve in calculating the mean velocity for each partial section. However, the price paid to achieve this accuracy is the time required in the field to measure 10 points along each

partial section. The two-point and three-point methods differ from the vertical-velocity method in that only two or three points, instead of ten, are measured along each vertical (partial cross section). The two-point method averages the velocities at the 0.2 and 0.8 depths and uses this average as the mean velocity in the vertical. At sections with normally distributed velocities in the vertical, this method has been shown to give more consistent and accurate results than any of the other methods except the vertical-velocity curve method. The three-point method calculates a mean velocity by averaging the 0.2 and 0.8 depth observations and then averaging the result with the 0.6 depth measurement. This method is used when the velocities in the vertical are abnormally distributed. After review of the field measurements it was apparent that abnormal velocity distribution exists at CRCW and O'Brien Lock and Dam.

39. In order to assess the applicability of the two-point and three-point methods, flows were developed for each method by using the measurements of the vertical-velocity method that was applied in the field. Coefficients relating these methods to the vertical-velocity method were calculated to determine if the two or three-point method could be used to estimate accurately the results of the vertical velocity method. If the coefficients of one of the methods proved to be stable, consideration would be given toward applying that method in the field. Application of the two-point or three-point method in the field would result in fewer measurements along each partial section so that an increased number of partial cross sections could be measured. Therefore, it would be possible to meet the USGS recommendations that at least 25 partial cross sections be measured and that no more than 10 percent of the total flow be contained in any one partial section. Application of the vertical-velocity method, although the most consistent and accurate of the methods, makes meeting these recommendations impractical due to the extreme amount of time necessary to obtain the measurements. For example, the measurement of 25 partial sections requires approximately 6 hours to complete one flow measurement at either CRCW or O'Brien Lock and Dam.

40. The coefficients developed for the two-point and three-point methods are presented in Table 7. The complete development of the coefficients is presented in Appendix G. The coefficients for both methods prove to be unstable. Therefore, neither method should be used to estimate the flow near the three control structures. The suitability of the two-point or three point methods could not be determined at the Wilmette Controlling Works since at some shallow partial sections it was not possible to obtain measurements at the 6/10 and 8/10 depth observation. The reason for this was the one foot distance from the sounding weight bottom to the centerline of the Price AA meter's bucket wheel exceeded the distance from the channel bottom to the depth of the desired measurement. Because of this limitation the Price AA and Pygmy-type current meters are unable to obtain measurements at the 8/10 depth location at partial sections less than 5 feet deep.

TABLE 7

TWO-POINT AND THREE-POINT METHOD COEFFICIENTS FOR CRCW AND O'BRIEN LOCK AND DAM

CHICAGO RIVER CONTROLLING WORKS

DATE	VERTICAL VELOCITY METHOD (CFS)	2-POINT METHOD (CFS)	COEFFICIENT
23 July 1990	907	744	1.22
24 July 1990	836	832	1.00
25 July 1990	933	1020	.91
26 July 1990	573	583	.98
27 July 1990	902	944	.96

DATE	VERTICAL VELOCITY METHOD (CFS)	3-POINT METHOD (CFS)	COEFFICIENT
23 July 1990	907	947	.96
24 July 1990	836	854	.98
25 July 1990	933	991	.94
26 July 1990	573	489	1.17
27 July 1990	902	876	1.03

O'BRIEN LOCK AND DAM

DATE	VERTICAL VELOCITY METHOD (CFS)	2-POINT METHOD (CFS)	COEFFICIENT
23 July 1990	540	489	1.10
24 July 1990	718	710	1.01
25 July 1990	951	558	1.71
26 July 1990	666	560	1.19
27 July 1990	673	635	1.06

DATE	VERTICAL VELOCITY METHOD (CFS)	3-POINT METHOD (CFS)	COEFFICIENT
23 July 1990	540	590	.92
24 July 1990	718	746	.96
25 July 1990	951	791	1.20
26 July 1990	666	583	1.14
27 July 1990	673	622	1.08

PROBABILITY OF HIGH BIASED MEASUREMENTS

41. Through field observations of the current meter measurements it is apparent that several reasons exist for the measured flows to exhibit a high bias. An attempt should be made to eliminate the possibility of upward biased flows for any future current meter measurements. A list of the reasons for the measured flows to exhibit a high bias follows: inadvertent counts caused by turning on the power, upward rounding of counts upon switching off the power, the presence of lateral flow components, the presence of vertical flow components, wind induced reverse flows, and meter sway at the 9/10 depth observation.

42. Electrical surges caused by switching on the power to the counter box inadvertently caused the counter to count 1/2 revolution of the bucket wheel. This occurred during approximately half of the point measurements. Additionally, shutting off the power caused the counter to round up to the next highest whole number upon shut-off. This occurred at times when the counter was at half step intervals between whole numbers. The initial 1/2 count caused by turning on the power and the problem of rounding up 1/2 count upon shutting off the power are significant when measuring small velocities. Because the three measured sites exhibited low flow velocities, the surge induced 1/2 count and the rounding up of 1/2 count are the two primary reasons for the probable existence of high biased flow measurements at the three measured sites.

43. Additionally, the presence of lateral horizontal flow components, vertical flow components, and wind induced flow reversals would also lead to suspicions concerning the possibility of upward biased flow measurements. Because of the inability of the Price AA current meter to measure flow direction, most of the measured flows were assumed as flowing in the direction of the channel. This direction was normal to the cross section since the cross section was perpendicular to the channel. It was possible to determine the direction of some surface flows by observing the meter. However, due to poor water visibility, visual determination of the flow direction was only possible down to the 1/10 depth location. Consequently, horizontally skewed flows (lateral horizontal flows) and wind induced reverse flows could be accurately identified only at the 1/10 depth location while the identification of vertical flow components was not possible at any depth.

44. It is possible that horizontally skewed and/or vertical flow components exist at some locations. The possibilities of these types of flows existing at the measurement sites are greatest near the banks and behind mooring piers at both CRCW and O'Brien Lock and Dam. There exists one pier at Columbus Drive along the north bank of the Chicago River and there also exists one pier at 130th Street along the east bank of the Calumet River. Due to the inability of the Price AA current meter to determine these flow components, any horizontally skewed flows or vertical flows were unfor-

tunately measured along with, and added to, the flow component normal to the plane of the partial cross sections.

45. While the presence of horizontally skewed or vertical flows are unconfirmed, the existence of wind induced reverse flows at the 1/10 depth location were confirmed at O'Brien Lock and Dam on three of the five days. Because the winds were strong and the flow velocity was very low, the depth to which the wind affected the flow is in question. It appeared that in several cases flow reversals occurred down to the 2/10 depth observation and possibly down to the 3/10 depth observation. Because of limited visibility, the only way to identify reverse flows at these depths was by quickly raising the meter from the lower depths up to the surface so that the tailpiece of the meter could be sighted as an indicator of flow direction. Since the Price AA meter cannot decipher flow direction; any lateral flows, vertical flows, or flow reversals were recorded as occurring normal to the plane of the cross section except in those locations where a visual identification of flow direction was possible.

46. Another reason for the possible existence of high biased measured flows is meter sway at the 9/10 depth location. This sway was caused by the quick submergence of the meter down to the 9/10 depth location, the first measurement point along each partial cross section. The speed at which the meter was lowered would sometimes cause drift in the line resulting in the meter swaying back and forth. Eventually it would come to rest. If the meter was not allowed sufficient time to stabilize, that first measurement point (9/10 depth) could tend to be on the high side.

47. Upstream and downstream sway is not critical provided that the sway is parallel to the direction of flow and provided that the sway velocity does not exceed the velocity of the water. If the sway velocity is less than the stream velocity and the sway direction is parallel to the flow direction, the lesser flows measured on the downstream swing are offset by the increased flows measured on the upstream swing. However, if the velocity of the river is low or if the sway contains lateral components, the problem of sway is much more critical. If the sway velocity exceeds the stream velocity, the relative reverse (negative) flow on the downstream swing is measured as positive and does not offset the increase in flow measured on the upstream sway. Instead, the downstream measured flow is added to the increased flows measured on the upstream swing. Any lateral component of sway, sway in a direction other than parallel to the flow direction, also contributes a high bias to the measurement. Therefore, high biased flow measurements occur if the sway velocity exceeds the stream velocity and/or if the sway is in a direction other than parallel to the direction of flow. Since the point velocities at the measurement sites on the Chicago and Calumet rivers sometimes fell below 0.10 fps, sway is a significant concern. Consequently, care must be taken in the field to limit or remove sway entirely during the measurements.

IMPROVING THE ACCURACY OF FUTURE CURRENT METER MEASUREMENTS

48. Due to the probability that the measured flows contained in this report may exhibit a high bias, recommendations will be made for improving future current meter measurements so as to minimize or eliminate the likelihood of upward bias. As previously presented, problems associated with the counter included erroneous initial counts of one-half revolution of the bucket wheel upon switching the power on and rounding up one-half count upon power shut-off. Therefore, it is recommended that a digital indicator is used in place of the analog counter box containing a spool-type counter. A digital indicator eliminates the possibility of erroneous counts due to electrical surges and rounding upon power shut-off. It also eliminates the need for stopwatches and cumbersome battery packs. Several digital indicators are capable of direct display of flow velocity and almost all digital indicators are compatible with either Price AA or Pygmy-type current meters.

49. Because of the possible existence of lateral horizontal flow components, vertical flow components, and wind induced flow reversals it is recommended that an electromagnetic-type current meter, such as a Marsh-McBirney electromagnetic current meter, be used for future measurements at CRCW and O'Brien Lock and Dam. Marsh-McBirney electromagnetic current meters are capable of accurately measuring both the X and Y directional vectors in a horizontal plane. This allows the calculation of both the direction and magnitude of the true horizontal water velocities. Additionally, the Marsh-McBirney electromagnetic current meters are equipped with a spherical sensor that detects vertical motion, thus eliminating the possibility of vertical velocity components being translated into the horizontal components - a problem that exists with the current Price AA and Pygmy-type current meters.

50. Another reason for recommending the use of an electromagnetic current meter at the three measurement sites is that they have a much lower minimum threshold value (0.02 fps). In comparison, the Price AA current meter has a minimum threshold value of 0.10 fps which equals the lowest mean velocity for a partial section measured during the period 23 through 27 July 1990. Some point velocities measured along the partial sections at both CRCW and O'Brien Lock and Dam were below the Price AA minimum threshold value of 0.10 fps. Consequently, the use of a Price AA meter is questionable at these sites. Pygmy-type current meters accurately measure velocities as low as 0.05 fps. However, this is only slightly more appropriate than the Price AA meter at these sites. The most appropriate meter for use at these sites is an electromagnetic current meter because of its capability to measure accurately flows down to 0.02 fps. This type of meter may even be capable of separately measuring the extremely small leakage flows occurring at the three lakefront control structures when all sluice gates are closed.

51. One final advantage of using an electromagnetic current meter is its ability to obtain measurements at the lower measurement points in shallow sections. This capability is necessary at the Wilmette Controlling Works where some partial sections near the banks contain shallow depths (see Appendix B). The electromagnetic current meter contains a sensor that is usually mounted approximately 8 inches above the bottom of the mounting rod (see Figure 12 of Appendix C). Consequently, the electromagnetic current meter is able to obtain measurements at the 9/10 depth location at partial sections with depths down to 6.7 feet and at the 8/10 depth location at partial sections with depths down to 3.3 feet. Because some electromagnetic current meters have sensors that are mounted closer to the bottom of the mounting rod, the meters are able to obtain measurements at the 8/10 and 9/10 depth locations at even shallower partial sections. On the other hand, the Price AA and Pygmy current meters are constructed such that the distance from the bottom of the sounding weight to the centerline of the bucket wheel is approximately one foot. Consequently, the Price AA or Pygmy current meters are unable to obtain measurements at the 9/10 depth location at partial sections less than 10 feet deep or at the 8/10 depth location at partial sections less than 5 feet deep. Because of this limitation a determination could not be made as to the suitability of the two-point or three-point method at the Wilmette Controlling Works (see Table 7 on page 19).

52. Although an attempt was made to use a Marsh-McBirney Model 527 electromagnetic current meter on 25 July 1990, problems encountered in the field made it difficult to evaluate its performance. The first attempt to use the meter was at CRCW. Unfortunately, the meter readings fluctuated over a wide range of values while the meter remained stationary. This either occurred because of electrical interference from the high concentration of utilities at this downtown location or because the meter was in need of repairs or recalibration. Although the attempt to use an electromagnetic current meter was unsuccessful, it is recommended that the application of this type of current meter be further investigated at all three sites because of its low minimum threshold value and because of its ability to measure horizontal flow direction without adding the effects of vertical velocity.

53. Because the velocities on the Chicago and Calumet rivers are quite low, care must be taken to minimize any sway of the meter that would result in upward biased measurements. This is accomplished by lowering the meter at a slow rate and also by allowing sufficient time to pass so that the meter may come to rest in a stationary position prior to taking each point measurement.

54. In order to improve quality control, it is also suggested that the upstream and downstream water surface elevations reported by the MWRDGC for all three lakefront structures be verified in the field. On 26 and 27 July 1990 a discrepancy of 0.15 to 0.20 feet

was found between the stages recorded by the MWRDGC and the stages observed by the lockmaster at O'Brien Lock and Dam. Although both the upstream and downstream stages were usually found to differ by equal amounts, the difference between the stages could have an effect on the accuracy of the discharges determined from sluice gate rating curves and/or tables.

IMPROVING THE SAFETY OF FUTURE CURRENT METER MEASUREMENTS

55. In addition to the previous recommendations for improving the accuracy of the flow measurements by reducing the probability of high bias, a few suggestions will be made for improving the overall safety of future measurements. It is suggested that the field crew be equipped with a marine radio transmitter. This is necessary to issue an immediate warning concerning the flow measurements to any boaters who appear unaware of the measurement activities. Although various steps were taken to inform boaters (warnings issued by the Coast Guard on marine radio, navigation notices mailed to appropriate parties, and highly visible fluorescent tape attached to the cable suspended from the bridges) it appeared that some vessels approached the area of measurement without any caution. In one instance, a barge almost struck the meter while an attempt was made to raise it to safety. In another instance, a speeding recreational boater came very close to running into the suspended cable. Equipping the field crew with a marine radio transmitter allows immediate action to be taken to lessen the chance of accidents occurring in the field.

BENEFITS OF IN-HOUSE FLOW MEASURING EQUIPMENT

56. As previously discussed, the cost savings per week of measurements is approximately $1,500. This is the difference between having the Detroit District conduct the measurements versus having in-house measurement capabilities. The savings become even greater when comparing the in-house measurements against other outside assistance (ie. USGS). The savings increase as the number of measurements increase. Additionally, greater savings are realized in the event of inclement weather. If outside resources are used for the measurements, the Chicago District must pay for the outside labor that remains idle and unproductive during inclement weather. With in-house capabilities, the Chicago District employees are able to stay productive by remaining at or returning to the office during inclement weather.

57. One final benefit of having in-house flow measuring equipment is its availability for use in other areas or other projects. The equipment is not restricted for use at the lakefront control structures, but also may be used for various open channel and closed conduit applications.

CONCLUSIONS

58. The flow measurements showed, with full consideration of the accuracy problems detailed below, that the discretionary sluice gate flow and the leakage flows could be underreported by an average of 352 cfs at CRCW, 398 cfs at O'Brien Lock and Dam, and 103 cfs at Wilmette Controlling Works during the period 23 through 27 July 1990.

59. It should be emphasized that the underreporting of lakefront flows will require further verification. Sound quantitative conclusions cannot be drawn at this point due to:

a. the limited number of flow measurements,

b. and the tendency for the measured flows to exhibit a high bias, demonstrating that flow measurement procedures must be improved to develop a reliable flow measurement database.

60. Additional verification of these results requires that more flow measurements be taken to expand the size of the database to include flows over a wide range of sluice gate settings and upstream and downstream water surface elevations. It is recommended that improvements be made to the flow measurement procedure prior to expanding the database to improve the accuracy and safety of future measurements.

61. Based on the flow measurements, it is probable that there exists some underreported flows at the three lakefront control structures. It is conceivable that the underreporting of lakefront flows is a source of the canal system flow imbalance determined in Budget 13. The results of the initial flow measurements discussed in this report emphasize the need for further analysis of the specific sources and magnitudes of underreported direct diversion flows.

APPENDIX A

NAVIGATION NOTICES FOR CURRENT METER MEASUREMENTS

FIGURE A-1

Navigation Notice

US Army Corps of Engineers
Chicago District

111 N. Canal St.
Chicago, Il 60606

River:
CHICAGO RIVER
CALUMET RIVER

Date:
22 MAY 1990

Location:
MILE 0.0, CHICAGO RIVER
MILE 315, CALUMET RIVER, CHICAGO, IL
(130TH ST. BRIDGE)

Effective Period
SEE BELOW

In Reply Refer to:
CENCC-CO-O

RESTRICTION DUE TO FLOW MEASUREMENT
CHICAGO RIVER, Mile 0.0
CALUMET RIVER, Mile 315

(Reference NOAA Chart #14926)

1. The U.S. Army Corps of Engineers will be performing current meter measurements at the following sites during the period 23 through 27 July 1990.

a. Chicago River from Columbus Drive bridge. (Appx. 1/2 mile downstream (west) of Chicago Harbor Lock)

b. Calumet River from 130th Street bridge. (Appx. 1/3 mile upstream (north) of O'Brien Lock and Dam)

2. Mariners will not be allowed to pass through the locks during the times of measurement which will be announced via marine radio approximately two hours prior to the actual measurements.

3. Mariners are requested to proceed with caution in the vicinity of the aforementioned bridges during the times of measurement.

4. All inquiries pertaining to this restriction should be directed to the U.S. Army Corps of Engineers, Chicago District at (312) 353-6472.

90-03

JAMES E. EVANS, P.E.
Chief, Construction-Operations Division

FIGURE A-2

Navigation Notice

US Army Corps of Engineers
Chicago District

111 N. Canal St.
Chicago, Il 60606

River:
CHICAGO RIVER
CALUMET RIVER

Date:
26 JUNE 1990

Location:
MILE 0.0, CHICAGO RIVER
MILE 315, CALUMET RIVER, CHICAGO, IL
(130TH ST. BRIDGE)

Effective Period
SEE BELOW

In Reply Refer to:
CENCC-CO-O

AMENDENMENT TO NOTICE NO. 90-03

RESTRICTION DUE TO FLOW MEASUREMENT
CHICAGO RIVER, Mile 0.0
CALUMET RIVER, Mile 315

(Reference NOAA Chart #14926)

1. The U.S. Army Corps of Engineers will be performing current meter measurements at the following sites during the period 23 through 27 July 1990.

a. Chicago River from Columbus Drive bridge. **During the period of 0600 through 0900 hours.** (Appx. 1/2 mile downstream (west) of Chicago Harbor Lock)

b. Calumet River from 130th Street bridge. **During the period of 1000 through 1400 hours.** (Appx. 1/3 mile upstream (north) of O'Brien Lock and Dam)

2. Mariners will not be allowed to pass through the locks during the times of measurement which will be announced via marine radio approximately two hours prior to the actual measurements.

3. Mariners are requested to proceed with caution in the vicinity of the aforementioned bridges during the times of measurement.

4. All inquiries pertaining to this restriction should be directed to the U.S. Army Corps of Engineers, Chicago District at (312) 353-6472.

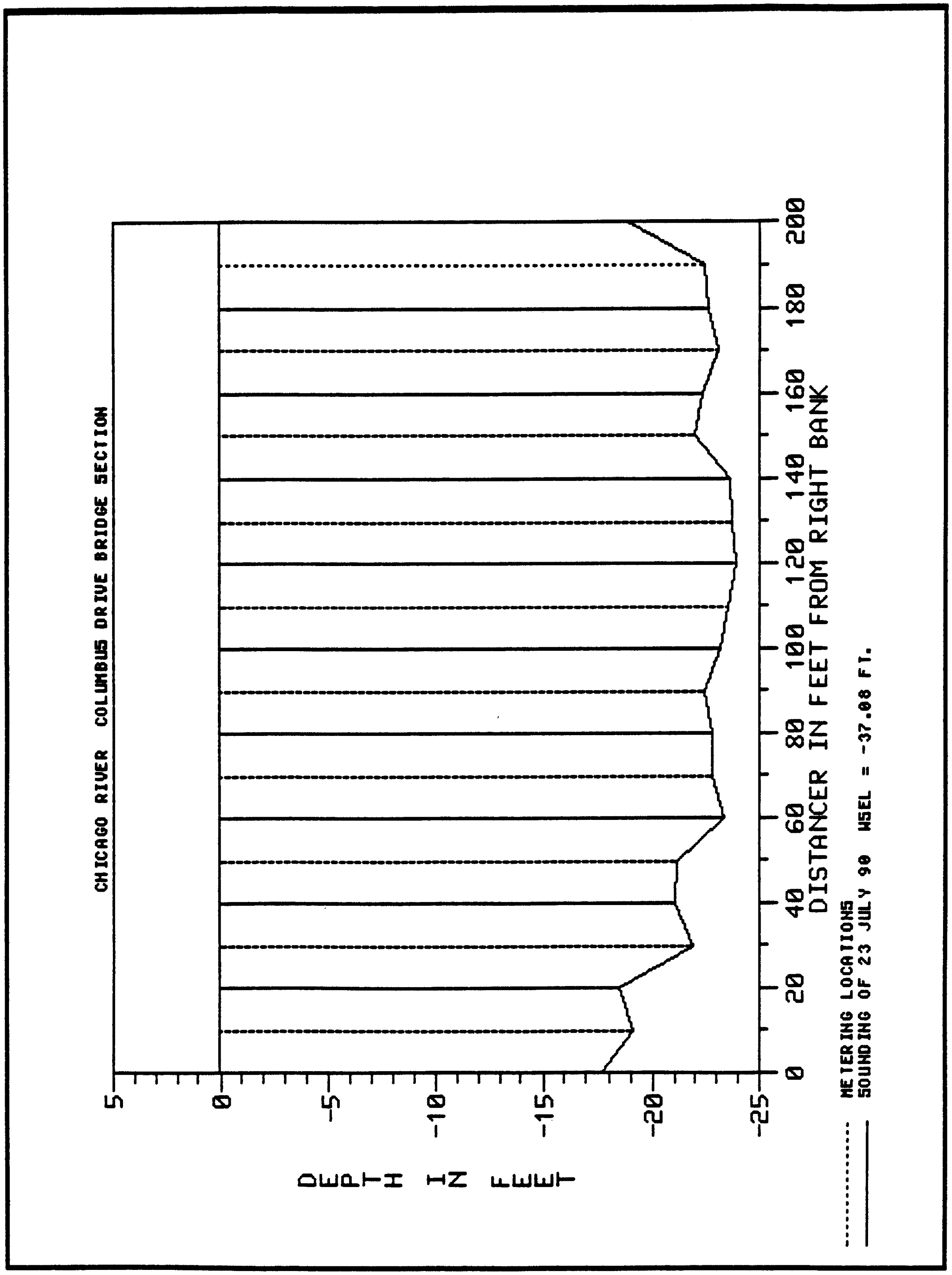
Donald Wadleigh
Chief, Operations Branch

90-04

APPENDIX B

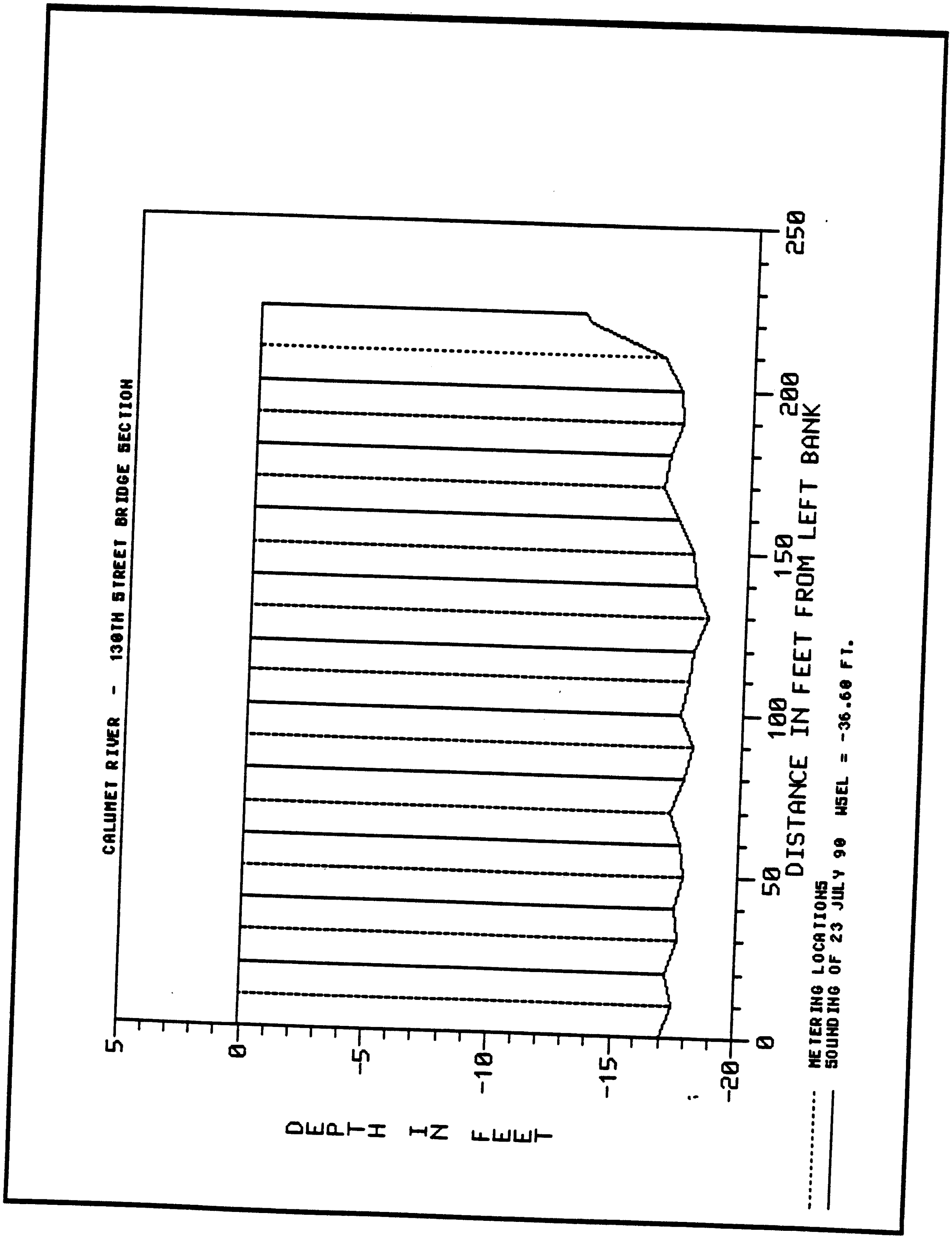
FLOW MEASUREMENT CROSS SECTIONS

FIGURE B-1



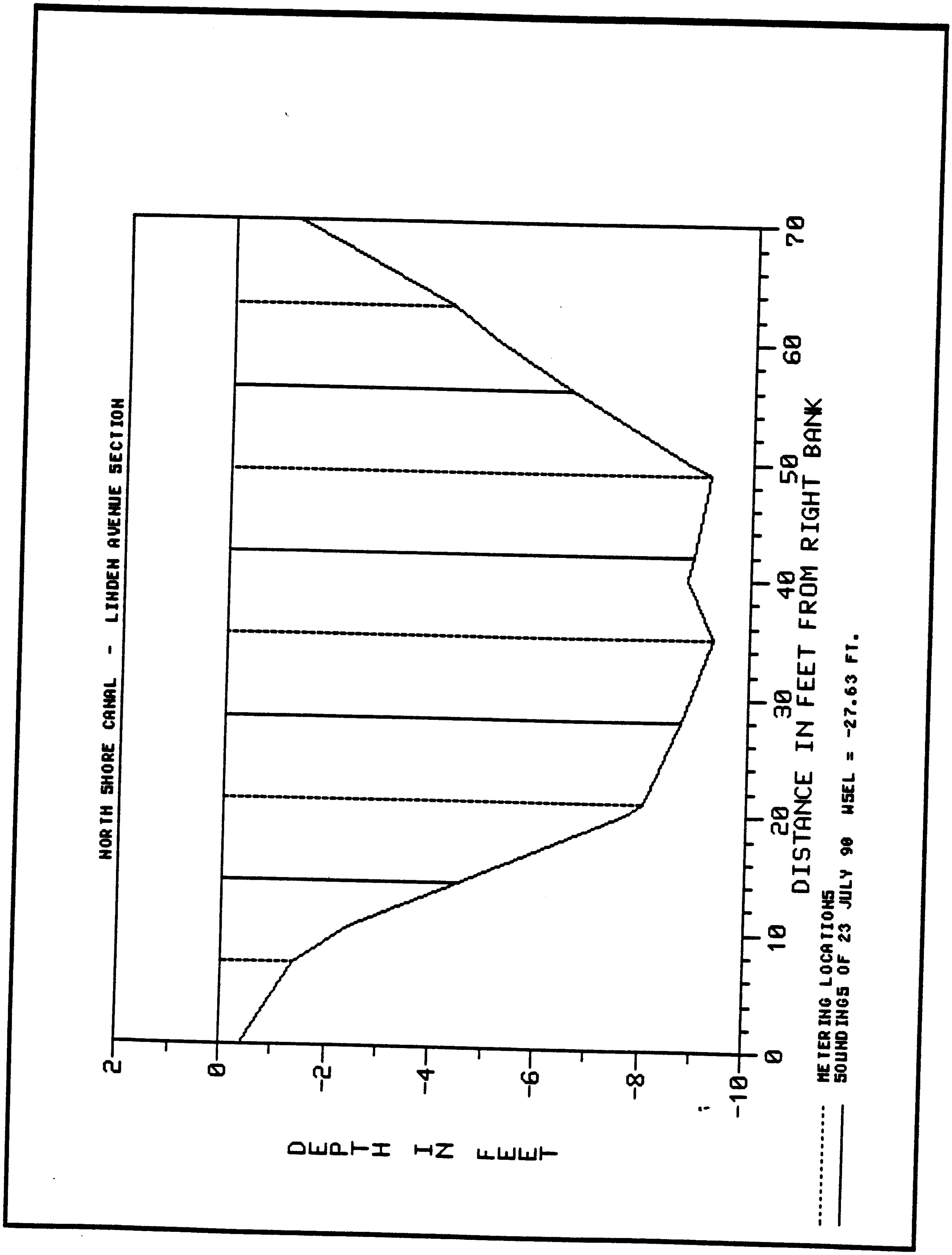
CHICAGO RIVER COLUMBUS DRIVE BRIDGE SECTION
5
0
-5
-10
-15
-20
-25
DEPTH IN FEET
0
20
40
60
80
100
120
140
160
180
200
DISTANCER IN FEET FROM RIGHT BANK
METERING LOCATIONS
SOUNDING OF 23 JULY 90 WSEL = -37.08 FT.

FIGURE B-2



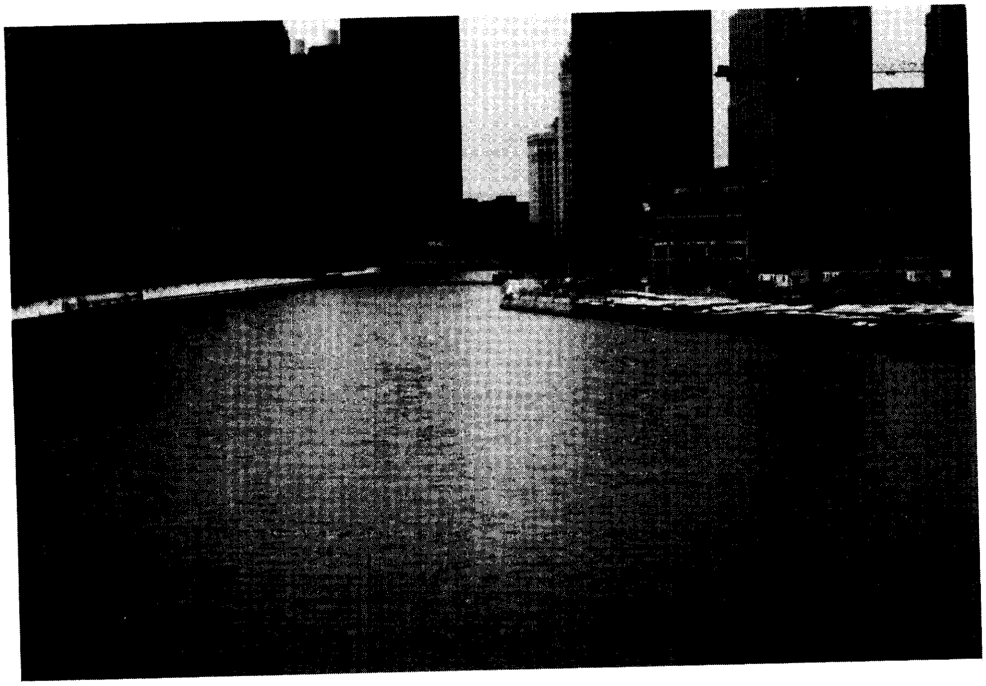
CALUMET RIVER - 130TH STREET BRIDGE SECTION
DEPTH IN FEET
5
0
-5
-10
-15
-20
0
50
100
150
200
250
DISTANCE IN FEET FROM LEFT BANK
METERING LOCATIONS
SOUNDING OF 23 JULY 90 WSEL = -36.60 FT.

FIGURE B-3


NORTH SHORE CANAL - LINDEN AVENUE SECTION
DEPTH IN FEET
2
0
-2
-4
-6
-8
-10
DISTANCE IN FEET FROM RIGHT BANK
0
10
20
30
40
50
60
70
METERING LOCATIONS
SOUNDINGS OF 23 JULY 90 WSEL = -27.63 FT.

APPENDIX C

PHOTOGRAPHS OF MEASUREMENT SITES AND EQUIPMENT

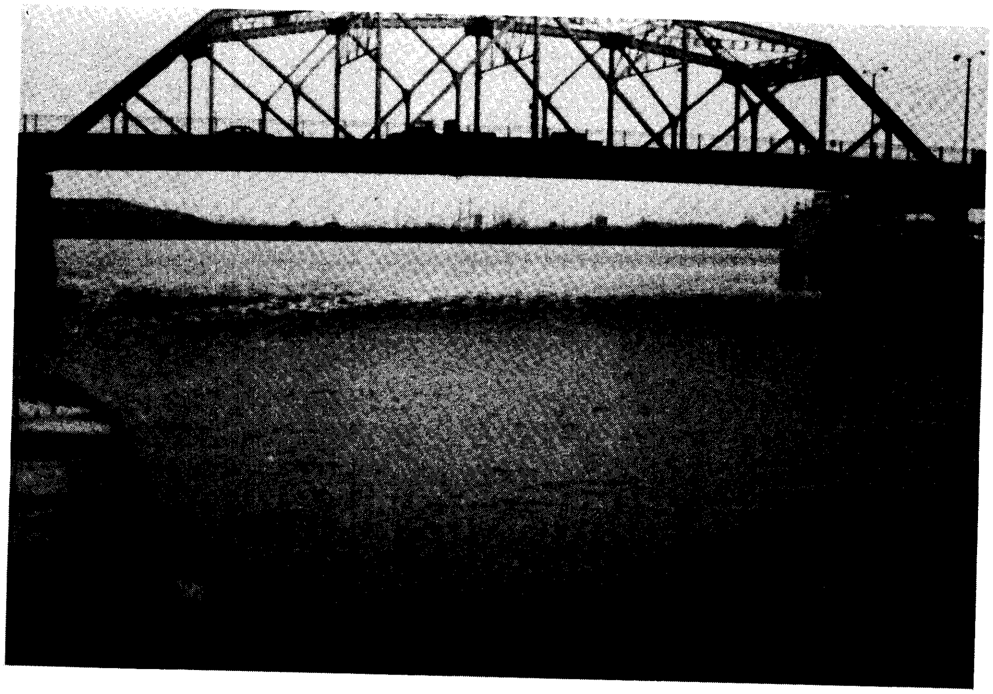


Date: 3-7-90 **Location:** Columbus Drive/Chicago River
Description: Upstream (east) face of bridge.
Downstream of Chicago River Controlling Works.

FIGURE C-1

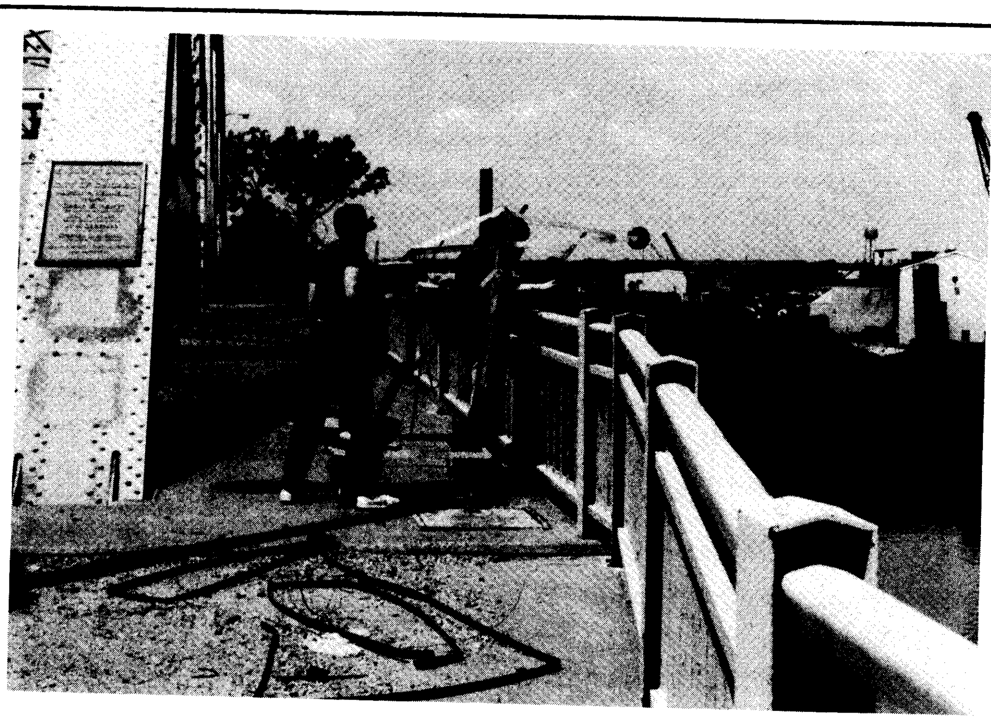
Date: 7-23-90 **Location:** Columbus Drive Bridge
Description: Current meter measurements on upstream side.

FIGURE C-2



Date: 3-7-90 **Location:** 130th Street/Calumet River
Description: Downstream(south) face of bridge.
Upstream of O'Brien Lock.

FIGURE C-3

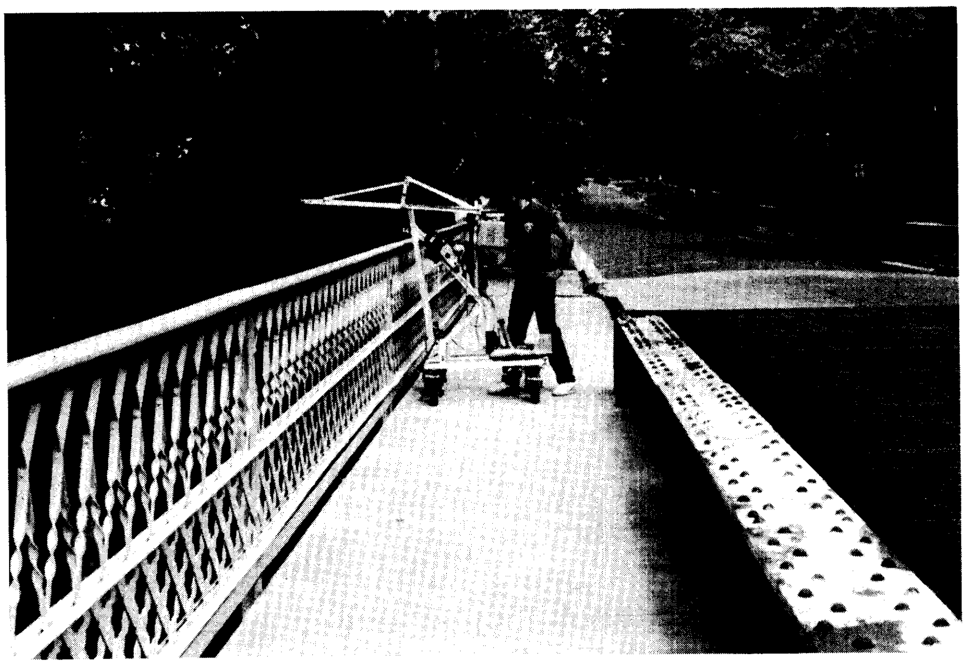


Date: 7-23-90 **Location:** 130th Street Bridge
Description: Current meter measurements on upstream side.

FIGURE C-4

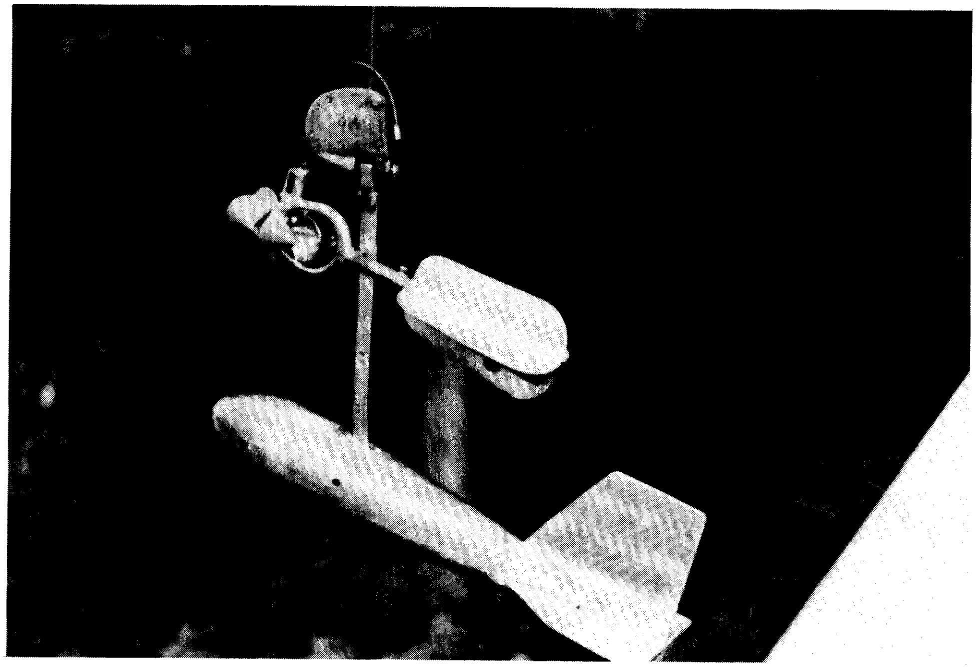
Date: 3-7-90 **Location:** Linden Ave./North Shore Channel
Description: Upstream (north) face of bridge.
Downstream of Wilmette Pumping Station.

FIGURE C-5



Date: 7-23-90 **Location:** Linden Avenue Bridge
Description: Current meter measurements on upstream side.

FIGURE C-6

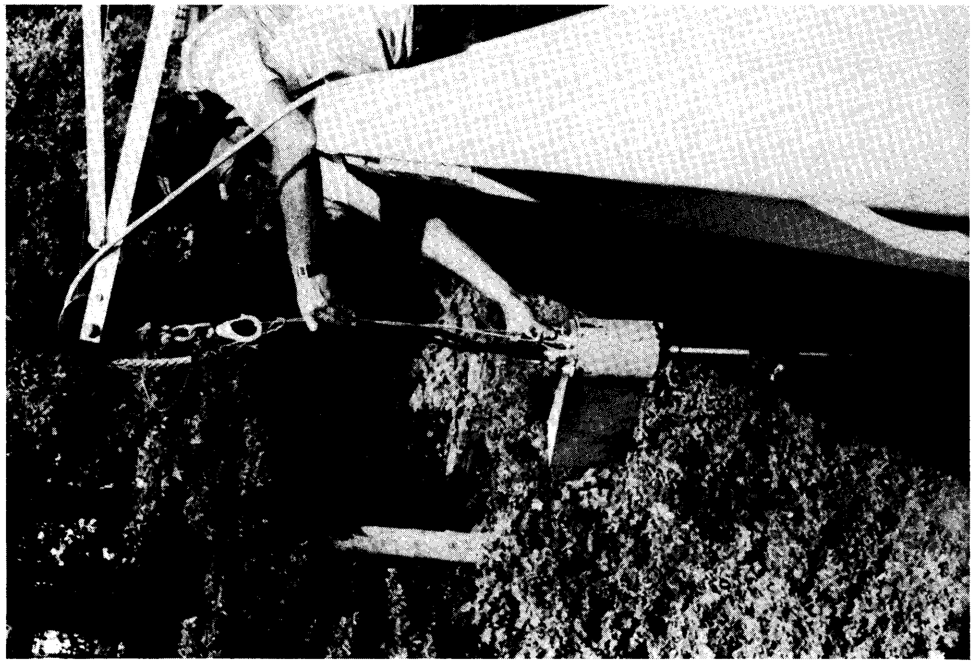


Date: 7-26-90 **Location:** ______________
Description: Price AA current meter with lead weight.

FIGURE C-7

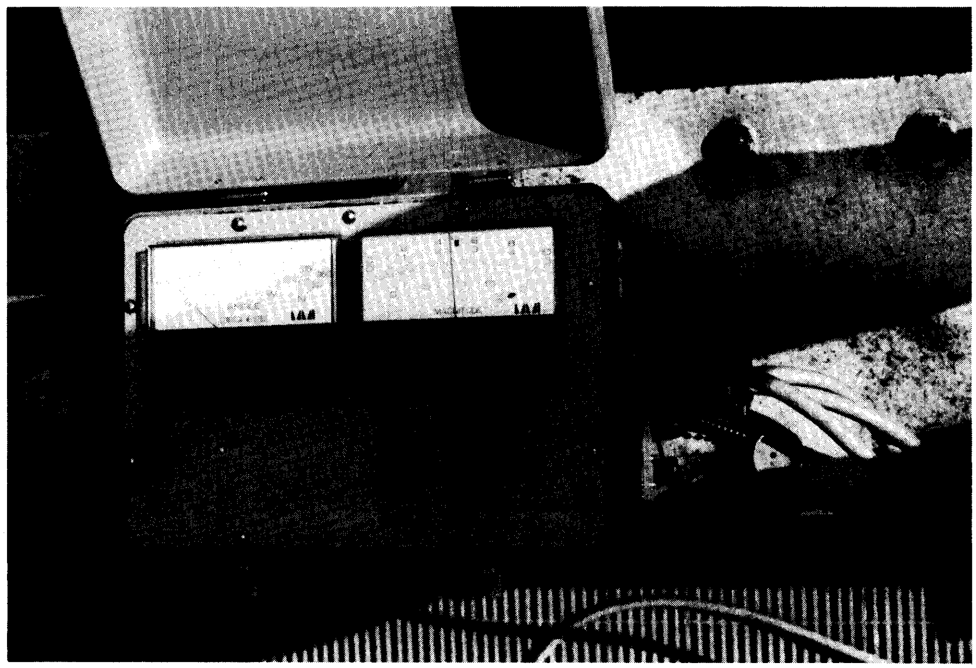
Date: 7-26-90 **Location:** ______________
Description: Pygmy current meter with lead weight.

FIGURE C-8



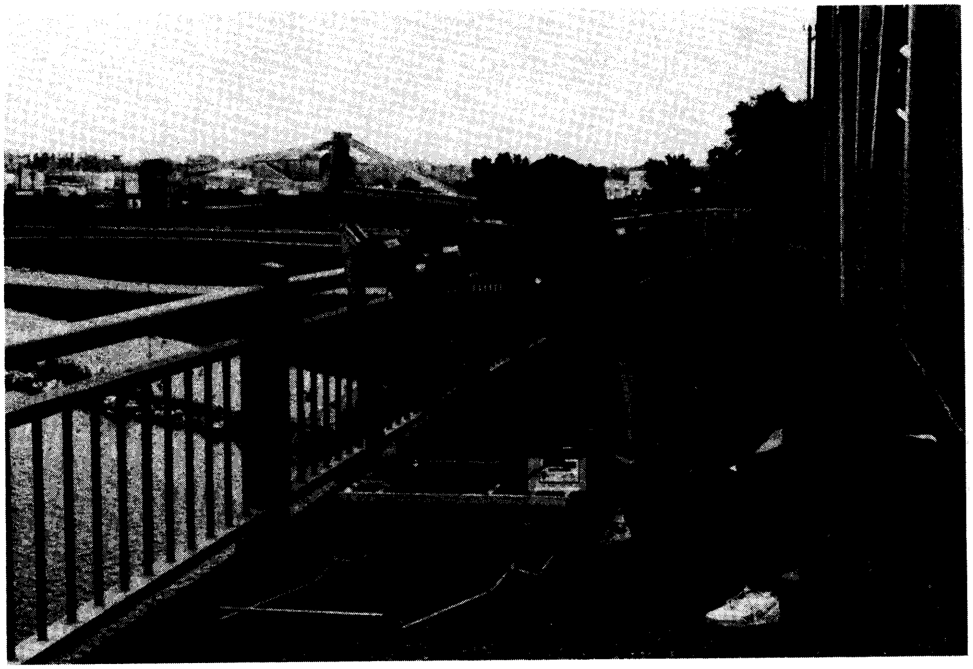
Date: 7-25-90 **Location:** ____________________
Description: Marsh - McBirney Electromagnetic Current Meter.

FIGURE C-9



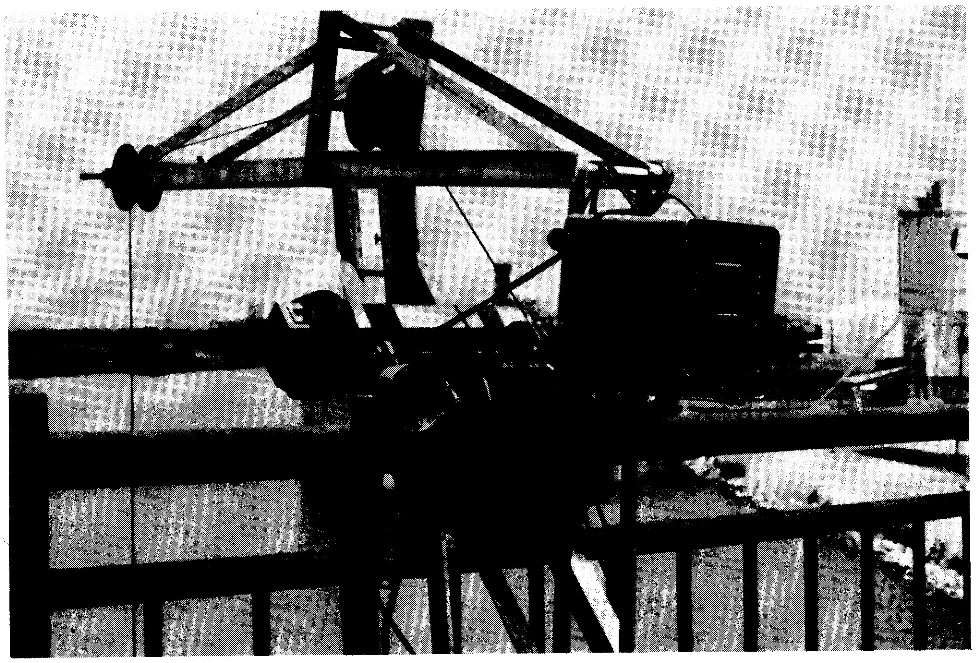
Date: 7-25-90 **Location:** ____________________
Description: Marsh - McBirney analog processor

FIGURE C-10



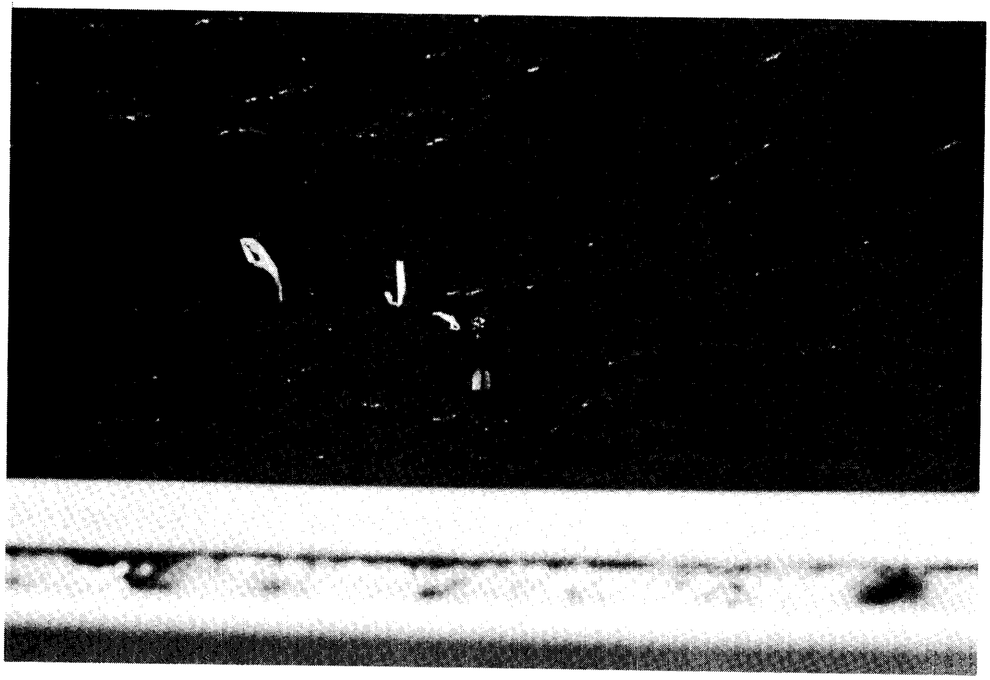
Date: 7-23-90 **Location:** 130th Street/Calumet River
Description:
Type A Four-Wheel Truck with
Type A Crane.

FIGURE C-11



Date: 7-23-90 **Location:** 130th Street/Calumet River
Description: Current meter rig showing counter box, Cable spool, and depth gage. Spool crank hidden behind counter box.

FIGURE C-12



Date: 7-26-90 **Location:** Columbus Drive/Chicago River
Description: Price AA current meter with flagged cable. Positioned for zeroing out depth gage - bucket wheel centerline at water surface.

FIGURE C-13

APPENDIX D

JULY 1990 LMO-6 REPORTS

FOR

CHICAGO RIVER CONTROLLING WORKS
O'BRIEN LOCK AND DAM
WILMETTE CONTROLLING WORKS

FIGURE D-1

FORM LMO-6

DIRECT DIVERSION

CHICAGO RIVER CONTROLLING WORKS

JULY 1990

DATE	Navigational Make-up	Lockages Number	Lockages Amount	Leakage	Discretionary	Total
	DIRECT DIVERSION (cfs)					
1	0	55	81	7	440	528
2	0	47	74	11	453	538
3	0	48	68	10	174	252
4	0	60	77	5	410	492
5	0	50	77	9	322	408
6	0	47	74	11	454	539
7	0	58	91	6	453	550
8	0	49	68	9	426	503
9	0	52	75	8	436	519
10	0	50	84	10	315	409
11	0	44	73	12	194	279
12	0	44	80	13	488	581
13	0	44	81	13	490	584
14	0	55	96	8	478	582
15	0	40	64	14	457	535
16	0	48	73	10	293	376
17	0	48	70	10	382	462
18	0	48	68	10	304	382
19	0	52	76	8	243	327
20	67	43	41	9	0	117
21	163	57	92	7	57	319
22	239	51	82	9	298	628
23	0	40	58	13	435	506
24	0	48	74	10	450	534
25	0	45	69	12	447	528
26	0	51	80	9	452	541
27	0	52	78	8	444	530
28	0	53	82	8	451	541
29	0	54	83	8	114	205
30	0	37	60	16	389	465
31	0	44	67	12	447	526
MONTHLY TOTAL	469	1514	2316	305	11196	14286
AVG	15.1		74.7	9.8	361.2	460.8

FIGURE D-2

FORM LMO-6

DIRECT DIVERSION

O BRIEN LOCK AND DAM

JULY 1990

DATE	DIRECT DIVERSION (cfs)					
	Navigational Make-up	Lockages Number	Lockages Amount	Leakage	Discretionary	Total
1	0	28	99	8	377	484
2	0	25	90	9	341	440
3	0	28	90	8	280	378
4	0	32	97	6	271	374
5	171	18	65	12	178	426
6	0	25	92	9	299	400
7	0	29	106	8	298	412
8	0	27	84	8	275	367
9	0	26	87	9	286	382
10	0	20	73	12	221	306
11	0	17	59	13	122	194
12	0	10	41	17	318	376
13	0	12	51	16	322	389
14	0	22	86	11	308	405
15	0	25	95	10	303	408
16	260	7	23	17	210	510
17	163	4	13	18	189	383
18	0	8	25	16	272	313
19	0	10	33	15	153	201
20	0	10	12	9	0	21
21	0	10	35	16	86	137
22	272	19	67	12	192	543
23	0	11	35	14	279	328
24	0	23	79	10	420	509
25	0	21	74	11	293	378
26	0	24	86	10	295	391
27	0	20	68	11	288	367
28	0	32	114	6	294	414
29	0	18	64	12	179	255
30	0	16	61	14	257	332
31	0	18	63	12	291	366
MONTHLY TOTAL	866	595	2067	359	7897	11189
AVG	27.9		66.7	11.6	254.7	360.9

FIGURE D-3

FORM LMO-6

DIRECT DIVERSION

WILMETTE PUMPING STATION

JULY 1990

DATE	DIRECT DIVERSION (cfs)					
	Navigational Make-up	Lockages Number	Lockages Amount	Leakage	Discretionary	Total
1	-----	---	-----	2	114	116
2	-----	---	-----	2	115	117
3	-----	---	-----	2	105	107
4	-----	---	-----	2	90	92
5	-----	---	-----	2	63	65
6	-----	---	-----	2	127	129
7	-----	---	-----	2	123	125
8	-----	---	-----	2	117	119
9	-----	---	-----	2	100	102
10	-----	---	-----	3	0	3
11	-----	---	-----	3	0	3
12	-----	---	-----	3	70	73
13	-----	---	-----	3	90	93
14	-----	---	-----	3	0	3
15	-----	---	-----	3	0	3
16	-----	---	-----	2	75	77
17	-----	---	-----	2	90	92
18	-----	---	-----	2	65	67
19	-----	---	-----	2	24	26
20	-----	---	-----	0	0	0
21	-----	---	-----	3	6	9
22	-----	---	-----	2	75	77
23	-----	---	-----	2	78	80
24	-----	---	-----	2	115	117
25	-----	---	-----	2	116	118
26	-----	---	-----	2	121	123
27	-----	---	-----	2	85	87
28	-----	---	-----	3	0	3
29	-----	---	-----	3	0	3
30	-----	---	-----	2	105	107
31	-----	---	-----	2	119	121
MONTHLY TOTAL				69	2188	2257
AVG				2.2	70.6	72.8

APPENDIX E

MWRDGC
RATING TABLES, LEAKAGE EQUATIONS, AND
CIRCULAR WATER SURFACE ELEVATION CHARTS

FOR

CHICAGO RIVER CONTROLLING WORKS
O'BRIEN LOCK AND DAM
WILMETTE CONTROLLING WORKS

FIGURE E-1

CHICAGO RIVER LOCKS AND *SLUICE GATES*

GATE OPENING IN FEET
DISCHARGE IN C.F.S.

Head	1	2'	3'	4'	5'	6'	7'	8'	9'	10'
0.1	15	30	46	61	76	91	106	122	137	152
0.2	22	43	65	86	108	130	151	173	194	216
0.3	26	53	79	106	132	158	185	211	238	264
0.4	30	61	91	122	152	182	213	243	274	304
0.5	34	68	102	136	171	205	239	273	307	341
0.6	37	74	112	149	186	223	260	298	335	372
0.7	40	81	121	161	202	242	282	322	363	403
0.8	40	86	129	172	215	258	301	344	387	430
0.9	46	91	137	182	228	274	319	365	410	456
1.0	48	96	144	192	241	287	337	385	433	481
1.1	51	101	152	202	253	303	354	404	455	505
1.2	53	106	158	211	264	317	370	422	475	528
1.3	55	110	165	220	275	330	385	440	495	550
1.4	57	114	171	228	285	342	399	456	513	570
1.5	59	118	177	236	295	354	413	472	531	590
1.6	61	122	183	244	305	366	427	488	549	610
1.7	63	126	189	252	315	377	440	503	566	629
1.8	65	129	194	259	324	388	453	518	582	647
1.9	66	133	199	266	332	398	465	531	598	664
2.0	68	136	204	272	340	409	477	545	613	681
2.1	70	140	210	280	350	419	489	559	629	699
2.2	72	143	215	286	358	429	501	572	644	715
2.3	73	146	219	292	365	438	511	584	657	730
2.4	75	149	224	298	373	448	522	597	671	746
2.5	76	152	229	305	381	457	533	610	686	762
2.6	78	156	233	311	389	467	545	622	700	778
2.7	79	159	238	317	397	476	555	634	714	793
2.8	81	161	242	323	404	484	565	646	726	807
2.9	82	164	246	328	411	493	575	657	739	821
3.0	84	167	251	334	418	501	585	668	752	835
3.1	85	170	255	340	425	509	594	679	764	849
3.2	86	172	259	345	431	517	603	690	776	862
3.3	88	175	263	350	438	525	613	700	788	875
3.4	89	178	266	355	444	533	622	710	799	888
3.5	90	180	270	360	451	541	631	721	811	901
3.6	91	183	274	366	457	548	640	731	823	914
3.7	93	185	278	371	464	556	649	742	834	927
3.8	94	188	282	376	470	563	657	751	845	939
3.9	95	190	285	380	476	571	666	761	856	951
4.0	96	192	289	385	481	577	673	770	866	962

$C = 0.6$

Sluice gates 10' x 10'

FIGURE E-2

O'BRIEN LOCK SLUICE GATE

Gate Openings in FEET — Discharge in C.F.S

HEAD	1	2	3	4	5	6	7	8	9	10
0.1	20	39	59	78	98	117	137	156	176	195
0.2	28	55	83	111	138	166	193	221	249	276
0.3	34	68	102	135	169	203	237	271	305	338
0.4	39	78	117	156	195	234	274	313	352	391
0.5	44	87	131	175	218	262	306	350	393	437
0.6	48	96	144	191	239	287	335	383	431	479
0.7	52	103	155	207	258	310	362	414	465	517
0.8	55	111	166	221	276	332	387	442	497	553
0.9	59	117	176	234	293	352	410	469	528	586
1.0	62	124	185	247	309	371	433	494	556	618
1.1	65	130	194	259	324	389	454	518	583	648
1.2	68	135	203	271	338	406	474	542	609	677
1.3	70	141	211	282	352	423	493	564	634	705
1.4	73	146	219	292	366	439	512	585	658	731
1.5	76	151	227	303	378	454	530	605	681	757
1.6	78	156	234	313	391	469	547	625	703	782
1.7	81	161	242	322	403	483	564	645	725	806
1.8	83	166	249	332	415	497	580	663	746	829
1.9	85	170	256	341	426	511	596	681	767	852
2.0	87	175	262	350	437	524	612	699	786	874
2.1	90	179	269	358	448	537	627	716	806	895
2.2	92	183	275	367	458	550	642	733	825	917
2.3	94	187	281	375	469	562	656	750	843	937
2.4	96	191	287	383	479	574	670	766	862	957
2.5	98	195	293	391	489	586	684	782	879	977
2.6	100	199	299	399	498	598	697	797	897	996
2.7	102	203	305	406	508	609	711	812	914	1015
2.8	103	207	310	414	517	620	724	827	931	1034
2.9	105	210	316	421	526	631	737	842	947	1052
3.0	107	214	321	428	535	642	749	856	963	1070
3.1	109	218	326	435	544	653	762	870	979	1088
3.2	111	221	332	442	553	663	774	884	995	1105
3.3	112	225	337	449	561	674	786	898	1010	1123
3.4	114	228	342	456	570	684	798	912	1025	1139
3.5	116	231	347	462	578	694	809	925	1040	1156
3.6	117	234	352	469	586	703	821	938	1055	1172
3.7	119	238	357	475	594	713	832	951	1070	1189
3.8	120	241	361	482	602	723	843	964	1084	1205
3.9	122	244	366	488	610	732	854	976	1098	1220
4.0	124	247	371	494	618	742	865	989	1112	1236

Based on C=.77

20-Jun-81

FIGURE E-3

WILMETTE SLUICE GATE

Gate Opening in FEET

Discharge in C.F.S

HEAD	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5
0.1	21	65	110	156	203	251	300	349	397	446
0.2	30	92	156	221	287	355	424	493	562	631
0.3	37	113	191	270	352	435	520	604	688	773
0.4	43	130	220	312	406	502	600	697	795	892
0.5	48	146	246	349	454	562	671	780	889	998
0.6	53	160	270	382	497	615	735	854	973	1093
0.7	57	172	291	413	537	665	794	923	1051	1180
0.8	61	184	311	441	574	711	848	986	1124	1262
0.9	64	196	330	468	609	754	900	1046	1192	1338
1.0	68	206	348	493	642	794	949	1103	1257	1411
1.1	71	216	365	517	673	833	995	1156	1318	1480
1.2	74	226	381	540	703	870	1039	1208	1377	1545
1.3	77	235	397	562	732	906	1082	1257	1433	1609
1.4	80	244	412	584	760	940	1122	1305	1487	1669
1.5	83	253	426	604	786	973	1162	1350	1539	1728
1.6	86	261	440	624	812	1005	1200	1395	1590	1785
1.7	88	269	454	643	837	1036	1237	1438	1639	1839
1.8	91	277	467	662	862	1066	1273	1479	1686	1893
1.9	94	284	480	680	885	1095	1307	1520	1732	1945
2.0	96	292	492	698	908	1124	1341	1559	1777	1995
2.1	98	299	504	715	931	1151	1375	1598	1821	2044
2.2	101	306	516	732	952	1178	1407	1635	1864	2093
2.3	103	313	528	748	974	1205	1439	1672	1906	2140
2.4	105	319	539	764	995	1231	1469	1708	1947	2186
2.5	107	326	550	780	1015	1256	1500	1743	1987	2231
2.6	109	332	561	795	1035	1281	1529	1778	2026	2275
2.7	111	339	572	811	1055	1305	1559	1812	2065	2318
2.8	114	345	582	825	1075	1329	1587	1845	2103	2361
2.9	116	351	593	840	1094	1353	1615	1878	2140	2402
3.0	118	357	603	854	1112	1376	1643	1910	2177	2444
3.1	119	363	613	869	1131	1399	1670	1941	2213	2484
3.2	121	369	623	882	1149	1421	1697	1972	2248	2524
3.3	123	375	632	896	1167	1443	1723	2003	2283	2563
3.4	125	380	642	910	1184	1465	1749	2033	2317	2601
3.5	127	386	651	923	1201	1486	1775	2063	2351	2639
3.6	129	391	660	936	1218	1507	1800	2092	2384	2677
3.7	131	397	669	949	1235	1528	1825	2121	2417	2714
3.8	132	402	678	962	1252	1549	1849	2149	2450	2750
3.9	134	407	687	974	1268	1569	1873	2178	2482	2786
4.0	136	412	696	987	1284	1589	1897	2205	2513	2822

Based on C=0.6

26-Sep-81

LEAKAGE FORMULA FOR THREE LAKE MICHIGAN INLETS

CRCW	$QL = 20.32 \sqrt{H} \frac{(24-0.33N)}{24}$
O'BRIEN	$QL = 12.8 \sqrt{H} \frac{(24-0.5N)}{24}$
WILMETTE	$QL = 3.04 \sqrt{H}$

WHERE:

QL = Leakage (average daily flow, cfs)

H = The difference in water elevation upstream and downstream of the lock or gate.

N = Number of lockages in a day.

FIGURE E-4

Chicago River Controlling Works
(upstream)

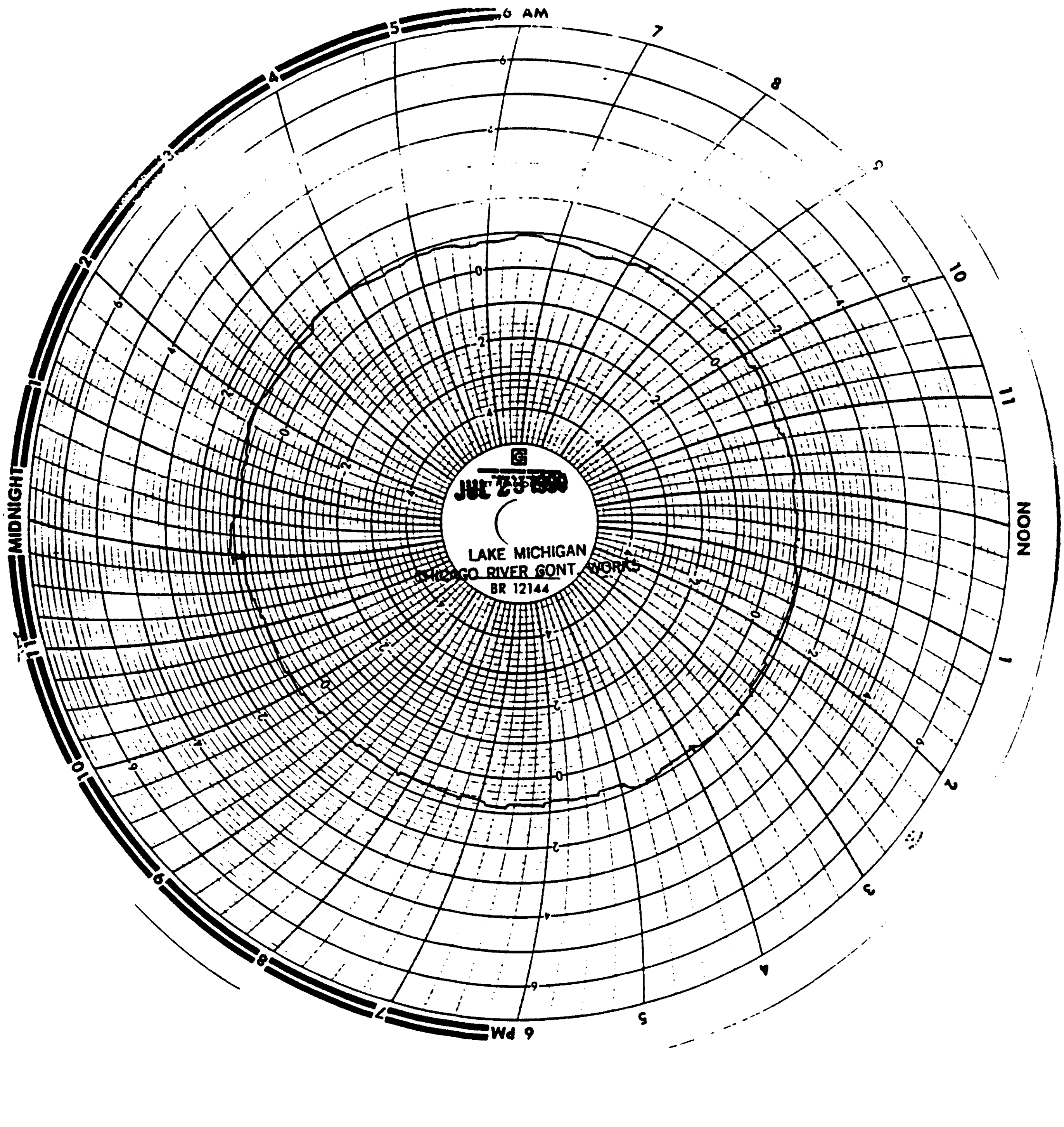


FIGURE E-5

Chicago River Controlling Works
(downstream)

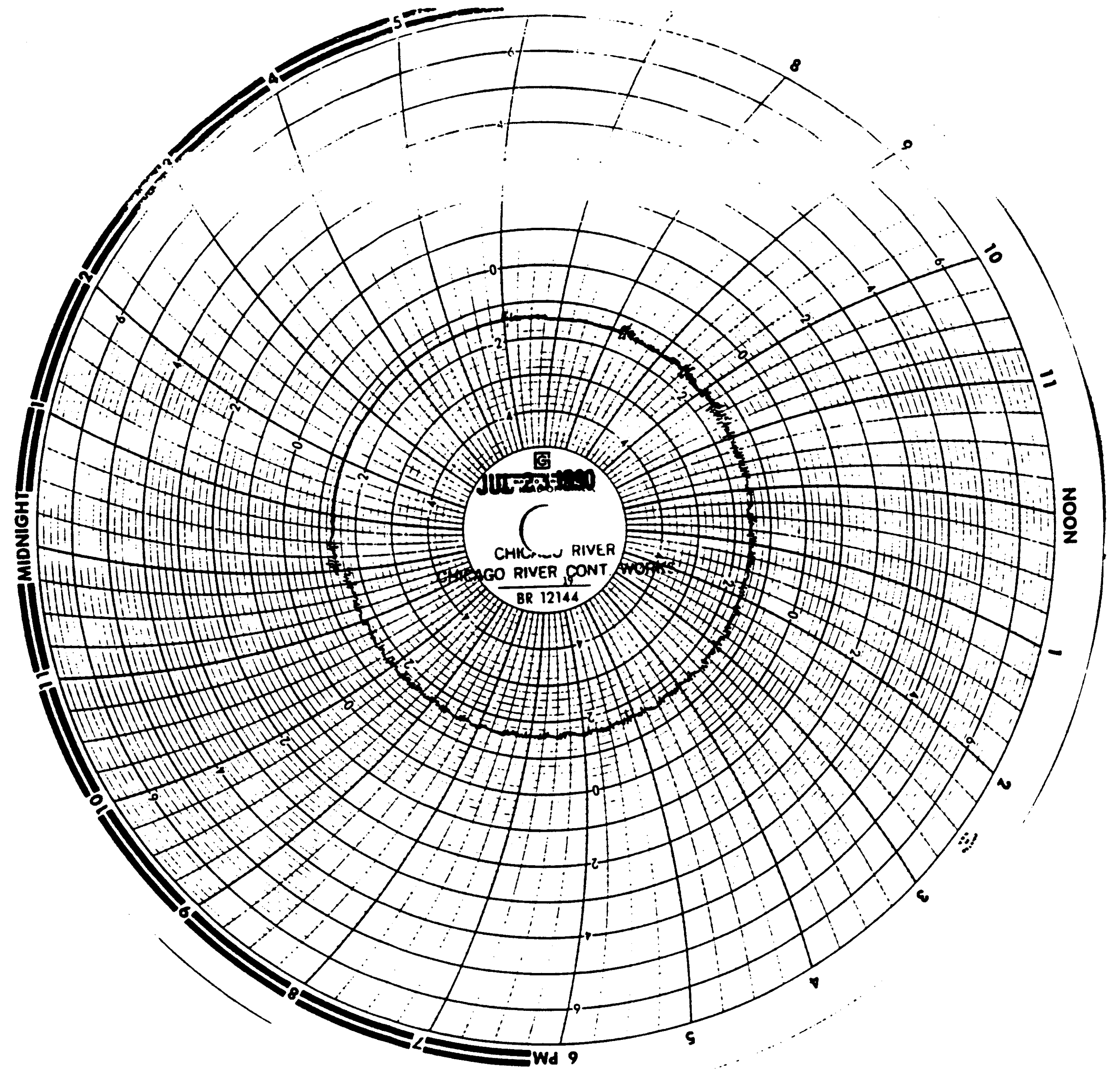


FIGURE E-6

O'Brien Lock and Dam
(upstream)

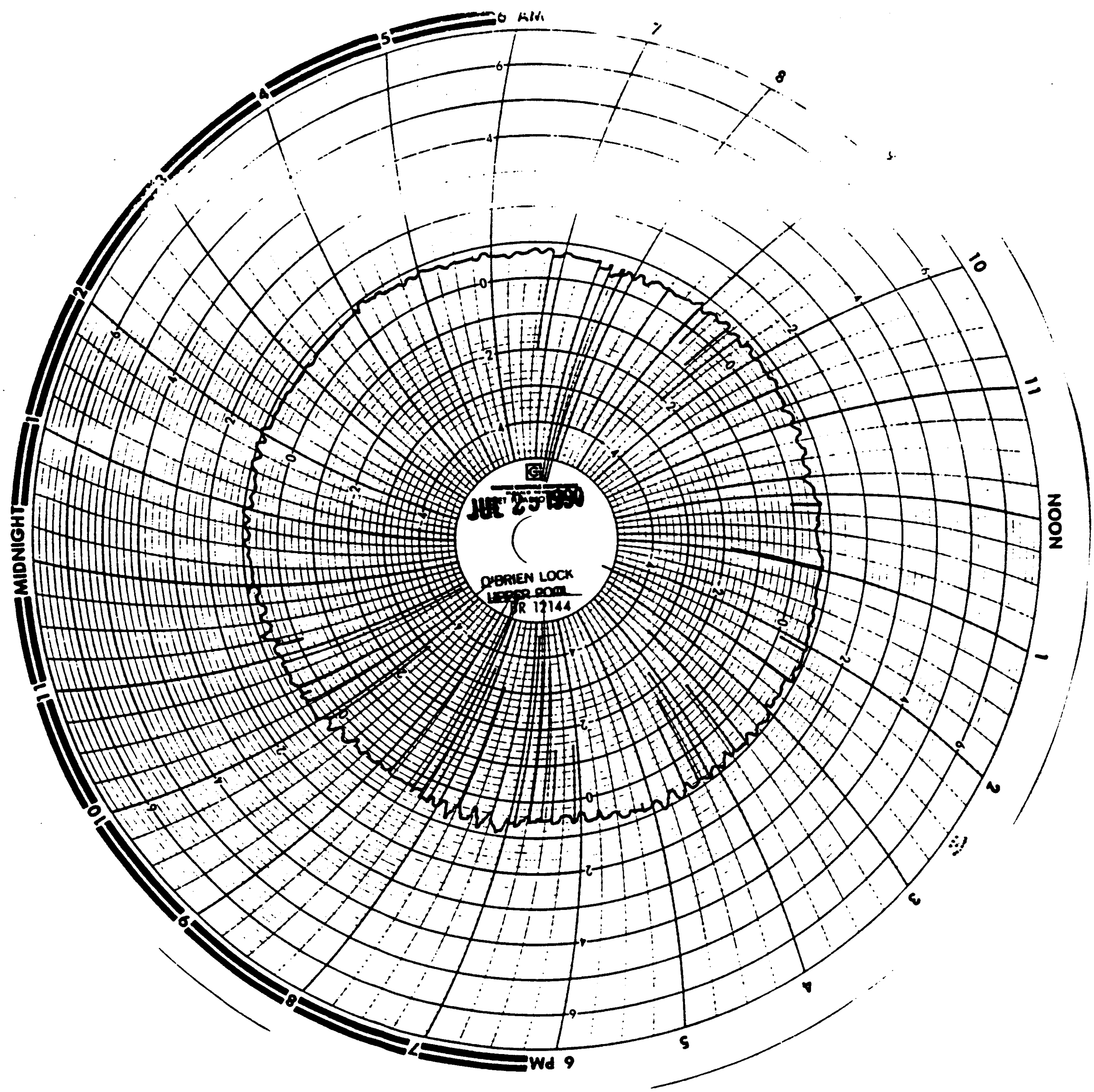


FIGURE E-7

O'Brien Lock and Dam
(downstream)

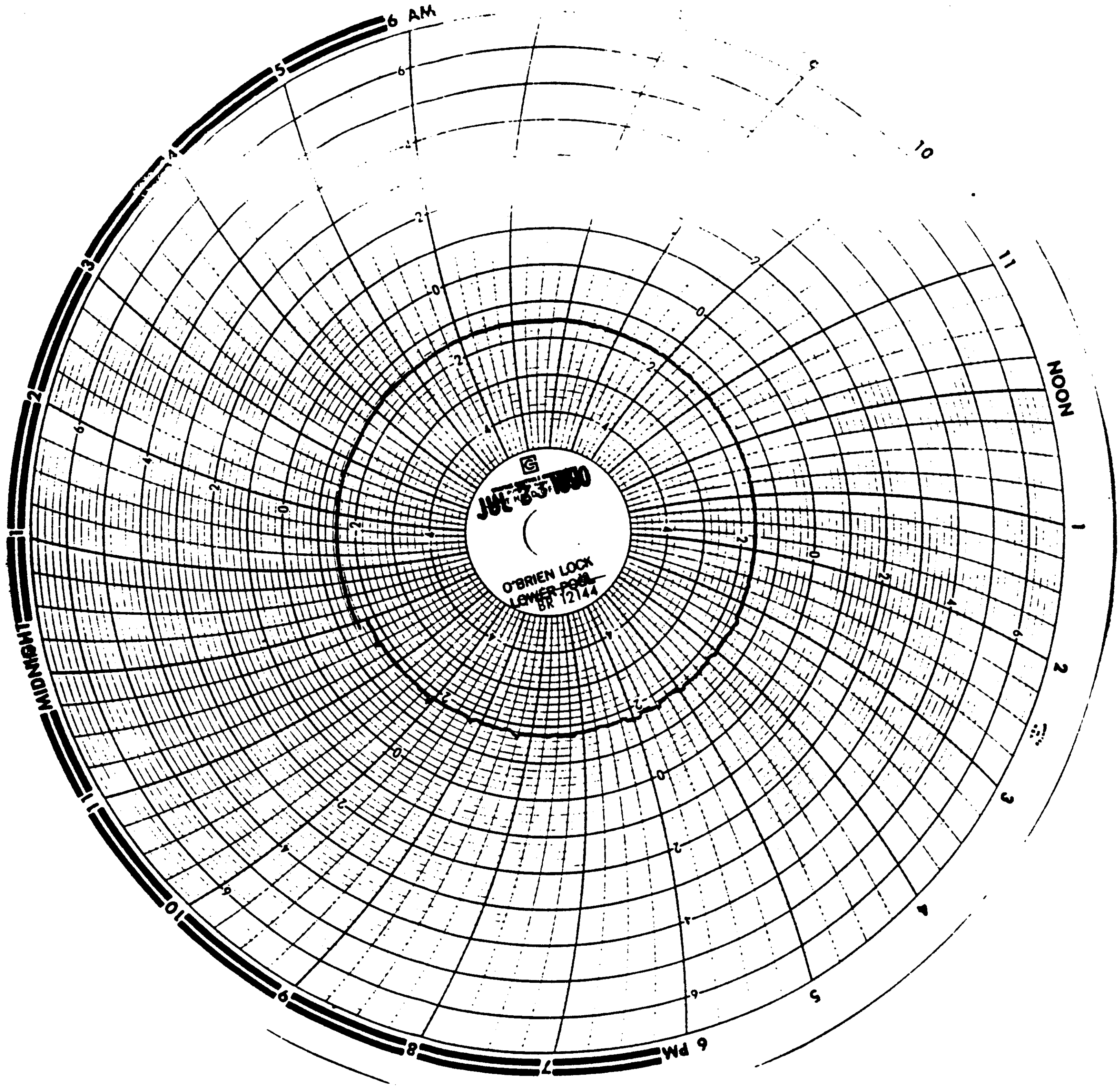


FIGURE E-8

Wilmette Controlling Works
(upstream)

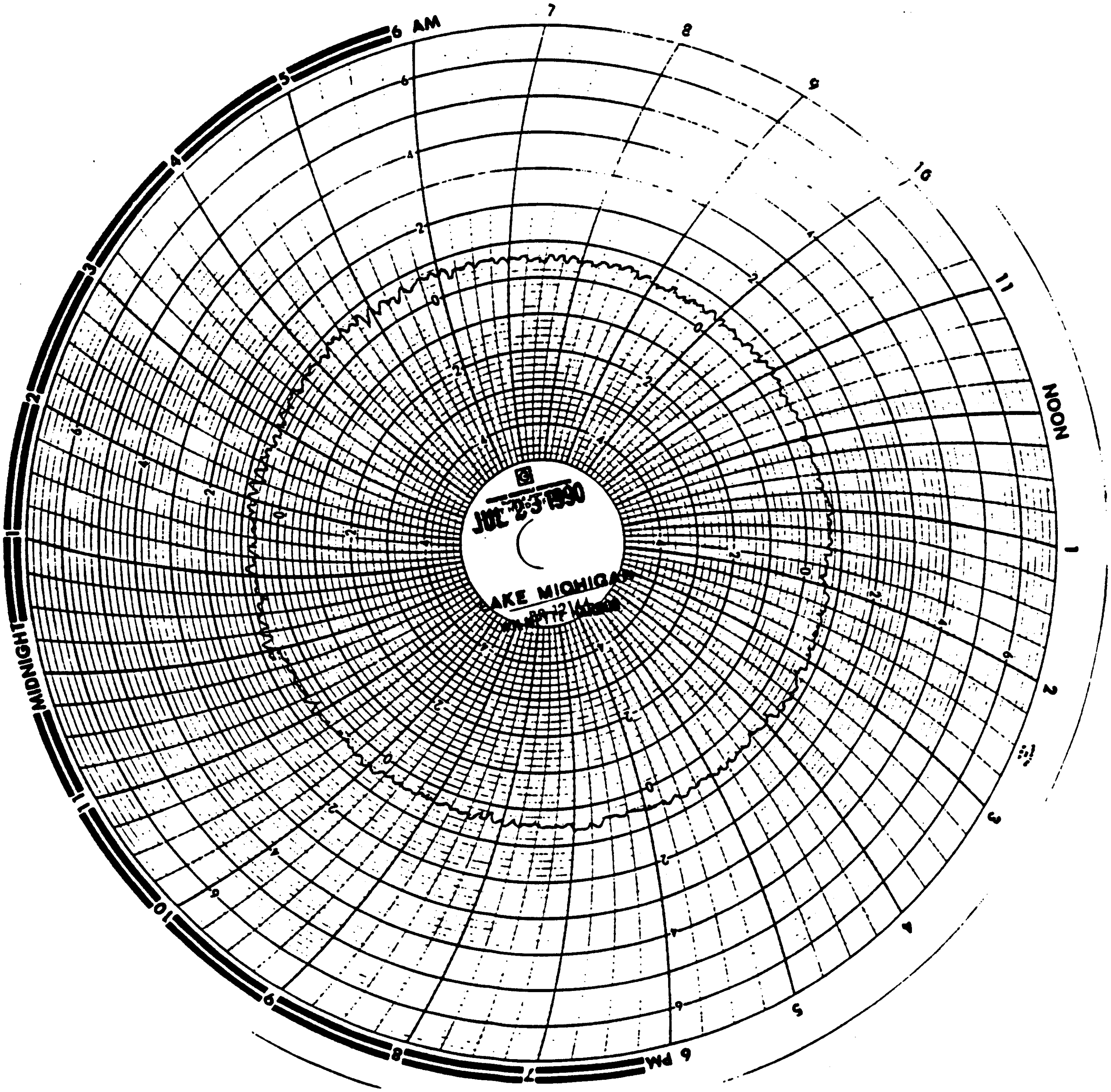
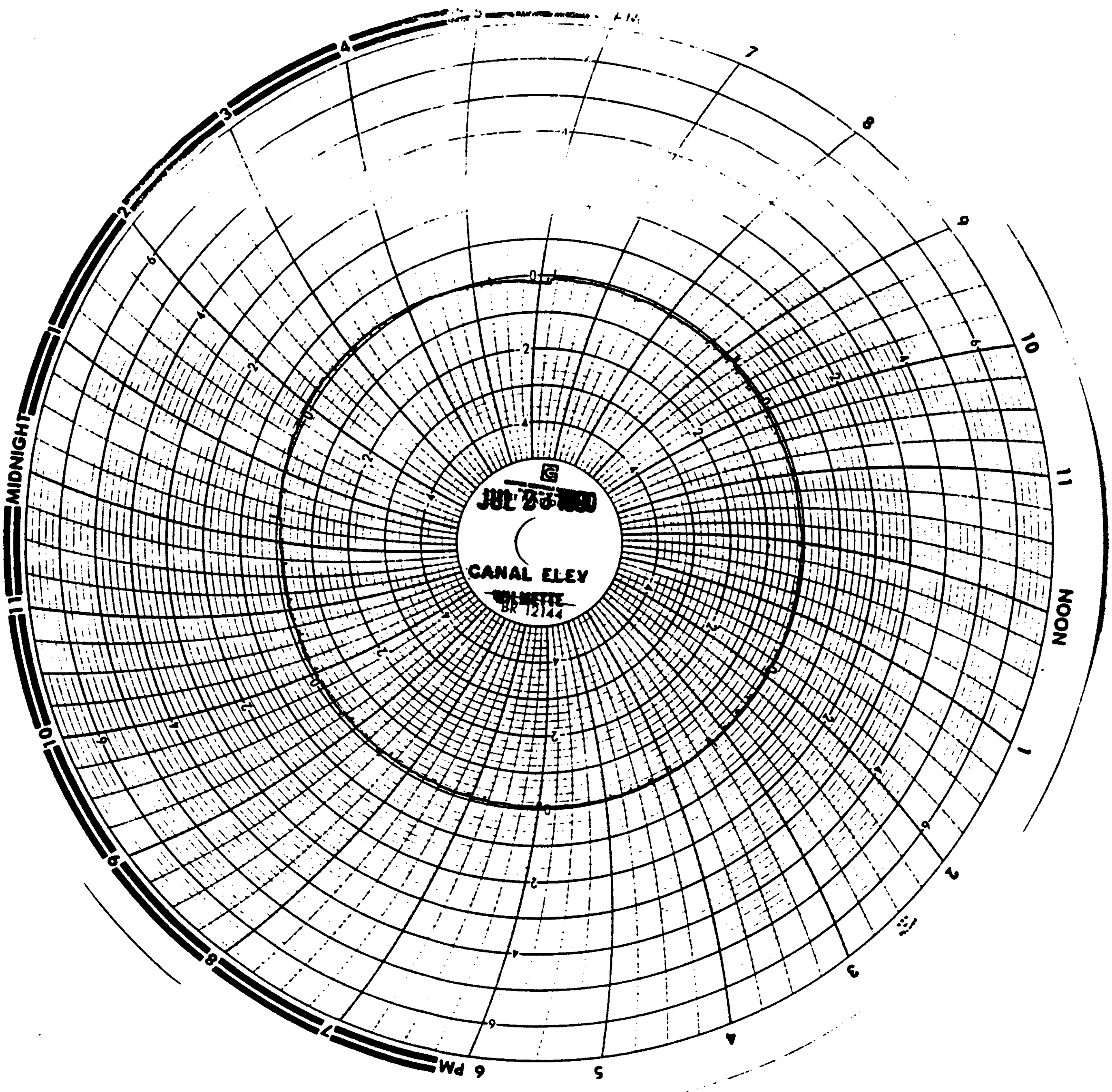


FIGURE E-9

Wilmette Controlling Works
(downstream)



APPENDIX F

CALCULATIONS OF INSTANTANEOUS MWRDGC DISCRETIONARY AND LEAKAGE FLOWS

TABLE F-1

INSTANTANEOUS MWRDGC
DISCRETIONARY AND LEAKAGE FLOWS

DATE	GATE OPENING (ft)	NO.OF OPEN GATES	AVG. HEAD (ft)	FLOW PER GATE (cfs)	TOTAL GATE FLOW (cfs)	LEAKAGE (cfs)	SUM (cfs)
CRCW							
7-23	1.5	4	2.16	106.5	426.0	29.5	455.5
7-24	1.5	4	2.51	114.3	457.2	32.2	489.4
7-25	1.5	4	2.45	113.0	452.0	31.8	483.8
7-26	1.5	4	2.53	114.9	459.6	32.3	491.9
7-27	1.5	4	2.32	110.0	440.0	31.0	471.0
O'BRIEN							
7-23	3	1	2.34	283.4	283.4	19.6	303.0
7-24	3	1	2.43	288.8	288.8	20.0	308.8
7-25	3	1	2.63	300.8	300.8	20.8	321.6
7-26	3	1	2.62	300.2	300.2	20.7	320.9
7-27	3	1	2.37	285.2	285.2	19.7	304.9
WILMETTE							
7-23	1	1	0.64	109.7	109.7	2.4	112.1
7-24	1	1	0.78	120.9	120.9	2.7	123.6
7-25	1	1	0.75	118.5	118.5	2.6	121.1
7-26	1	1	0.82	124.0	124.0	2.8	126.8
7-27	1	1	0.80	122.5	122.5	2.7	125.2

Column Description:

Gate Opening = Vertical opening of sluice gate.

Number of Open Gates = The number of sluice gates with a vertical opening equal to that specified in "Gate Opening".

Avg. Head = Average head across sluice gates during the measurement. See Tables F-2, F-3, and F-4 for water surface elevations. Water surface elevations obtained from MWRDGC circular stage charts (See Figures E-4 through E-9).

Flow per Gate = Flow through one sluice gate as determined by rating tables in Appendix E.

Total Gate Flow = "Number of Open Gates" x "Flow per Gate".

Leakage = Leakage through sluice gates and lock gates as calculated by equations in Appendix E. "Average Head" used as "H" in leakage equation. Number of lockages "N" equal zero.

Sum = "Total Gate Flow" + "Leakage"

TABLE F-2
WATER SURFACE ELEVATIONS (CCD)
AT CHICAGO RIVER CONTROLLING WORKS

DATE	TIME		UPSTREAM ELEV. (LAKE)	DOWNSTREAM ELEV. (RIVER)	HEAD (ft)
7-23	730		+0.60	-1.40	2.00
	800		+0.75	-1.45	2.20
	830		+0.75	-1.45	2.20
	900		+0.70	-1.45	2.15
	930		+0.80	-1.45	2.25
			-----	-----	----
		AVG.=	+0.72	-1.44	2.16
7-24	630		+0.70	-1.85	2.55
	700		+0.60	-1.85	2.45
	730		+0.60	-1.85	2.45
	800		+0.65	-1.85	2.50
	830		+0.60	-1.95	2.55
	900		+0.60	-1.95	2.55
			-----	-----	----
		AVG.=	+0.63	-1.88	2.51
7-25	600		+0.80	-1.70	2.50
	630		+0.75	-1.70	2.45
	700		+0.75	-1.75	2.50
	730		+0.70	-1.75	2.45
	800		+0.65	-1.75	2.40
	830		+0.65	-1.80	2.45
	900		+0.60	-1.80	2.40
			-----	-----	----
		AVG.=	+0.70	-1.75	2.45
7-26	630		+0.75	-1.80	2.55
	700		+0.80	-1.80	2.60
	730		+0.80	-1.80	2.60
	800		+0.65	-1.75	2.40
	830		+0.75	-1.75	2.50
			-----	-----	----
		AVG.=	+0.75	-1.78	2.53
7-27	600		+0.80	-1.45	2.25
	630		+0.80	-1.45	2.25
	700		+0.95	-1.50	2.45
	730		+0.80	-1.55	2.35
	800		+0.75	-1.50	2.25
	830		+0.80	-1.55	2.35
	900		+0.75	-1.55	2.30
			-----	-----	----
		AVG.=	+0.81	-1.51	2.31

TABLE F-3
WATER SURFACE ELEVATIONS (CCD)
AT O'BRIEN LOCK AND DAM

DATE	TIME		UPSTREAM ELEV.(LAKE)	DOWNSTREAM ELEV.(RIVER)	HEAD (ft)
7-23	1200		+0.65	-1.60	2.25
	1230		+0.60	-1.60	2.20
	1300		+0.75	-1.60	2.35
	1330		+0.80	-1.60	2.40
	1400		+0.85	-1.65	2.50
			-----	-----	----
		AVG.=	+0.73	-1.61	2.34
7-24	1030		+0.40	-1.80	2.20
	1100		+0.65	-1.85	2.50
	1130		+0.70	-1.85	2.55
	1200		+0.55	-1.85	2.40
	1230		+0.60	-1.85	2.45
	1300		+0.65	-1.85	2.50
			-----	-----	----
		AVG.=	+0.59	-1.84	2.43
7-25	1100		+0.60	-1.95	2.55
	1130		+0.65	-1.95	2.60
	1200		+0.75	-1.95	2.70
	1230		+0.70	-1.95	2.65
	1300		+0.70	-1.95	2.65
	1330		+0.65	-1.95	2.60
	1400		+0.70	-1.95	2.65
			-----	-----	----
		AVG.=	+0.68	-1.95	2.63
7-26	930		+0.70	-2.00	2.70
	1000		+0.60	-2.00	2.60
	1030		+0.65	-1.95	2.60
	1100		+0.70	-1.95	2.65
	1130		+0.55	-2.00	2.55
			-----	-----	----
		AVG.=	+0.64	-1.98	2.62
7-27	1000		+0.60	-1.75	2.35
	1030		+0.60	-1.80	2.40
	1100		+0.55	-1.80	2.35
	1130		+0.45	-1.85	2.30
	1200		+0.40	-1.85	2.25
	1230		+0.45	-1.90	2.35
	1300		+0.50	-1.90	2.40
	1330		+0.65	-1.90	2.55
			-----	-----	----
		AVG.=	+0.53	-1.84	2.37

TABLE F-4

WATER SURFACE ELEVATIONS (CCD)
AT WILMETTE CONTROLLING WORKS

DATE	TIME		UPSTREAM ELEV. (LAKE)	DOWNSTREAM ELEV. (RIVER)	HEAD (ft)
7-23	1700		+0.60	-0.05	0.65
	1715		+0.60	-0.05	0.65
	1730		+0.65	-0.05	0.70
	1745		+0.50	-0.05	0.55
			-----	-----	----
		AVG.=	+0.59	-0.05	0.64
7-24	1530		+0.60	-0.20	0.80
	1600		+0.60	-0.20	0.80
	1630		+0.55	-0.20	0.75
			-----	-----	----
		AVG.=	+0.58	-0.20	0.78
7-25	1630		+0.55	-0.15	0.70
	1700		+0.65	-0.15	0.80
			-----	-----	----
		AVG.=	+0.60	-0.15	0.75
7-26	1330		+0.65	-0.20	0.85
	1400		+0.60	-0.15	0.75
	1430		+0.70	-0.15	0.85
			-----	-----	----
		AVG.=	+0.65	-0.17	0.82
7-27	1430		+0.55	-0.20	0.75
	1500		+0.65	-0.20	0.85
			-----	-----	----
		AVG.=	+0.60	-0.20	0.80

APPENDIX G

CALCULATIONS OF COEFFICIENTS
FOR TWO-POINT AND THREE-POINT METHODS

TABLE G-1

CHICAGO RIVER CONTROLLING WORKS

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)
7-23-90	1	4	8	5	0.173	0.316	0.209	370	0.254	93.81	0.191	70.65
METER S	2	4	11	8	0.173	0.423	0.316	416	0.334	138.95	0.245	101.75
60 SEC.	3	4	6	3	0.173	0.245	0.137	433	0.200	86.55	0.155	67.19
	4	1	7	6	0.066	0.280	0.245	458	0.218	99.74	0.155	71.07
	5	1	5	7	0.066	0.209	0.280	453	0.191	86.50	0.173	78.40
	6	2	7	4	0.102	0.280	0.173	471	0.209	98.36	0.137	64.67
	7	2	5	6	0.102	0.209	0.245	475	0.191	90.70	0.173	82.21
	8	3	5	6	0.137	0.209	0.245	450	0.200	89.95	0.191	85.93
	9	2	6	5	0.102	0.245	0.209	456	0.200	91.15	0.155	70.76
	10	2	5	3	0.102	0.209	0.137	433	0.164	71.07	0.119	51.71
								TOTAL FLOW	=	946.79		744.35

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)
7-24-90	1	2	2	1	0.132	0.132	0.096	364	0.123	44.61	0.114	41.36
METER K	2	2	3	2	0.132	0.167	0.132	410	0.149	61.24	0.132	53.92
60 SEC.	3	3	4	5	0.167	0.203	0.239	427	0.203	86.68	0.203	86.68
	4	3	5	5	0.167	0.239	0.239	452	0.221	99.84	0.203	91.76
	5	5	3	4	0.239	0.167	0.203	447	0.194	86.75	0.221	98.73
	6	6	3	2	0.275	0.167	0.132	464	0.185	85.90	0.203	94.19
	7	6	6	5	0.275	0.275	0.239	469	0.266	124.55	0.257	120.36
	8	3	5	3	0.167	0.239	0.167	444	0.203	90.13	0.167	74.26
	9	6	4	4	0.275	0.203	0.203	450	0.221	99.39	0.239	107.44
	10	2	4	3	0.132	0.203	0.167	426	0.176	75.06	0.149	63.63
								TOTAL FLOW	=	854.15		832.32

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)
7-25-90	1	5	5	1	0.309	0.309	0.094	366	0.255	93.29	0.201	73.63
METER U	2	4	3	1	0.255	0.201	0.094	412	0.188	77.35	0.174	71.82
40 SEC.	3	4	4	3	0.255	0.255	0.201	428	0.241	103.35	0.228	97.60
	4	4	3	3	0.255	0.201	0.201	453	0.215	97.22	0.228	103.30
	5	5	4	4	0.309	0.255	0.255	447	0.268	119.94	0.282	125.95
	6	4	3	3	0.255	0.201	0.201	464	0.215	99.58	0.228	105.81
	7	3	3	5	0.201	0.201	0.309	468	0.228	106.72	0.255	119.29
	8	4	3	3	0.255	0.201	0.201	442	0.215	94.86	0.228	100.79
	9	5	3	3	0.309	0.201	0.201	448	0.228	102.16	0.255	114.20
	10	4	3	4	0.255	0.201	0.255	424	0.228	96.69	0.255	108.08
								TOTAL FLOW	=	991.16		1020.46

TABLE G-1

CHICAGO RIVER CONTROLLING WORKS

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)
7-26-90	1	3	2	2	0.191	0.137	0.137	365	0.151	55.01	0.164	59.91
METER S	2	2	1	1	0.137	0.084	0.084	411	0.097	39.89	0.110	45.41
40 SEC.	3	2	1	2	0.137	0.084	0.137	428	0.110	47.28	0.137	58.76
	4	3	0	1	0.191	0.000	0.084	453	0.069	31.10	0.137	62.20
	5	2	1	1	0.137	0.084	0.084	448	0.097	43.48	0.110	49.49
	6	3	1	1	0.191	0.084	0.084	465	0.110	51.37	0.137	63.84
	7	2	2	1	0.137	0.137	0.084	469	0.124	58.10	0.110	51.81
	8	3	1	1	0.191	0.084	0.084	444	0.110	49.05	0.137	60.96
	9	1	1	1	0.084	0.084	0.084	450	0.084	37.64	0.084	37.64
	10	4	2	3	0.245	0.137	0.191	426	0.178	75.63	0.218	92.77
								TOTAL FLOW	=	488.57		582.80

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)
7-27-90	1	6	4	2	0.255	0.183	0.112	369	0.183	67.63	0.183	67.63
METER U	2	6	4	2	0.255	0.183	0.112	414	0.183	75.87	0.183	75.87
60 SEC.	3	6	3	2	0.255	0.147	0.112	431	0.165	71.27	0.183	78.99
	4	7	3	4	0.291	0.147	0.183	456	0.192	87.65	0.237	108.07
	5	6	5	4	0.255	0.219	0.183	451	0.219	98.81	0.219	98.81
	6	9	5	4	0.362	0.219	0.183	468	0.246	115.10	0.273	127.67
	7	6	5	3	0.255	0.219	0.147	472	0.210	99.18	0.201	94.95
	8	8	5	5	0.327	0.219	0.219	447	0.246	109.94	0.273	121.95
	9	7	4	3	0.291	0.183	0.147	453	0.201	91.13	0.219	99.24
	10	5	2	2	0.219	0.112	0.112	429	0.138	59.41	0.165	70.94
								TOTAL FLOW	=	875.99		944.12

TABLE G-2

O' B R I E N   L O C K   A N D   D A M

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)
7-23-90	1	4	4	1	0.173	0.173	0.066	345	0.146	50.45	0.119	41.20
METER S	2	6	5	0	0.245	0.209	0.000	349	0.166	57.78	0.122	42.68
60 SEC.	3	2	4	1	0.102	0.173	0.066	353	0.128	45.31	0.084	29.53
	4	2	4	1	0.102	0.173	0.066	348	0.128	44.67	0.084	29.11
	5	3	3	4	0.137	0.137	0.173	355	0.146	51.92	0.155	55.09
	6	4	4	1	0.173	0.173	0.066	354	0.146	51.77	0.119	42.27
	7	3	5	2	0.137	0.209	0.102	364	0.164	59.74	0.119	43.47
	8	5	5	1	0.209	0.209	0.066	353	0.173	61.09	0.137	48.47
	9	1	5	1	0.066	0.209	0.066	334	0.137	45.86	0.066	21.97
	10	0	4	5	0.000	0.173	0.209	341	0.139	47.31	0.104	35.61
	11	1	3	13	0.066	0.137	0.495	355	0.209	74.14	0.280	99.53
								TOTAL FLOW	=	590.04		488.92

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)
7-24-90	1	5	4	3	0.239	0.203	0.167	333	0.203	67.60	0.203	67.60
METER K	2	5	5	4	0.239	0.239	0.203	337	0.230	77.45	0.221	74.43
60 SEC.	3	2	4	3	0.132	0.203	0.167	342	0.176	60.26	0.149	51.09
	4	3	4	3	0.167	0.203	0.167	337	0.185	62.39	0.167	56.36
	5	3	3	3	0.167	0.167	0.167	345	0.167	57.70	0.167	57.70
	6	7	4	1	0.310	0.203	0.096	344	0.203	69.83	0.203	69.83
	7	5	5	2	0.239	0.239	0.132	354	0.212	75.03	0.185	65.53
	8	4	5	3	0.203	0.239	0.167	343	0.212	72.69	0.185	63.50
	9	2	5	3	0.132	0.239	0.167	324	0.194	62.88	0.149	48.40
	10	5	4	5	0.239	0.203	0.239	332	0.221	73.33	0.239	79.27
	11	3	3	6	0.167	0.167	0.275	345	0.194	66.95	0.221	76.20
								TOTAL FLOW	=	746.10		709.91

TABLE G-2

O'BRIEN LOCK AND DAM

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	PANEL FLOW (cfs)
7-25-90	1	4	4	2	0.255	0.255	0.147	338	0.228	77.08	0.201	68.00
METER U	2	-3	8	5	-0.121	0.470	0.309	341	0.282	96.08	0.094	31.96
40 SEC.	3	-5	3	3	-0.229	0.201	0.201	345	0.094	32.34	-0.014	-4.74
	4	-3	4	5	-0.121	0.255	0.309	339	0.174	59.09	0.094	31.77
	5	-5	4	4	-0.229	0.255	0.255	346	0.134	46.37	0.013	4.55
	6	3	3	2	0.201	0.201	0.147	344	0.188	64.58	0.174	59.96
	7	3	4	4	0.201	0.255	0.255	352	0.241	85.00	0.228	80.27
	8	5	3	3	0.309	0.201	0.201	341	0.228	77.76	0.255	86.92
	9	3	5	3	0.201	0.309	0.201	321	0.255	81.82	0.201	64.58
	10	3	2	2	0.201	0.147	0.147	328	0.161	52.77	0.174	57.17
	11	5	8	2	0.309	0.470	0.147	339	0.349	118.28	0.228	77.30
								TOTAL FLOW =		791.17		557.75

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	PANEL FLOW (cfs)
7-26-90	1	1	2	1	0.084	0.137	0.084	345	0.110	38.11	0.084	28.86
METER S	2	1	1	2	0.084	0.084	0.137	349	0.097	33.87	0.110	38.56
40 SEC.	3	5	2	2	0.298	0.137	0.137	354	0.178	62.85	0.218	77.09
	4	2	4	3	0.137	0.245	0.191	349	0.204	71.32	0.164	57.28
	5	1	1	6	0.084	0.084	0.352	357	0.151	53.80	0.218	77.75
	6	3	3	2	0.191	0.191	0.137	356	0.178	63.20	0.164	58.43
	7	4	3	1	0.245	0.191	0.084	366	0.178	64.98	0.164	60.07
	8	1	1	3	0.084	0.084	0.191	355	0.110	39.22	0.137	48.74
	9	4	2	2	0.245	0.137	0.137	337	0.164	55.31	0.191	64.35
	10	-2	6	4	-0.077	0.352	0.245	344	0.218	74.91	0.084	28.78
	11	-7	1	8	-0.346	0.084	0.459	360	0.070	25.29	0.057	20.46
								TOTAL FLOW =		582.87		560.36

TABLE G-3

O'BRIEN LOCK AND DAM

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)
7-27-90	1	1	6	2	0.076	0.255	0.112	339	0.174	59.09	0.094	31.77
METER U	2	3	2	3	0.147	0.112	0.147	343	0.130	44.43	0.147	50.58
60 SEC.	3	4	2	3	0.183	0.112	0.147	348	0.138	48.20	0.165	57.54
	4	3	3	4	0.147	0.147	0.183	343	0.156	53.65	0.165	56.72
	5	2	4	3	0.112	0.183	0.147	351	0.156	54.90	0.130	45.47
	6	5	4	5	0.219	0.183	0.219	350	0.201	70.41	0.219	76.68
	7	4	4	5	0.183	0.183	0.219	359	0.192	69.01	0.201	72.22
	8	5	3	1	0.219	0.147	0.076	349	0.147	51.46	0.147	51.46
	9	4	6	5	0.183	0.255	0.219	330	0.228	75.25	0.201	66.39
	10	5	2	3	0.219	0.112	0.147	338	0.147	49.84	0.183	61.94
	11	2	1	6	0.112	0.076	0.255	352	0.130	45.60	0.183	64.51
								TOTAL FLOW =		621.83		635.28

WILMETTE CONTROLLING WORKS

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)	Estimated Measurement Locations
7-23-90	1	10	8	6	0.388	0.316	0.245	25	0.316	7.90	0.316	7.90	.2.6.8
METER S	2	16	13	12	0.602	0.495	0.459	102	0.513	52.31	0.531	54.13	
60 SEC.	3	17	16	11	0.638	0.602	0.423	125	0.567	70.81	0.531	66.34	
	4	16	15	11	0.602	0.567	0.423	118	0.540	63.68	0.513	60.52	
	5	13	10	7	0.495	0.388	0.280	56	0.388	21.71	0.388	21.71	.8
								TOTAL FLOW =		216.42		210.61	

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)	Estimated Measurement Locations
7-24-90	1	14	14	11	0.561	0.561	0.453	23	0.534	12.27	0.507	11.66	.6.8
METER K	2	20	20	17	0.775	0.775	0.668	100	0.748	74.82	0.721	72.14	
60 SEC.	3	17	17	16	0.668	0.668	0.632	122	0.659	80.38	0.650	79.28	
	4	17	17	11	0.668	0.668	0.453	114	0.614	70.01	0.561	63.90	
	5	17	16	12	0.668	0.632	0.489	52	0.605	31.47	0.578	30.08	.8
								TOTAL FLOW =		268.95		257.05	

TABLE G-3

W I L M E T T E   C O N T R O L L I N G   W O R K S

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)	Estimated Measurement Locations
7-25-90	1	9	7	5	0.524	0.416	0.309	24	0.416	9.99	0.416	9.99	.6.8
METER U	2	14	10	9	0.792	0.577	0.524	101	0.618	62.37	0.658	66.44	
40 SEC.	3	14	9	9	0.792	0.524	0.524	123	0.591	72.65	0.658	80.91	
	4	13	12	8	0.738	0.685	0.470	116	0.644	74.75	0.604	70.08	
	5	12	9	6	0.685	0.524	0.362	54	0.524	28.27	0.524	28.27	.8
								TOTAL FLOW	=	248.03		255.69	

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)	Estimated Measurement Locations
7-26-90	1	8	8	7	0.459	0.459	0.406	24	0.446	10.70	0.432	10.38	.6.8
METER S	2	11	11	10	0.620	0.620	0.567	101	0.607	61.28	0.593	59.93	
40 SEC.	3	11	13	12	0.620	0.727	0.674	124	0.687	85.21	0.647	80.22	
	4	12	11	9	0.674	0.620	0.513	116	0.607	70.38	0.593	68.83	
	5	10	7	6	0.567	0.406	0.352	54	0.432	23.35	0.459	24.80	.8
								TOTAL FLOW	=	250.92		244.15	

DATE METER DURATION	PANEL NO.	BUCKET WHEEL REVOLUTIONS 0.2	0.6	0.8	POINT VELOCITIES (fps) 0.2	0.6	0.8	PANEL AREA (sq.ft.)	3 POINT METHOD MEAN VELOCITY (fps)	3 POINT METHOD PANEL FLOW (cfs)	2 POINT METHOD MEAN VELOCITY (fps)	2 POINT METHOD PANEL FLOW (cfs)	Estimated Measurement Locations
7-27-90	1	14	13	11	0.541	0.506	0.434	23	0.497	11.42	0.488	11.22	.6.8
METER U	2	19	16	13	0.721	0.613	0.506	100	0.613	61.31	0.613	61.31	
60 SEC.	3	17	18	14	0.649	0.685	0.541	123	0.640	78.71	0.595	73.20	
	4	18	16	14	0.685	0.613	0.541	115	0.613	70.50	0.613	70.50	
	5	13	12	10	0.506	0.470	0.398	53	0.461	24.42	0.452	23.95	.8
								TOTAL FLOW	=	246.37		240.18	

TABLE G-4

CHICAGO RIVER CONTROLLING WORKS

PANEL	23 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	23 JULY 1990 THREE POINT METHOD (cfs)	COEF.	24 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	24 JULY 1990 THREE POINT METHOD (cfs)	COEF.	25 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	25 JULY 1990 THREE POINT METHOD (cfs)	COEF.	26 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	26 JULY 1990 THREE POINT METHOD (cfs)	COEF.	27 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	27 JULY 1990 THREE POINT METHOD (cfs)	COEF.
1	74	93.81	0.79	44	44.61	0.99	55	93.29	0.59	40	55.01	0.73	63	67.63	0.93
2	133	138.95	0.96	66	61.24	1.08	78	77.35	1.01	49	39.89	1.23	83	75.87	1.09
3	82	86.55	0.95	85	86.68	0.98	98	103.35	0.95	56	47.28	1.18	86	71.27	1.21
4	101	99.74	1.01	95	99.84	0.95	100	97.22	1.03	50	31.10	1.61	91	87.65	1.04
5	91	86.50	1.05	94	86.75	1.08	112	119.94	0.93	63	43.48	1.45	95	98.81	0.96
6	85	98.36	0.86	88	85.90	1.02	102	99.58	1.02	60	51.37	1.17	103	115.10	0.89
7	109	90.70	1.20	117	124.55	0.94	112	106.72	1.05	66	58.10	1.14	109	99.18	1.10
8	94	89.95	1.05	84	90.13	0.93	97	94.86	1.02	71	49.05	1.45	112	109.94	1.02
9	82	91.15	0.90	99	99.39	1.00	103	102.16	1.01	54	37.64	1.43	100	91.13	1.10
10	56	71.07	0.79	64	75.06	0.85	76	96.69	0.79	64	75.63	0.85	60	59.41	1.01
TOTAL =	907	947	0.96	836	854	0.98	933	991	0.94	573	489	1.17	902	876	1.03

PANEL	23 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	23 JULY 1990 TWO POINT METHOD (cfs)	COEF.	24 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	24 JULY 1990 TWO POINT METHOD (cfs)	COEF.	25 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	25 JULY 1990 TWO POINT METHOD (cfs)	COEF.	26 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	26 JULY 1990 TWO POINT METHOD (cfs)	COEF.	27 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	27 JULY 1990 TWO POINT METHOD (cfs)	COEF.
1	74	70.65	1.05	44	41.36	1.06	55	73.63	0.75	40	59.91	0.67	63	67.63	0.93
2	133	101.75	1.31	66	53.92	1.22	78	71.82	1.09	49	45.41	1.08	83	75.87	1.09
3	82	67.19	1.22	85	86.68	0.98	98	97.60	1.00	56	58.76	0.95	86	78.99	1.09
4	101	71.07	1.42	95	91.76	1.04	100	103.30	0.97	50	62.20	0.80	91	108.07	0.84
5	91	78.40	1.16	94	98.73	0.95	112	125.95	0.89	63	49.49	1.27	95	98.81	0.96
6	85	64.67	1.31	88	94.19	0.93	102	105.81	0.96	60	63.84	0.94	103	127.67	0.81
7	109	82.21	1.33	117	120.36	0.97	112	119.29	0.94	66	51.81	1.27	109	94.95	1.15
8	94	85.93	1.09	84	74.26	1.13	97	100.79	0.96	71	60.96	1.16	112	121.95	0.92
9	82	70.76	1.16	99	107.44	0.92	103	114.20	0.90	54	37.64	1.43	100	99.24	1.01
10	56	51.71	1.08	64	63.63	1.01	76	108.08	0.70	64	92.77	0.69	60	70.94	0.85
TOTAL =	907	744	1.22	836	832	1.00	933	1020	0.91	573	583	0.98	902	944	0.96

TABLE G-5

O'BRIEN LOCK AND DAM

PANEL	23 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	THREE POINT METHOD (cfs)	COEF.	24 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	THREE POINT METHOD (cfs)	COEF.	25 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	THREE POINT METHOD (cfs)	COEF.	26 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	THREE POINT METHOD (cfs)	COEF.	27 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	THREE POINT METHOD (cfs)	COEF.
1	38	50.45	0.75	60	67.60	0.89	81	77.08	1.05	41	38.11	1.08	54	59.09	0.91
2	59	57.78	1.02	71	77.45	0.92	116	96.08	1.21	35	33.87	1.03	65	44.43	1.46
3	42	45.31	0.93	65	60.26	1.08	83	32.34	2.57	53	62.85	0.84	56	48.20	1.16
4	52	44.67	1.16	61	62.39	0.98	75	59.09	1.27	63	71.32	0.88	65	53.65	1.21
5	57	51.92	1.10	66	57.70	1.14	80	46.37	1.73	75	53.80	1.39	63	54.90	1.15
6	50	51.77	0.97	69	69.83	0.99	69	64.58	1.07	68	63.20	1.08	66	70.41	0.94
7	55	59.74	0.92	74	75.03	0.99	84	85.00	0.99	59	64.98	0.91	65	69.01	0.94
8	46	61.09	0.75	72	72.69	0.99	92	77.76	1.18	53	39.22	1.35	66	51.46	1.28
9	40	45.86	0.87	62	62.88	0.99	90	81.82	1.10	61	55.31	1.10	63	75.25	0.84
10	48	47.31	1.01	66	73.33	0.90	69	52.77	1.31	93	74.91	1.24	64	49.84	1.28
11	53	74.14	0.71	52	66.95	0.78	112	118.28	0.95	65	25.29	2.57	46	45.60	1.01
TOTAL =	540	590	0.92	718	746	0.96	951	791	1.20	666	583	1.14	673	622	1.08

PANEL	23 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	TWO POINT METHOD (cfs)	COEF.	24 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	TWO POINT METHOD (cfs)	COEF.	25 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	TWO POINT METHOD (cfs)	COEF.	26 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	TWO POINT METHOD (cfs)	COEF.	27 JULY 1990 PANEL DISCHARGES VERTICAL VELOCITY METHOD (cfs)	TWO POINT METHOD (cfs)	COEF.
1	38	41.20	0.92	60	67.60	0.89	81	68.00	1.19	41	28.86	1.42	54	31.77	1.70
2	59	42.68	1.38	71	74.43	0.95	116	31.96	3.63	35	38.56	0.91	65	50.58	1.29
3	42	29.53	1.42	65	51.09	1.27	83	-4.74	-17.53	53	77.09	0.69	56	57.54	0.97
4	52	29.11	1.79	61	56.36	1.08	75	31.77	2.36	63	57.28	1.10	65	56.72	1.15
5	57	55.09	1.03	66	57.70	1.14	80	4.55	17.60	75	77.75	0.96	63	45.47	1.39
6	50	42.27	1.18	69	69.83	0.99	69	59.96	1.15	68	58.43	1.16	66	76.68	0.86
7	55	43.47	1.27	74	65.53	1.13	84	80.27	1.05	59	60.07	0.98	65	72.22	0.90
8	46	48.47	0.95	72	63.50	1.13	92	86.92	1.06	53	48.74	1.09	66	51.46	1.28
9	40	21.97	1.82	62	48.40	1.28	90	64.58	1.39	61	64.35	0.95	63	66.39	0.95
10	48	35.61	1.35	66	79.27	0.83	69	57.17	1.21	93	28.78	3.23	64	61.94	1.03
11	53	99.53	0.53	52	76.20	0.68	112	77.30	1.45	65	20.46	3.18	46	64.51	0.71
TOTAL =	540	489	1.10	718	710	1.01	951	558	1.71	666	560	1.19	673	635	1.06

TABLE G-6

DATE	COEFFICIENTS: 3 POINT METHOD CRCW	3 POINT METHOD O'BRIEN	2 POINT METHOD CRCW	2 POINT METHOD O'BRIEN
23 JULY 1990	0.96	0.92	1.22	1.10
24 JULY 1990	0.98	0.96	1.00	1.01
25 JULY 1990	0.94	1.20	0.91	1.71
26 JULY 1990	1.17	1.14	0.98	1.19
27 JULY 1990	1.03	1.08	0.96	1.06