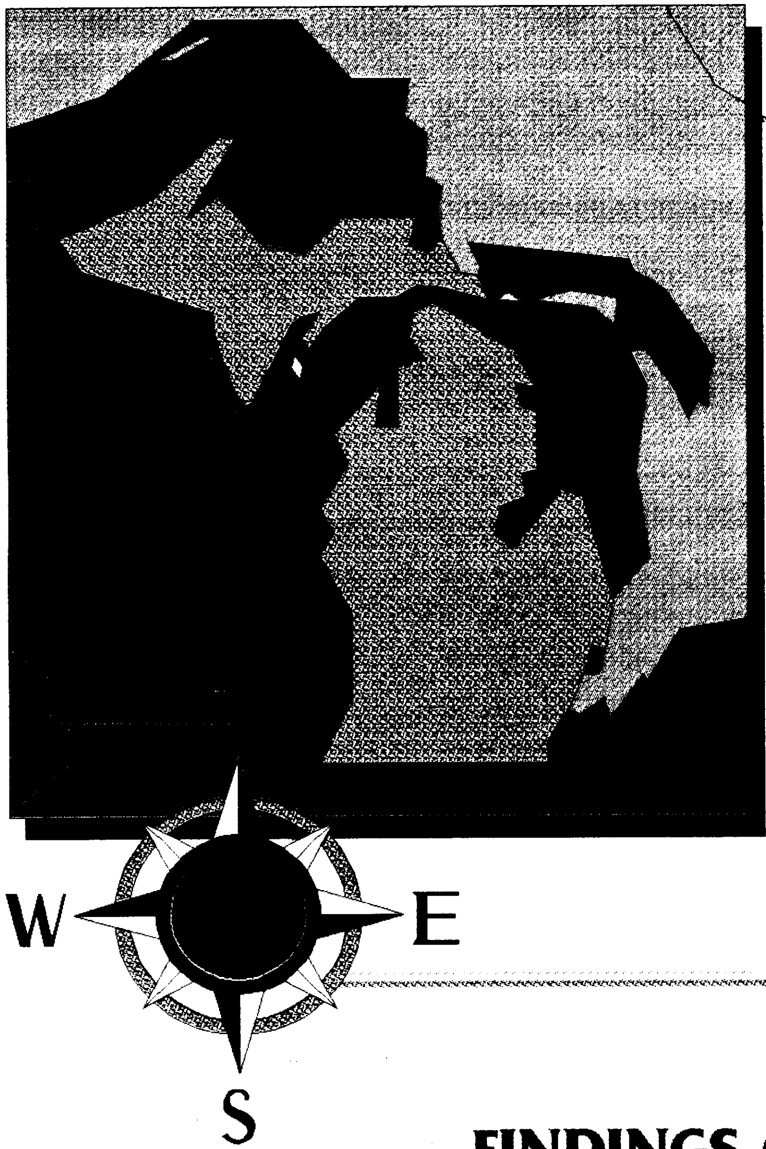
APPENDIX H

FINDINGS OF THE THIRD TECHNICAL COMMITTEE FOR REVIEW OF DIVERSION FLOW MEASUREMENTS AND ACCOUNTING PROCEDURES



LAKE MICHIGAN DIVERSION

FINDINGS OF THE THIRD TECHNICAL COMMITTEE FOR REVIEW OF DIVERSION FLOW MEASUREMENTS AND ACCOUNTING PROCEDURES

AUGUST 5, 1994

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Prepared for:
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Chicago District
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ACKNOWLEDGEMENTS

During the course of the Committee's work, a number of individuals and organizations were extremely helpful in assisting the Committee to accomplish its tasks. The Committee would like to express its appreciation for the assistance of the U.S. Army Corps of Engineers (USACE), Chicago District, and specifically, Mr. David Kiel and Mr. Thomas Fogarty for their contribution in providing numerous reports and data, and arranging and assisting the Committee in the various workshops and field trips. The Committee also acknowledges the assistance of Mr. Daniel Injerd, Illinois Department of Transportation (IDOT). Additionally, the Committee acknowledges the invaluable assistance from the U.S. Geological Survey (USGS) and especially from Mr. Kevin A. Oberg. The Committee acknowledges Ms. Mary Ellen Brown for her invaluable assistance in coordinating the preparation of this report and Mr. Harmon C. Miller for graphics support.

EXECUTIVE SUMMARY

The Third Technical Committee was appointed by the Corps of Engineers to conduct an assessment and evaluation of the accounting procedure and methodology used in the determination of the diversion from Lake Michigan and ascertain whether or not the methods are in accordance with the best current engineering practice and scientific knowledge, as stipulated in the 1980 modified Decree of the U.S. Supreme Court. This review is to be performed by a Technical Committee every five years, and a report evaluating the accounting and operational procedures is to be presented to the U.S. Army Corps of Engineers (USACE) and to other interested parties.

The Third Technical Committee was appointed by the Corps of Engineers in July of 1992 and convened in February of 1993. The Committee was appointed to conduct a comprehensive review of the current diversion accounting procedures. This task would consist of a review of the First and Second Committees' reports. Work would also include review of the automated diversion accounting system, the current diversion related measurement techniques at the Acoustical Velocity Meter Site, the Lockport control structure, the precipitation gage network, and other measurement locations to determine that these existing accounting measurement techniques and procedures are in accordance with the stipulation of the 1980 Supreme Court Decree. The specific objectives of the Committee were to (1) analyze of current diversion related measurement techniques and accounting procedures; (2) evaluate these techniques and procedures as to whether they are using the best current engineering practice and scientific knowledge; (3) recommend appropriate revisions within the legal constraints of the Decree; and (4) prepare draft and final reports.

The Third Technical Committee is in agreement with the findings of the 1987 report of the Second Technical Committee (Espey, et al, 1987). Considerable progress has been made in improvement of the accuracy of the current Lake Michigan diversion accounting procedures and measurements. Both the First and Second Technical Committees' recommendations have in general been initiated and/or completed. Significant progress has been made in upgrading the overall diversion program since the First Technical report in 1981.

With the incorporation of more sophisticated computer hydrologic models (HSPF, TNET, SCALP, etc.) in the accounting procedure, considerable effort has been expended to update basic model input and parameters as recommended by the Second Technical Committee. The Committee applauds the initiative of the Corps of Engineers for developing a better understanding of the complex hydrologic aspects of the accounting process with regards to flow diversion from Lake Michigan.

After confronting innumerable problems with the Sarasota AVM system which became operational in June 12, 1984, a new system (ORE, Inc.) was installed in November 1988, and reliable and more accurate flow records were being recorded by December 1, 1988. Analysis of these new data indicated the present flow diversion exceeds the limits set by the Court. The Committee concluded that the use of the more reliable AVM system contributed significantly to the improvement in accuracy of the accounting procedures.

The 1990-92 Annual Reports (USACE), which include Water Years 1986 through 1989 diversion, results indicate that the State of Illinois has exceeded the cumulative deviation (2,000 cfs) from the annual average diversion of 3,200 cfs by 2,189 cfs for Water Years 1981-1989. The Committee received (late July 1994) a draft copy of the Lake

Michigan Diversion Accounting Water Year 1993 Annual Report which includes 1990 diversion. This report indicates that the State of Illinois diverted 3,531 (Water Year 1990) and that the cumulative diversion has increased to 2,520 cfs years (Water Years 1981-1990).

The Committee's review and evaluation of Lockport and AVM records further support the conclusion that the earlier records at Lockport for low flow conditions were under reported, which represent primarily turbine flow. Since flow through the turbines on an annual basis represents approximately three-quarters of the amount of Lake Michigan diversion, the Committee recommends that Water Years 1981 through 1984 be re-evaluated with regards to the amount of diversion. The Committee recognizes the position of the Corps as stated in their 1988 annual report with respect to certification and the "moving target" issue related to management of Lake Michigan diversion. The Committee has concluded that the primary reason for the Lake Michigan diversion exceeding the flow limits of the Court is the improved accuracy of the accounting procedures and measurements. The major part of this improved accuracy can be attributed to the AVM system. The Committee has concluded, because of the significance of the 1990-92 Annual Report (Water Years 1986-89) and the draft 1993 Annual Report (Water Year 1990) indicating that the State of Illinois has exceeded the allowable cumulative diversion amount, that these diversion results will probably result in re-evaluation of the amount of Lake Michigan diversion. If this is the case, a re-evaluation of the entire record, beginning with 1980, would allow a more informed evaluation for possible future modifications of the amount of Lake Michigan diversion. In the Committee's opinion, more timely release of the Annual Reports of Lake Michigan diversion to the Court and all interested parties is important for timely and proper water management of Lake Michigan.

CHAPTER 1

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

The modified U.S. Supreme Court Decree for the Lake Michigan Diversion at Chicago, Illinois, adopted by the Court on December 1, 1980, provides the U.S. Army Corps of Engineers (USACE) convene a three-member Technical Committee at least every five years to review and report on the methods of flow measurement and procedures for diversion accounting. The Committee review is to include an evaluation of the current procedures used for the measurement and accounting of diversion in accordance with the best current engineering practice and scientific knowledge and recommendations for any appropriate changes to those procedures.

1.1.1 First Technical Committee

The first three-member Technical Committee was appointed in 1981 to review the diversion accounting procedures employed at that time. Their review and recommendations were reported (October 1981), and presented to the USACE for its use in providing supervision and direction of flow measurements, computations, and the accounting of diversion. As a result of review and comments by USACE, IDOT, MSD, and various other interested parties, an Addendum to the report was issued on March 30, 1982.

1.1.2 Second Technical Committee

In July 1986, the second three-member Technical Committee was appointed by the USACE to conduct its review of the diversion measurement and accounting procedures. Two of the three members of the Second Committee were also members of the First Committee. The purpose of the Second Committee review was twofold. First, to review the First Committee recommendations and the subsequent changes to the diversion measurements and accounting procedures during the past five years. Second, to review the current measurement techniques and accounting procedures used for computing diversion as being in accordance with the best current engineering practice and scientific knowledge. The basic tasks included: 1) analysis of current diversion-related measurement techniques and accounting procedures, 2) evaluation of these techniques and procedures as to whether the best current engineering practice and scientific knowledge are used, 3) recommendation for appropriate revisions within the legal constraints of the decree, and 4) preparation of draft and final reports.

1.1.3 Third Technical Committee

The third three-member Technical Committee was appointed by the USACE in July 1992, and convened in February of 1993, to conduct a review of the first and second Committees' reports and a comprehensive review of the current diversion accounting procedures. The Chairman, Dr. William H. Espey, Jr., has served in that capacity for both the first and second committees. Mr. Oscar Lara and Dr. Robert L. Barkau are new members.

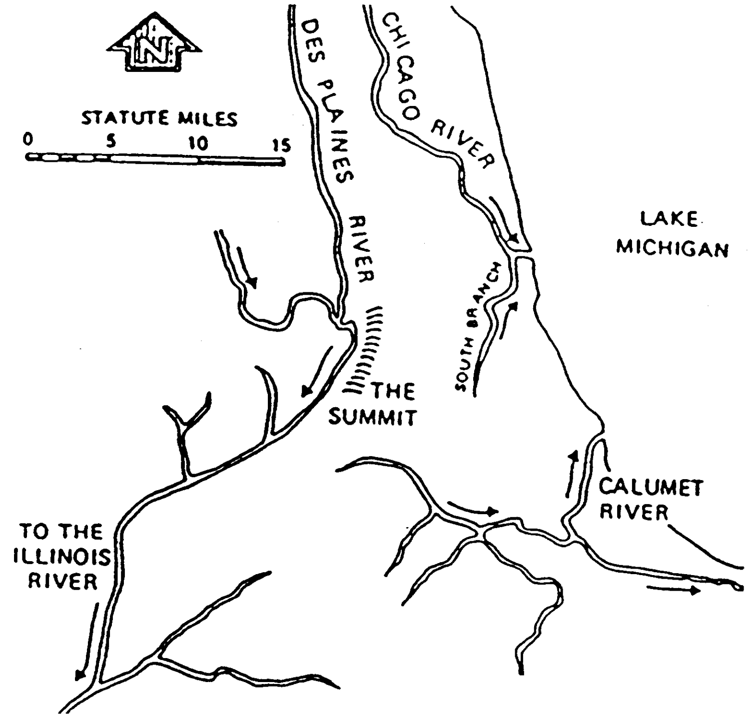
More specifically, the work included the review of the automated diversion accounting system as well as the review of current diversion related measurement techniques at the AVM site, the Lockport control structures, the precipitation gages, and other pertinent locations to determine the adequacy of these existing accounting procedures in accordance with the stipulations of the 1967 Supreme Court decree as modified in 1980. The basic tasks included: 1) analysis of current diversion-related measurement techniques and accounting procedures, 2) evaluation of these techniques and procedures as to whether they are using the best current engineering practice and scientific knowledge, 3) recommendation of appropriate revisions within the legal constraints of the decree, and 4) preparation of draft and final reports.

1.2 History of Lake Michigan Diversion

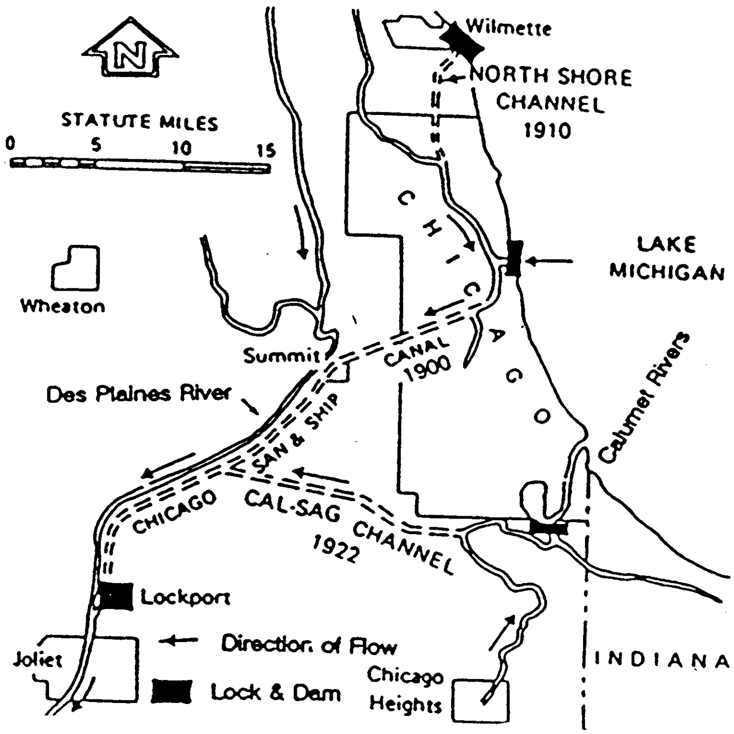
Water diversion from Lake Michigan at Chicago into the Mississippi River basin began in 1848 upon the completion of the Illinois and Michigan Canal at an average rate of 500 cfs. The current diversion of water from Lake Michigan at Chicago by the State of Illinois began in 1900 with the completion of the Sanitary and Ship Canal by the Metropolitan Sanitary District of Greater Chicago (MSD) as illustrated in Figure 1.1.

In 1908 and again in 1913, the United States brought actions to enjoin MSD from diverting more than the 4,167 cfs previously authorized in 1901. The two actions were consolidated, and the Supreme Court entered a decree on January 5, 1925 allowing the Secretary of War to issue diversion permits. In March of the

FIGURE 1.1



Rivers in Chicago Region Before 1848



Diversion in Canal System

same year, a permit was issued to divert 8,500 cfs which was about the average then being used.

In 1922, 1925, and finally in 1926, several Great Lakes states filed similar original actions in the U.S. Supreme Court seeking to restrict diversion at Chicago. A Special Master, appointed by the Court to hear the combined three suits, found the 1925 permit to be valid and recommended dismissal of the action. However, the Supreme Court reversed his finding. Subsequently, the Court instructed the Special Master to determine the steps necessary for Illinois and MSD to reduce diversion. Consequently, a 1930 Decree reduced the allowable diversion (in addition to domestic pumpage) in three steps: 6,500 cfs, after July 1, 1930; 5,000 cfs after December 30, 1935; and 1,500 cfs after December 31, 1938.

The 1967 Decree limited the diversion, including domestic pumpage, to an average of 3,200 cfs over a five-year running accounting period. The first accounting period began March 1, 1970 and ended to February 28, 1975. During this period, the average diversion was 3,183 cfs. The sixth and latest accounting period began March 1, 1975 and ended February 29, 1980. During this period, the average diversion was 3,044 cfs.

The U.S. Supreme Court amended its 1967 Decree on December 1, 1980. The amendment changes, in part, the provisions of the 1967 Decree which prevented the State of Illinois from effectively utilizing and managing the 3,200 cfs of Lake Michigan water which had been allocated previously by the Court.

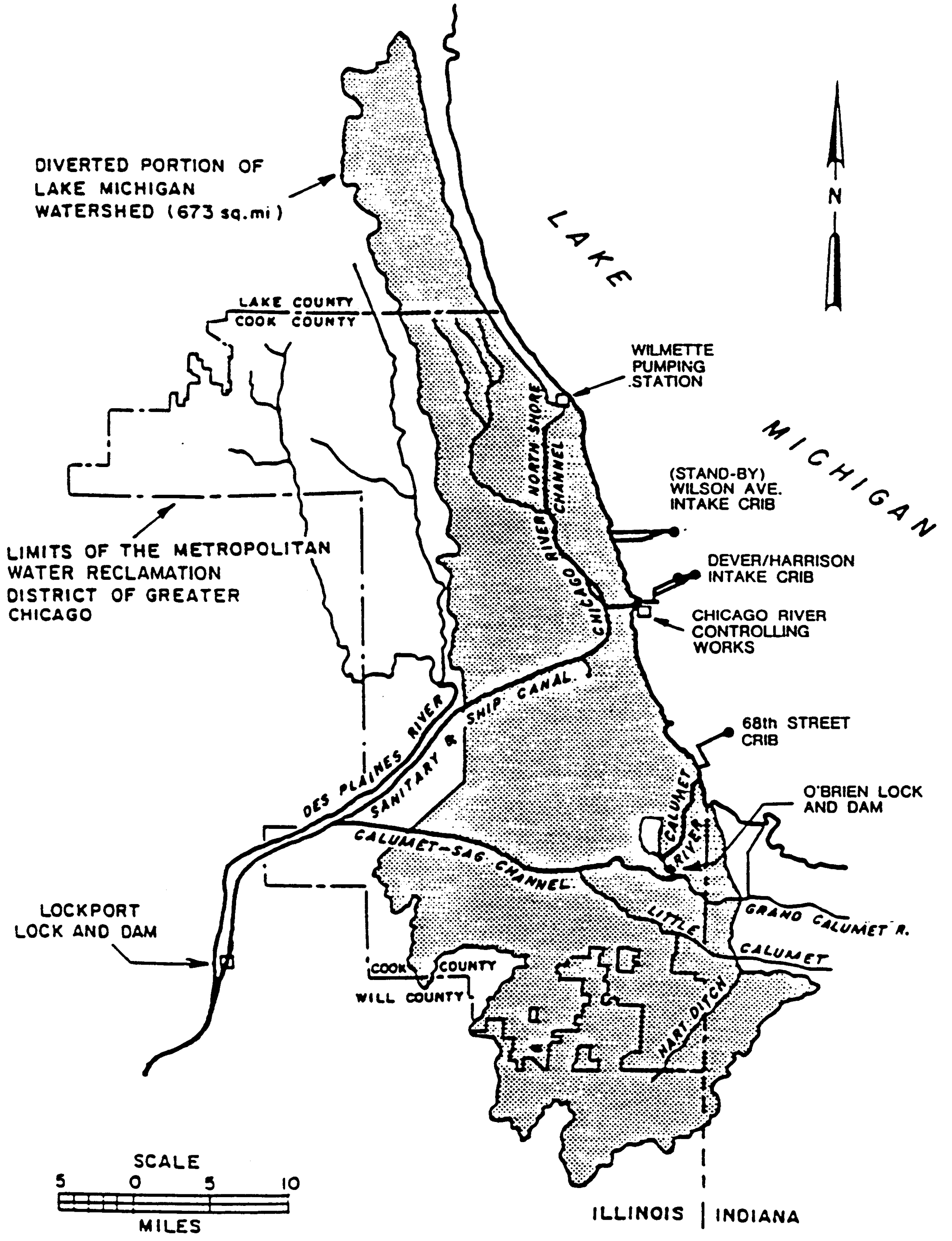
This amendment forms the current diversion criteria this report addresses. These criteria can be summarized as follows:

1. An increase in the period for determining compliance with the diversion rate limit from a 5-year running average to a 40-year running average;
2. Changing the beginning of the accounting year from March 1 to October 1;
3. A limit on the average diversion in any accounting year to 3,680 cfs, except for an average diversion of 3,840 cfs in any two accounting years within a 40-year period; and
4. A limit on the cumulative algebraic sum of the average annual diversions minus 3,200 cfs during the first 39 years to 2,000 cfs-years.

1.3 COMPONENTS OF DIVERSION

The geographic area of concern is illustrated in Figure 1.2 which shows part of Lake Michigan, the diverted watershed, the canal system, and the location of the major hydraulic structures. The primary components of the Lake Michigan diversion are illustrated in Figure 1.3. The contribution shown for each water supply for Accounting Year 1989 from Lake Michigan intake cribs and discharged into the river and canal system in the greater Chicago area as treated sewage is 61.1 percent.

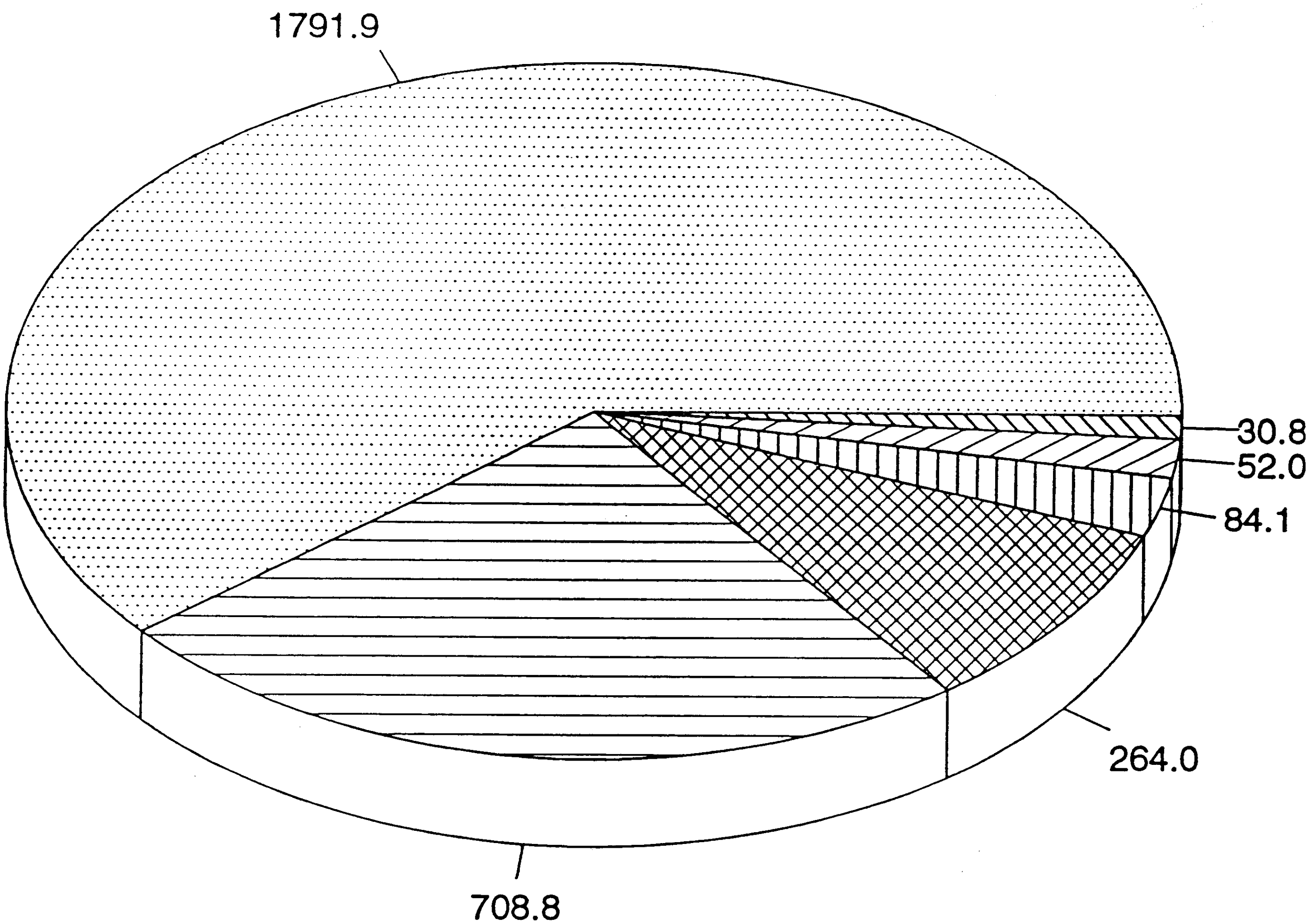
FIGURE 1.2



LOCATION PLAN-LAKE MICHIGAN DIVERSION AT CHICAGO

FIGURE 1.3

Component Breakdown of Illinois' Lake Michigan Diversion - 1989



DIVERSION COMPONENTS

WATER SUPPLY 61.1 %
RUNOFF 24.2 %
DISCRETIONARY 9.0 %
LOCKAGES 2.9 %
NAV MAKEUP 1.8 %
LEAKAGES 1.0 %

1.4 COMMITTEE FINDINGS

1.4.1 Review of First Committee Report

The report of the first three-member Technical Committee, dated October 1981, provided a discussion of the history of diversion, the components of diversion, and the various flow measurements and computations used to determine diversion. The First Committee found virtually every aspect of the program to account for diversion of Lake Michigan to be in need of improvement. The diversion accounting process lacked credibility. The measurement of flow at Lockport, the cornerstone for diversion accounting, at that time, was found to be lacking with respect to best current engineering practice and scientific knowledge and deficient in terms of techniques and reliability.

The First Committee report was reviewed to establish a base of reference for the evaluation of diversion activities initiated since 1981. The following brief summary of recommendations made by the First Committee was useful for that purpose:

- Preparation of a Master Plan for Diversion Accounting;
- Establishment of a Quality Assurance Program including an Operational Procedure Manual;
- Consideration of Alternatives to Measurements at Lockport Facilities; and
- Modifications and improvements to Flow Measurement Practices for Facilities including:

- Lockport turbines
- Lockport powerhouse sluice gates
- Lockport controlling works

The Committee also recommended modifications to flow measurements practices for Lockport lock leakage.

- Monitoring of Flow Measurement Devices for Industrial Diversion
- Modifications for Flow Measurement Practices for Domestic Pumpage
- Modifications to Flow Measurement Practices for Storm Runoff and Infiltration from Illinois Watershed
- Revaluation of Upper Des Plaines Pumping Station Data

1.4.2 Review of Second Committee Report

The following is a brief summary of the major conclusions and recommendations of the Second Committee.

1.4.2.1 First Technical Committee Report (1981)

1. The Second Committee was in general agreement with the findings and recommendations made by the First Committee (1981).
2. The Master Plan for diversion accounting and the Quality Assurance program are essential elements of the diversion accounting program.

1.4.2.2 Diversion Accounting Reports Water Years 1981 -1984

1. The diversion accounting certification report should provide the reader a narrative description of the facts which support the certification evaluation.

2. At some appropriate time, probably no earlier than after the completion of the 1987 Water Year, the diversion records for water years after 1980, should be reviewed, and if appropriate, revised as necessary to account for the apparent errors in the Lockport discharge rating used during the 1981-84 Water Years.

1.4.2.3 Diversion Accounting Procedures

1. Columns 7 and 9, representing the so-called sewer induced groundwater inflow should be withdrawn from the diversion accounting format.
2. Columns 4 and 15 of the Diversion Accounting Report should be discontinued.
3. Action should be initiated to address the deficiencies in the data bases for parameter values and model calibration, verification, and simulation, especially as they pertain to those drainage areas used directly in computing diversion (e.g., Column 8 deductions).
4. Examine the constancy of the relation between water supply pumpage and sewage treatment plan inflows and its applications for the purpose of estimating infiltration and inflow deductions for the Des Plaines watershed.
5. Reconsider the alternatives (modeling, etc.) for estimating the annual runoff from the Lake Michigan watershed.
6. Redefine or restate the goals and technical objectives for the simulation modeling.

7. Evaluate the simulation modeling requirements within the frame of reference provided by recommendations 2-6 above.

8. Measures should be taken, depending on the response to the broader recommendations given above, to deal with the unreported inflows perceived to be derived from the waterways and reported in Columns 8 and 14.

1.4.2.4 Acoustical Velocity Meter - Romeoville

1. The efforts by the USGS to establish written guidelines to promote improvement in the quality of the AVM records should be continued.

2. The current regressions of the daily discharges for the AVM and MSD Lockport, used for the AVM back-up, should be reconsidered specifically giving attention to the actual Lockport operating configurations.

3. A technical review of the AVM flow records should be conducted annually by the participating agencies.

4. The flow records for the AVM and MSD Lockport should be reviewed and compared for consistency on an annual basis.

5. The mean bed elevation for the canal in the reach defined by the transducer locations should be determined, as well as along the transducer paths.

1.4.2.5 Lockport Lock and Dam Facilities

1. The Lockport facilities of MSDGC and USACE should be used for the back-up to the AVM system at Romeoville.

2. Execute a set of field measurements designed to verify the WES ratings for both the Lockport Powerhouse sluice gates and the Controlling Works.

1.4.2.6 TARP

1. Infiltration and inflow of groundwater into the TARP tunnels should be treated as a deduction to the flows measured at Lockport. It should be computed by using the inflow rate of 0.05 MGD per mile of tunnel.
2. The runoff to the TARP system from the Lower Des Plaines combined sewer system should be determined and included in Column 8 as a deduction.

2.0 REVIEW OF LAKE MICHIGAN DIVERSION ACCOUNTING PERIOD 1981-1989

2.1 FIRST AND SECOND TECHNICAL COMMITTEES FINDINGS - ACCOUNTING PERIOD 1981-1986

Based in part on the recommendations (by the First and Second Technical Committees) to diversion accounting procedures along with the modifications to diversion accounting as contained in the amended Decree, numerous changes were made to the Lake Michigan accounting procedures for diversion during the past nine years. To logically review and evaluate these changes in chronological order, a discussion will be presented of each annual report prepared by the USACE. The three annual reports on Lake Michigan diversion reviewed by the First Technical Committee provide a detailed accounting of diversion flow for Water Years 1981-83 and diversion-related activities through Water Year 1986. Under the terms of the modified Decree, the USACE is required to report annually to the parties of the litigation on the measurement and computation of diversion by the State of Illinois.

2.1.1 1983 Annual Report

The report of the diversion for Water Years 1981 and 1982 is dated September 1983, some 16 months after completion of the First Technical Committee's work. The Corps certification of the 1981-82 diversion accounting is without qualifications. The First Technical Committee questioned the unqualified certification of the diversion record by USACE in light of deficiencies in the Lockport measurement system.

2.1.2 1985 Annual Report

The 1985 Annual Report contains IDOT's computation of diversion flow for Water Year 1983, as well as a summary of significant hydrologic and related events through Water Year 1985. The diversion flow of Water Year 1983 is based on a new accounting procedure. The procedure, proposed by IDOT, utilizes a NIPC-developed version of the Hydrocomp computer simulation model. The technical merits of the new process are examined in detail in Section 3.0.

The IDOT report of the 1983 Water Year diversion is appended to the Corps' 1985 Annual Report. Several problems encountered in the first year's use of the new accounting process were discussed by IDOT. The USACE review of the 1983 Water Year diversion flows addresses the accounting process in some detail but does certify the diversion record without qualification. The process used to certify the 1983 Water Year diversion is somewhat paradoxical because the process, a comparison of similar trends for AVM vs. MSD Lockport and MSD Lockport simulated vs. recorded flows, clearly suggests errors in the MSD Lockport recorded flows, both high and low.

2.1.3 1986 Annual Report

Section 1142 of the Water Resources Development Act of 1986, Public Law 99-662, provides that beginning on October 1, 1987, the Secretary of the Army in cooperation with the State of Illinois shall carry out measurements and make necessary computations required by the Supreme Court decree.

2.1.4 Summary of First and Second Technical Committees' Findings

The review of the USACE Annual Report is in essence a review of the USACE diversion related activities. The annual reports should reflect the direction, activity, and evaluation of the diversion accounting process. The presentation should be objective, substantive, and informative enough for the interested parties and the Court to fully understand and appreciate the technical considerations of the accounting process. The evaluation of the annual diversion record should include narrative statements which provide the reader with an understanding of the process. The narrative should provide information describing the quality of the basic records and the analytical techniques in sufficient detail to support whatever diversion record certification is made. For example: the certification of the diversion records for 1981-82 Water Years should have been, at least, certified with the condition that the 1981 Technical Committee found cause to suspect inaccuracies, perhaps even significant errors, in the Lockport flow record for prior years. Similarly, the 1983 Water Year record certification should have been conditional because of the questionable ratings for the Lockport turbines. Certainly, the certification statement for all three years should have provided for a subsequent review and revision of the diversion records if found to be necessary. At some appropriate time, probably no earlier than after completion of the 1987 Water Year, the diversion records for the period after 1980 should be reviewed, and if appropriate, revised to account for the apparent errors in the Lockport ratings used during the 1981-84 Water Years.

2.2 Third Technical Committee Review, Findings and Recommendations - Accounting Period 1986-1989

As part of the U.S. Corps of Engineers responsibilities as stated in the modified U.S. Supreme Court Decree (1980) for Lake Michigan diversion at Chicago, Illinois, adopted by the Court on December 1, 1980, is the issuing of annual reports on the measurements and computations of Lake Michigan diversion at Chicago, Illinois. Summarized in Table 2.1a and 2.1b is a Chronological history of major technical events regarding the Lake Michigan diversion program with respect to the Technical Committees.

TABLE 2.1a

CHRONOLOGICAL SUMMARY OF LAKE MICHIGAN DIVERSION EVENTS		
First Technical Committee Convened June 1981, Final Report - October 1981 Reviewed Status of Diversion Computation as Stipulated by the 1980, Modified Decree of the U.S. Supreme Court		
Second Technical Committee		
Annual Report	**Water Year Diversion Results**	**Remarks**
1981, 1982 Annual Report 11/83 - Released	1981/82	First Technical Committee convenes June 1981 Lockport Measurement Site - First Committee Report (October 1981 Harza report proposed new diversion accounting system WY 81-82 Diversion certified despite Technical Committee (1981) concerns regarding Lockport rating
1983, 1984, 1985 Annual Report 2/86 - Released	1983	New Accounting System (NIPC) Use hydrologic computer models. WES Report (1985) Powerhouse and Controlling Works sluice gate - new rating resulted in a reduced diversion (180 cfs) for 1988 WY AVM installation (March 18-23, 1984), AVM data suggest Lockport Turbine/low flows consistently low. 1983 diversion certified despite concerns on Lockport rating (Technical Committee, 1981) findings
1986 Annual Report 3/87 - Released	X	TARP - Began new accounting system, development of a computerized water budget, HEC analysis of Hydrologic Simulation procedures Second Committee convenes
Legend: WY = Diversion Calculation X = No diversion results		

CHRONOLOGICAL SUMMARY OF LAKE MICHIGAN DIVERSION EVENTS

Third Technical Committee

Annual Report	Water Year Diversion Results	Remarks
1987 Annual Report 9/88 - Released	X	The Water Resource Development Act of 1986 gave USCE responsibility for the computation of diversion flow. (effective October 1987) Second Technical Committee draft report (in review)
1988 Annual Report 3/89 - Released	X	Continuing problems with AVM - new system; new AVM system to be installed Diversion Accounting certification suspended in FY 88 pending revision of modeling parameters Second Technical Committee Final Report (November 1987) Released
1989 Annual Report 11/93 - Released	1984-85	November 1988 - ORE AVM installed First Annual Report that USCE assumes responsibility for the compilation of diversion Diversion Account Report developed by NIPC, reviewed and updated by USCE USCE updated model parameters and revised 1984-85 flows based on AVM records
1990-92 Annual Report 1/94 - Released	1986-87 1988-89	New Regression Equations (USGS)(WY 86, 87, 88, 89) — 1986 problem with AVM Modeling update - TARP — 1987 AVM - little missing record Lakefront measurements — 1988-89 Solar Radiation Correction New rain gage network - installed (October 1990) Grand Calumet River West Branch gage established Diversion results indicated State of Illinois exceeded allowable diversion - 1988
1993 - Annual Report+ 8/94 - Draft	1990	Incorporate the 25-gage precipitation network into the WY 1990 diversion accounting procedures and computations. In addition, updated combined sewer special contributing areas and land-use/land-cover to reflect the revised precipitation network and land cover assignments.
Future		Des Plaines Pumping Station Investigation Lakefront measurements/analysis Additional ADCP measurements at Romeoville Grand Calumet River Gage first used WY 1991
Legend:	WY = Diversion Calculation X = No diversion results	

+Committee received the Draft Report in late July 1994, during final preparation of the Committee's report; therefore, time did not permit a detailed review of this report.

2.2.1 1987 Annual Report (no diversion accounting report)

The 1987 Annual Report was published in July of 1988 and did not include any diversion accounting for Water Year 1987. The report is a summary of events occurring during the 1987 Water Year. During this reporting period, the 1984 Water Year accounting report, which had been submitted by the State of Illinois, was under review. Major events during this period included the performance and evaluation of the Sarasota acoustical velocity meter to measure flow at Romeoville and the refinement of the new diversion accounting system and progress made by the Second Technical Committee. Based on the Water Resources Development Act of 1986, the Corps assumed, effective October 1, 1987, total responsibility for the measurements and computations necessary to account for the amount of water diverted from Lake Michigan at Chicago. Based in part on a recommendation by the First Technical Committee, a master plan for Lake Michigan diversion monitoring activities was developed and presented in the 1986 Annual Report. The purpose of this master plan was to define the responsibilities of the Corps of Engineers with regards to Lake Michigan diversion, establish routine annual goals and objectives, establish a generic annual schedule of activities and provide specific short- and long-range objectives for this program. An important part of this master plan was a series of standard operating procedures. A major element of the Corps' activity during 1987 was assisting the Second Technical Committee in prosecution of its work. The Second Technical Committee was convened in July 1986. The first two workshops were convened during the 1986 Water Year. The work of the Committee continued throughout the course of the 1987 accounting year with two additional workshops. The third workshop was held in Chicago, October 21 through 24, 1986. The fourth workshop was also held in Chicago from January 27 through 30, 1987. The initial draft of the Committee's report was provided to the Corps on June 9, 1987, and a second draft on August 3, 1987. The final Committee report was submitted to the Corps in November 1987.

2.2.2 1988 Annual Report Review (no diversion accounting report)

The 1988 accounting year represents a transition to the USACE of primary responsibility for diversion computations. The 1988 Annual Report discussed modifications, based on the Second Committee's findings, to the hydrologic modeling parameters used in the diversion accounting. The Chicago District, in cooperation with the U.S. Geological Survey, contracted with ORE, Inc. for installation of a new AVM measurement flow at Romeoville because of the continuing problems with the Sarasota AVM. The Chicago District released a draft report "Acoustic Velocity Meter Regression Analysis" (August 1988) for an AVM backup system, as recommended by the Second Technical Committee. Mainstream Tunnel and Reservoir Plan (TARP) was brought on line at the beginning of FY 1986. The TARP impact and diversity will be a simulated and incorporated into the accounting diversion procedure prior to the FY 1986 accounting year.

In summary, the Lake Michigan diversion accounting program experienced significant modifications of the technical methodology and procedures used in computing the total flow at Lockport and in the computations of diversion deductions. The 1988 Annual Report was released March 1989.

2.2.3 1989 Annual Report Review (Water Year 1984 and Water Year 1985 accounting reports)

The 1989 accounting year was marked the first year in which the Chicago District Corps of Engineers initiated compiling the diversion accounting data and calculating Lake Michigan diversion flows. The Second Technical Committee completed its report November 1987. Major activities described in this Annual Report included revision of the diversion accounting modeling parameters development of a backup system to the AVM system, and installation of precipitation gage network. The 1989 Annual Report was released in November 1993. This report presented the accounting computation for Lake Michigan diversion for Water Year 1984-85, the first published since the First Technical Committee Report. The 1984-85 Water Year accounting flows developed by NIPC were recalculated based on revised modeling parameters and based on AVM flows rather than Lockport flows for water year 1984. The Corps updated the modeling parameters and calculated AVM flows for Water Year 1984 using Lockport flows and the regression equation AVM backup system. The Corps recalculated the diversions for both Water Year 1984 and Water Year 1985 using the updated modeling parameters and Romeoville AVM flows. Water Year 1984 was the first year in which the AVM (installed March 1984 and began reporting June 12, 1984) was used to measure the flow in the canal system. In Water Year 1984, the AVM measured flow was 314 cfs greater than the Lockport flow, and in Water Year 1985, the AVM flow was 229 cfs greater than the Lockport flow.

2.2.4 The 1990 - 1992 Annual Report Review (diversion accounting years 1986, 1987, 1988, and 1989)

The 1990-1992 Annual Report was released in draft form in November 1993, and the final in January 1994. The 1986 Water Year accounting was a joint effort with NIPC and the Corps of Engineers. Water Years 1987, 1988, and 1989 were calculated by the Corps of Engineers. This represents approximately a seven-year delay in releasing the diversion computations for Water Year 1986. Major accomplishments during this reporting period include the following:

1. Hydrologic simulation models were revised and updated to reflect the addition and impact of the TARP system.
2. The Illinois State Water Survey initiated and collected data from a precipitation network which included 25 gages.
3. New regression equations were developed for the Romeoville AVM gage for calculating flows when the AVM is out of operation. The USGS revised the regression equations, and the updated flows have been included in the accounting report for Water Year 1986 through 1989. The 1990-1992 Annual Report reflects a comprehensive presentation of the U.S. Corps of Engineers diversion related activities. The report reflects a detailed

discussion of the various activities, computational and evaluation processes of the diversion accounting process. This Annual Report provides the basis for interested parties and the Court to evaluate the technical aspects of the accounting process.

2.2.5 Summary of Lake Michigan Diversion Accounting

Lake Michigan diversion flow data are summarized in accounting reports prepared on an annual basis as flows are certified. Table 2.2 presents certified accounting flows for Water Years 1981-1989, the running average flows, and the cumulative deviation from the allowable diversion of 3,200 cfs.

Table 2.2

Status of the State of Illinois' Diversion from Lake Michigan

Under the 1980 Modified U.S. Supreme Court Decree

Accounting Year	Certified Flow (cfs)	Running Average (cfs)	Cumulative Deviation (cfs)
1981	3,106	3,106	94
1982	3,087	3,097	207
1983	3,613	3,269	-206
1984	3,432	3,310	-438
1985	3,472	3,342	-710
1986	3,751	3,410	-1,261
1987	3,774	3,462	-1,835
1988	3,376	3,451	-2,011
1989	3,378	3,443	-2,189

The running average diversion for the period Water Year 1981 through Water Year 1989 is 3,443 cfs, 236 cfs greater than the 3,200 cfs, 40-year average diversion specified by the modified decree. The annual flow has twice exceeded 3,680, the maximum number of occurrences allowed under the decree, and the annual flows have not exceeded the two-year upper limit of 3,840 cfs. The cumulative deviation, the sum of the annual average flows over the allowed 3,200 cfs, is -2,189 cfs-years. The negative cumulative deviation indicates a flow debt against the maximum debt allowed of 2,000 cfs-years over the first 39 years of the 40-year averaging period.

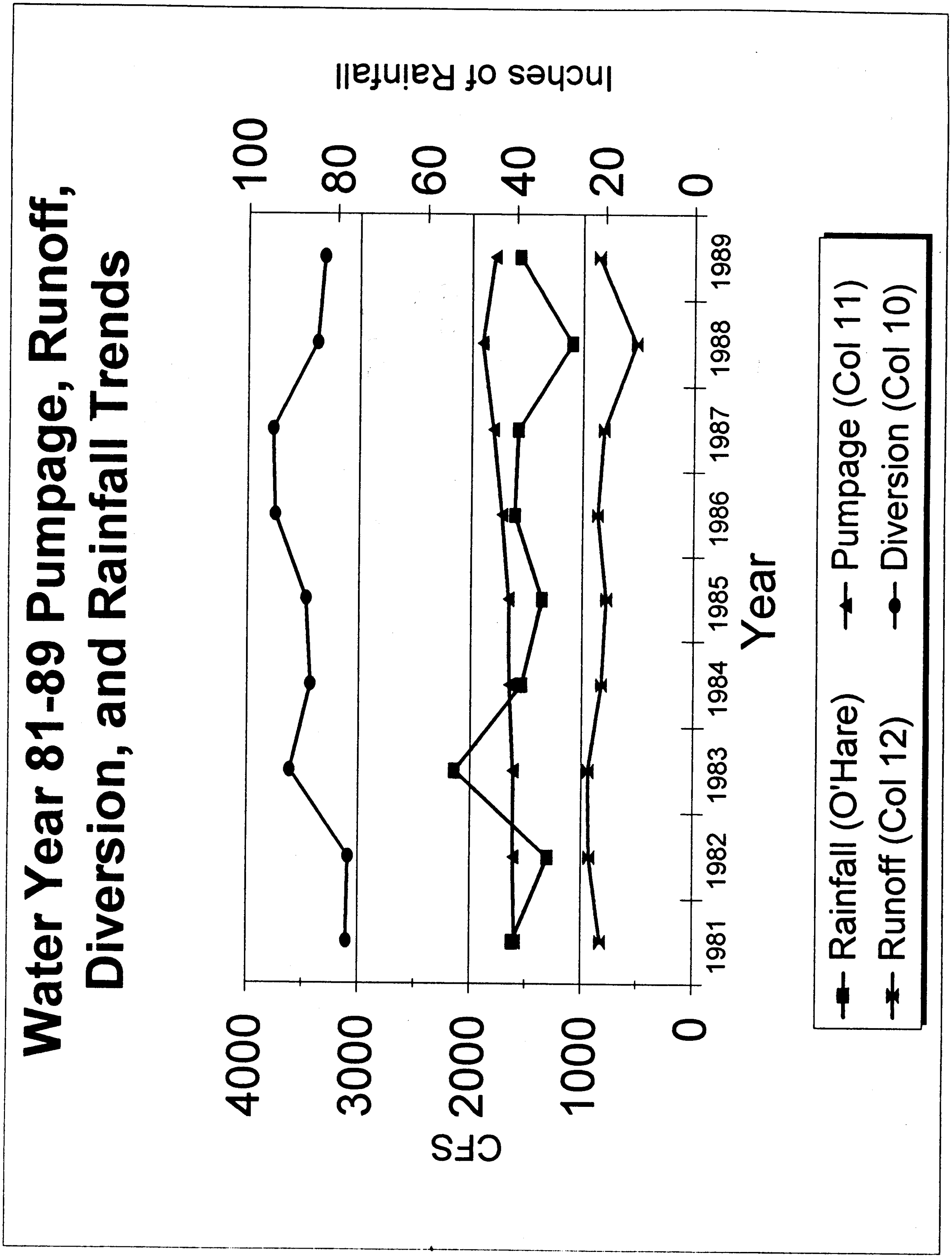
2.2.6 Technical Committee's Findings and Recommendations

The modified U.S. Supreme Court Decree (1980) for Lake Michigan diversion at Chicago, Illinois required that an annual report on the measurement and computations of Lake Michigan diversion be issued by the Corps of Engineers. This annual report was the instrument to release information and the results of the Lake Michigan diversion computations. These annual reports, therefore, provide the basis for interested parties and Court to understand and evaluate the progress and status of the Lake Michigan diversion. The Second Technical Committee recommended these annual reports include narrative statements which would aid the reviewer in understanding the Lake Michigan diversion process. These narratives should provide information describing the quality of the basic record and the analytical techniques in sufficient detail to support whatever diversion record certification is made by the Corps of Engineers. The Second Committee took exception to the Corps' certification of the diversion record for 1981 and 1982 Water

Years in light of the findings of the 1981 Technical Committee with regards to apparent errors in the Lockport flow. Similarly, the Second Technical Committee further questioned the certification of the 1983 Water Year with regards to questionable rating for the Lockport turbines. The 1990-92 annual report is a significant improvement toward providing interested parties with a comprehensive, orderly presentation of the components of diversion with regards to methodology, technical approach, and the various issues with regards to the determination of the amount of Lake Michigan diversion. The 1990-92 Annual Report represents the first combination of multiple year (three) annual reports finally released in January 1994. This combined annual report contains diversion results for 1986 through 1989 Water Years. The release of this 1990-92 Annual Report reflects considerable delay in the release of the annual diversion computations. The reasons for delay are combinations of various technical issues not being timely resolved combined with the lack of resources and appropriate priorities. Because of the obvious major issue concerning the State of Illinois exceeding the Court's cumulative diversion of 2,000 cfs, a more timely release of this information could have allowed a more timely response by the various parties and possible action by the State of Illinois with regards to management alternatives.

Analysis of historical trends in the Lake Michigan data (Figure 2.1) suggest that basically pumpage and runoff have not increased significantly while Lake Michigan diversion displayed a marked increase in 1983. Water Year 1983 was a "wet" year and also marked the first year the AVM was used to compute Lake Michigan diversion. The Committee has concluded that the primary reason for the Lake Michigan diversion exceeding the flow limits of the Court is the improved accuracy of the accounting procedures. The major part of this improved accuracy can be attributed to the AVM system.

FIGURE 2.1



Water Year 81-89 Pumpage, Runoff, Diversion, and Rainfall Trends
CFS
0
1000
2000
3000
4000
Inches of Rainfall
0
20
40
60
80
100
1981
1982
1983
1984
1985
1986
1987
1988
1989
Year
Rainfall (O'Hare)
Pumpage (Col 11)
Runoff (Col 12)
Diversion (Col 10)

Chapter 3

3.0 REVIEW OF CURRENT ACCOUNTING SYSTEM

There are three components to the Lake Michigan diversion: direct diversion through three lakefront structures; pumpage from the lake for domestic water supply which is not returned to the lake; and stormwater runoff from the Lake Michigan watershed that is diverted from the lake. Direct diversion occurs at the Chicago River Controlling Works, the O'Brien Lock and Dam, and the Wilmette Controlling Works and consists of four components: lockage, leakage, discretionary flow, and navigation makeup flow. Discretionary flow is that which the MWRDGC (note changed from MSD) releases to dilute the effluent from sewage discharges into the canal. Navigation makeup flow is used by the MWRDGC to raise the level of the canal after it has been drawn down in anticipation of a rain event. Domestic pumpage is used to provide Chicago and suburbs with its water supply. The effluent resulting from that water supply is discharged into Water Reclamation's plants and eventually discharged to either the canal system or the Des Plaines River and its tributaries. Stormwater runoff that previously drained into Lake Michigan now drains into the Chicago Sanitary and Ship Canal or the Calumet Sag Channel (SCCS).

The amount of diversion is calculated using an acoustic velocity meter (AVM) which has been installed at Romeoville, just upstream from Lockport. The AVM measures the total flow of water in the CSSC. Most of the Lake Michigan diversion flows, and some non-Lake Michigan flows, flow by the AVM site. The diversion accounting system takes the total flow measured at Romeoville and subtracts from it, flows not attributable to the diversion. Diversion flows which by pass Romeoville are added to the figure derived from the AVM, yielding the net computed diversion of water from Lake Michigan.

Deductions from Romeoville include groundwater supply effluent discharged into the canal, Lake Michigan pumpage by Federal facilities that discharge to the CSSC; runoff from the Des Plaines River watershed discharged into the canal, domestic pumpage from all sources by Indiana and Wisconsin the effluent of which reaches the CSSC, and any water diverted by Illinois into the Lake from outside the Lake Michigan watershed. Any amount of domestic pumpage by Illinois, the effluent of which bypasses the canal and instead reaches the Illinois waterway is then added to the amount at Romeoville.

3.1 Accounting Report

The format of the diversion accounting tables have been revised for Water Year 1986 due to the streamlining of the computational process and to make the results easier to interpret. The diversion accounting results are presented as a series of columns that are listed in Table 3.1 and Table 3.2 (Example Water Year 1989). Appendix 1 describes the various components of Columns 4-13. Column 1 through 3 compute the total flow in the Sanitary and Ship Canal. Column 4 through Column 7 presents the deductions from the Canal system flows with the total deduction in Column 8. Column 9 presents the additions to the Canal system record. Column 10 is the computed Lake Michigan diversion accountable to Illinois and is equal to the canal system flow minus the deductions plus the additions. Columns 11 through 13 are independent flow estimates for the three sources of diversion: water supply pumpage from Lake Michigan, runoff from the diverted Lake Michigan Watershed, and direct diversion through the lakefront structures. Column 11 through Column 13 are not used in the diversion calculation but are included as another estimate of the diversion for comparison of the diversion flows in Column 10. The sum of Column 11 through Column 13 should theoretically equal the flow in Column 10.

TABLE 3.1

Description of Diversion Accounting Columns

COLUMN	DESCRIPTION
1	Chicago Sanitary and Ship Canal (CSSC) at Romeoville, USGS AVM Gage Record
2	Diversions from the CSSC above the Gage
3	Total Flow Through the CSSC
4	Groundwater Pumpage Discharge into the CSSC and Adjoining Channels
5	Water Supply Pumpage from Indiana Reaching the CSSC
6	Runoff from the Des Plaines River Watershed Reaching the CSSC
7	Lake Michigan Pumpage by Federal Facilities Which Discharge to the CSSC
8	Total Deduction from the CSSC Romeoville Gage Record
9	Lake Michigan Pumpage not Discharged into the CSSC
10	Total Diversion Accountable to the State of Illinois
11	Pumpage from Lake Michigan Accountable to the State of Illinois
12	Runoff from the Diverted Lake Michigan Watershed
13	Direct Diversion Through Lake Front Control Structures Accountable to the State of Illinois

Lake Michigan Diversion Accounting – WY 1989

Summary of Diversion Flows (cfs)

LAKE MICHIGAN DIVERSION ACCOUNTING WY 1989	ROMEOVILLE GAGE RECORD	DIVERSIONS ABOVE THE GAGE	TOTAL FLOW THROUGH THE CANAL	GROUNDWATER PUMPAGE DISCHARGED INTO THE CANAL	WATER SUPPLY PUMPAGE FROM INDIANA REACHING THE CANAL	RUNOFF FROM THE DES PLAINES RIVER WATERSHED REACHING THE CANAL	LAKE MICHIGAN PUMPAGE BY FEDERAL FACILITIES DISCHARGED TO THE CANAL	TOTAL DEDUCTION FROM THE ROMEOVILLE GAGE RECORD	LAKE MICHIGAN PUMPAGE NOT DISCHARGED TO THE CANAL	TOTAL DIVERSION ACCOUNTABLE TO THE STATE OF ILLINOIS	PUMPAGE FROM LAKE MICHIGAN ACCOUNTABLE TO THE STATE OF ILLINOIS	RUNOFF FROM THE DIVERTED LAKE MICHIGAN WATERSHED	DIRECT DIVERSION ACCOUNTABLE TO THE STATE OF ILLINOIS
MONTH	1	2	3	4	5	6	7	8	9	10	11	12	13
OCT 88	3235.5	1.2	3236.7	79.5	27.8	68.2	2.2	177.7	103.6	3162.6	1745.9	478.0	552.4
NOV 88	3928.4	0.6	3929.0	110.5	27.2	262.2	2.5	402.3	99.5	3626.2	1672.1	1366.6	180.9
DEC 88	2782.2	1.1	2783.3	80.9	27.2	154.6	2.6	265.3	102.0	2619.9	1663.7	567.9	144.8
JAN 89	2743.2	2.1	2745.3	77.1	27.3	151.3	1.8	257.5	96.9	2584.7	1674.0	694.4	76.3
FEB 89	2346.8	1.6	2348.4	63.9	27.2	102.7	2.2	196.0	93.8	2246.2	1664.0	376.8	69.9
MAR 89	3099.1	1.0	3100.1	94.5	27.4	185.0	2.7	309.6	92.7	2883.2	1652.5	805.6	66.8
APR 89	2617.5	1.6	2619.1	61.3	27.6	104.7	2.1	195.7	95.9	2519.4	1674.1	432.0	100.8
MAY 89	2813.8	0.6	2814.4	67.3	28.0	56.1	1.5	152.8	112.0	2773.6	1796.4	378.4	182.8
JUN 89	4483.4	1.2	4484.5	80.6	28.4	152.5	1.5	262.9	137.2	4358.9	1989.0	1166.1	402.2
JUL 89	4317.1	0.9	4318.0	86.8	29.6	93.8	1.5	211.7	139.5	4245.8	2215.4	636.9	777.5
AUG 89	4738.7	3.4	4742.1	97.2	28.3	111.2	2.0	238.7	116.5	4619.9	1947.5	715.5	1168.8
SEP 89	5027.4	0.6	5028.0	83.2	27.8	178.5	1.8	291.3	107.2	4843.9	1794.7	868.3	1422.7
AVERAGES	3515.2	1.3	3516.5	82.0	27.8	134.9	2.0	246.8	108.2	3377.9	1791.9	706.8	430.7

(Light shading, columns 4–7: DEDUCTIONS FROM THE ROMEOVILLE GAGE RECORD)

(Dark shading, column 9: ADDITIONS TO THE ROMEOVILLE GAGE RECORD)

COMPUTATIONS:

1. COLUMN 3 EQUALS THE SUM OF COLUMN 1 AND COLUMN 2.
2. COLUMN 8 EQUALS THE SUM OF COLUMN 4 THROUGH COLUMN 7.
3. COLUMN 10 EQUALS COLUMN 3 MINUS COLUMN 8 PLUS COLUMN 9.

NOTES:

1. ALL VALUES ARE ROUNDED TO THE NEAREST TENTH.
2. MATHEMATICAL COMPUTATIONS BETWEEN COLUMNS UTILIZE UNROUNDED VALUES.
3. AVERAGE VALUES FOR WY89 WERE COMPUTED USING DAILY VALUES.

TABLE 3.2

Thirteen computational budgets are prepared as input to the diversion calculation and to estimate flows that cannot be measured. A summary of these budgets is presented in Appendix 2. Budgets 1 and 2 are summations of critical water supply pumpage data. Budget 3 through Budget 6 partition stream gage records into runoff and sanitary/industrial discharge components to estimate a portion of the runoff from the diverted watershed that is used as input to Column 13, (Runoff from the Diverted Lake Michigan Watershed.) Budget 7 through Budget 13 compare simulated to measured flows at MWRDGC facilities. These budgets are for verification of the diversion accounting procedures and give an indication of the accuracy of the diversion accounting. Budget 14 compares canal system inflows and outflows. The following is a brief narrative description of each column:

<u>Column 1: Chicago Sanitary and Ship Canal (CSSC) at Romeoville (USGS - AVM Gage)</u>

Column 1 represents the discharge at the Romeoville gage located on the CSSC approximately 5.2 miles upstream of the Lockport Powerhouse. Records are computed by the U.S. Geological Survey using the acoustical velocity meter gage at this station location. Initially, records were based on the Sarasota AVM from the 12th of June 1984 to the 3rd of November 1988. A new AVM manufactured by ORE became operational on the 17th of November 1988.

<u>Column 2: Diversion From the CSSC Above the Gage</u>

This column represents diversions from the CSSC flow, either municipal or industrial. Argonne National Laboratories and Uno-Ven Corporation presently are the only entities diverting flow from the CSSC upstream of the Romeoville gage. The average withdrawal for Water Year 1989 was 1.3 cfs.

Column 3: Total Flow Through the CSSC

Column 3 represents the Column of 1 and 2 and represents the total flow entering the canal system.

Column 4: Groundwater Discharge to the CSSC and Adjoining Canals

Column 4 represents the effluent whose source is groundwater supply, pumpage by communities, industrial users, and other private users as reported by the Illinois State Water Survey (ISWS). Groundwater seepage into the TARP system that is discharged to the canal is included. Groundwater discharge is determined by summing all reported groundwater sources in the area tributary to the canal and the estimated groundwater seepage into the Mainstream and Calumet TARP systems. This total flow is then adjusted by subtracting the groundwater normally tributary to the canal that is contained in the combined sewer overflows which discharge to the Des Plaines River and other water courses not tributary to the CSSC. Groundwater seepage into the mainstream TARP system was determined through simulation and pumpage records. Groundwater constituent of combined sewer outflow is determined entirely through simulation. Groundwater pumpage from the Lake Michigan watershed whose effluent is discharged to the canal is a deduction.

Column 5: Water Supply Pumpage From Indiana Reaching and the Chicago Sanitary and Ship Canal

Column 5 is the water supply pumpage by the State of Indiana which reaches the canal in the form of effluent. This water is not charged to Illinois' allotment. It is a deduction from the flow measurement at Lockport. This column is the same as Column 6 of the previous accounting format. Computation of the Indiana water supply reaching the canal through the Grand Calumet and Little Calumet River represents a complex drainage system with respect to Little Calumet River and Hart Ditch. Grand Calumet River has a summit. On one side of the summit, the flow is towards Lake Michigan. On the other side, the flow is towards the Calumet Sag Canal. However, this location of the summit is variable and highly influenced by Lake Michigan levels (USGS 1984). Thus the calculation of the Indiana deduction from the Romeoville record is influenced by Lake Michigan levels. Because of no stream gaging station on the Grand Calumet River to measure westward flow into Illinois, the flow is based on statistical relationships and computed from regression equations of which the principal independent variable is lake level. The flow in the Grand Calumet is estimated to be in excess of 90 percent sanitary effluent. It is therefore assumed the portion of this flow which is attributable to domestic water supply is equal to the sum of the daily water supply for East Chicago, Hammond, and Whiting, Indiana unless the sum is greater than the flow in the Grand Calumet River. If the combined water supply from these communities is in excess of the flow in the Grand Calumet, it is assumed that the flow consists entirely of effluent that originates from water supply. The USGS has established a gaging station on the Grand Calumet River to better define the variable flow conditions. The results of this gage will be used for the Water Year 1991 accounting.

Column 6: Runoff from the Des Plaines River Watershed (DPW) Reaching the Chicago Sanitary and Ship Canal

This column is made up of the following flow components:

1. Infiltration and inflow from the DPW discharged to the Water Reclamation's plants;
2. Infiltration and inflow from the DPW reaching the canal through the combined sewer; and overflows
3. Runoff from the Lower Des Plaines and Summit conduit areas.

This flow deduction is mainly determined by computer simulation. But, it is also influenced by the O'Hare basin flow transfer.

Column 7: Lake Michigan Pumpage by Federal Facilities Which Discharge to Chicago Sanitary and Ship Canal

Column 7 represents Lake Michigan diversion by federal facilities not chargeable to the State of Illinois allocation. Federal facilities represented by this column are as follows:

- Hines VA Hospital
- Fort Sheridan
- Glenview Naval Air Station
- U.S. Army Corps Emergency Navigation Makeup

Column 8: Total Deductions from Chicago Sanitary and Ship Canal at Romeoville Gage Records

Column 8 is the sum of columns 4, 5, 6, and 7 and represents the total deductions from Romeoville record.

Column 9, Lake Michigan Pumpage not discharged to the Chicago Sanitary and Ship Canal.

This column represents water supply pumpage from Lake Michigan that is not discharged to the canal. The water supply pumpage not discharged to the canal has two basic components: (1) water supply used by communities serviced by water reclamation facilities that do not discharge to the CSSC; and (2) the sanitary portion of combined sewer overflows that do not discharge to the CSSC which is attributable to Lake Michigan domestic water supply.

Column 10: Total Diversion

Column 10 is equal to Column 3 minus Column 8 and plus Column 9. Columns 11, 12, and 13 are not used in the computation of diversion but represent the flow estimate of the three basic components of Lake Michigan diversion.

Column 11:

Column 11 is the summarization of Lake Michigan pumpage for which Illinois is accountable. This is the same as Column 13 in the previous accounting report.

Column 12:

Column 12 represents the simulated runoff from the Lake Michigan watershed and includes infiltration and inflow entering the storm sewer system. This runoff is estimated using the computer simulation hydrologic models.

Column 13:

Column 13 represents the total direct diversion of Lake Michigan water into the diverted rivers systems through the controlling structure at Wilmette, the Chicago River Controlling Works, and the O'Brien Lock.

Because the diversion estimated from Columns 11 through 13 is based on computer simulation, questionable rating of the lakefront structures and simple flow separation techniques, the estimate is not expected to be as accurate as the AVM based calculations.

3.2 ACCOUNTING - HYDROLOGIC MODELING

The flow record at the AVM at Romeoville represents the majority of volume of water diverted from Lake Michigan. But in addition to the Chicago Sanitary and Ship Canal flow, the record also contains the following deductions:

- Runoff from the Des Plaines River watershed that was diverted into the canal system by the network of sewers.
- Groundwater water supply pumpage from outside the basin that was treated and discharged from sewage treatment plants into the canal system.
- Water supply pumpage from the State of Indiana, entering from the Calumet River.

- Water supply pumpage from Federal Facilities that is discharged into the canal is deducted from the Romeoville flow.

The hydrologic model computes the runoff from the entire watershed and routes the water through the network of sewers and the TARP system. The water is not routed through the canal system because of the short travel time. **The primary goal of the hydrologic runoff modeling and the hydraulic sewer routing models is to estimate the volume of water from the Des Plaines River watershed that enters the canal.** The contributing Des Plaines River watershed is about 217 square miles, about 35 percent of the 673 squares miles that the canal drains. The secondary goal for the hydrologic and hydraulic modeling is to compute the entire hydrologic budget for the Chicago Canal System. From these budgets, considerable information can be determined. The total diverted runoff from the Chicago River can be calculated. Additionally, the budgets are used as a verification of simulated flows and to indicate problems associated with the simulated or recorded flows used in computing the diversion.

3.2.1 Modeling Approach

The hydrology of the basin is simulated on a continuous basis. The Hydrocomp Simulation Program Fortran (HSPF) model is used to simulate the hydrology. The product of the HSPF model is runoff in inches. The runoff is applied to the SCALP model which converts the runoff into sewer discharge and routes the flow through the sewer networks either to sewage treatment plants or to the drop shafts of the TARP system. The TARP model, which uses TNET, routes the flow through the TARP tunnels from which the wastewater is pumped into the Water Reclamation's Stickney and Calumet Treatment plants. The outfalls from the sewage treatment plants flow into the Chicago Sanitary and Ship Canal. There is no routing through the Sanitary and Ship Canal. Routing of flow through the Sanitary and Ship Canal is not simulated in the HSPF model applied in the diversion accounting.

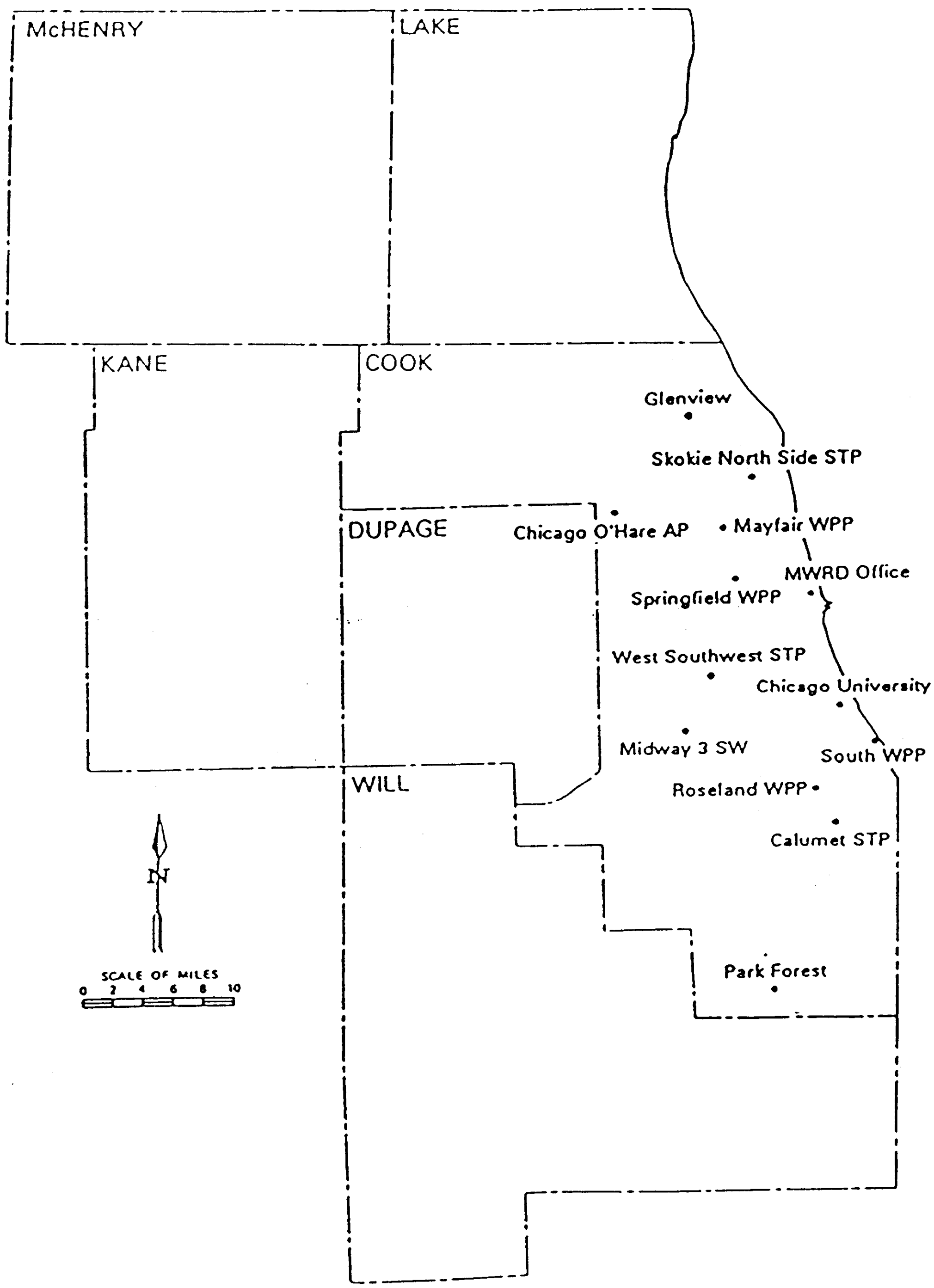
3.2.1.1 Precipitation Network

Prior to Water Year 1990, a network of 13 precipitation gages was used to collect rainfall data over the watersheds. Figure 3.1 shows this network. This network had problems. The gages were maintained by MWRD, the City of Chicago, and the National Weather Service. Each of these agencies had different procedures for maintaining the gages and for collecting and reducing the data. The gages were of different types. Many of the gages had poor exposure being overshadowed by rooftops and trees. Moreover, the distribution of gages was uneven causing inconsistent sampling of precipitation. The problems resulted in unusual precipitation patterns as shown in Figure 3.2. The spacial variation in rainfall from 20 to 40 inches was unreasonable for a basin of this size. The Corps of Engineers retained the Illinois State Water Survey to adjust the data. The rain gage at O'Hare Field was determined to be accurate, and the rainfall was adjusted by a complex procedure which analyzed each individual storm. The adjustments to each rain gage for the Water Year 1987 is shown in Table 3.3. The maximum adjustment is almost 50% at the West Southwest Sewage Treatment Plant. The adjusted precipitation pattern is shown in Figure 3.3.

Table 3.3

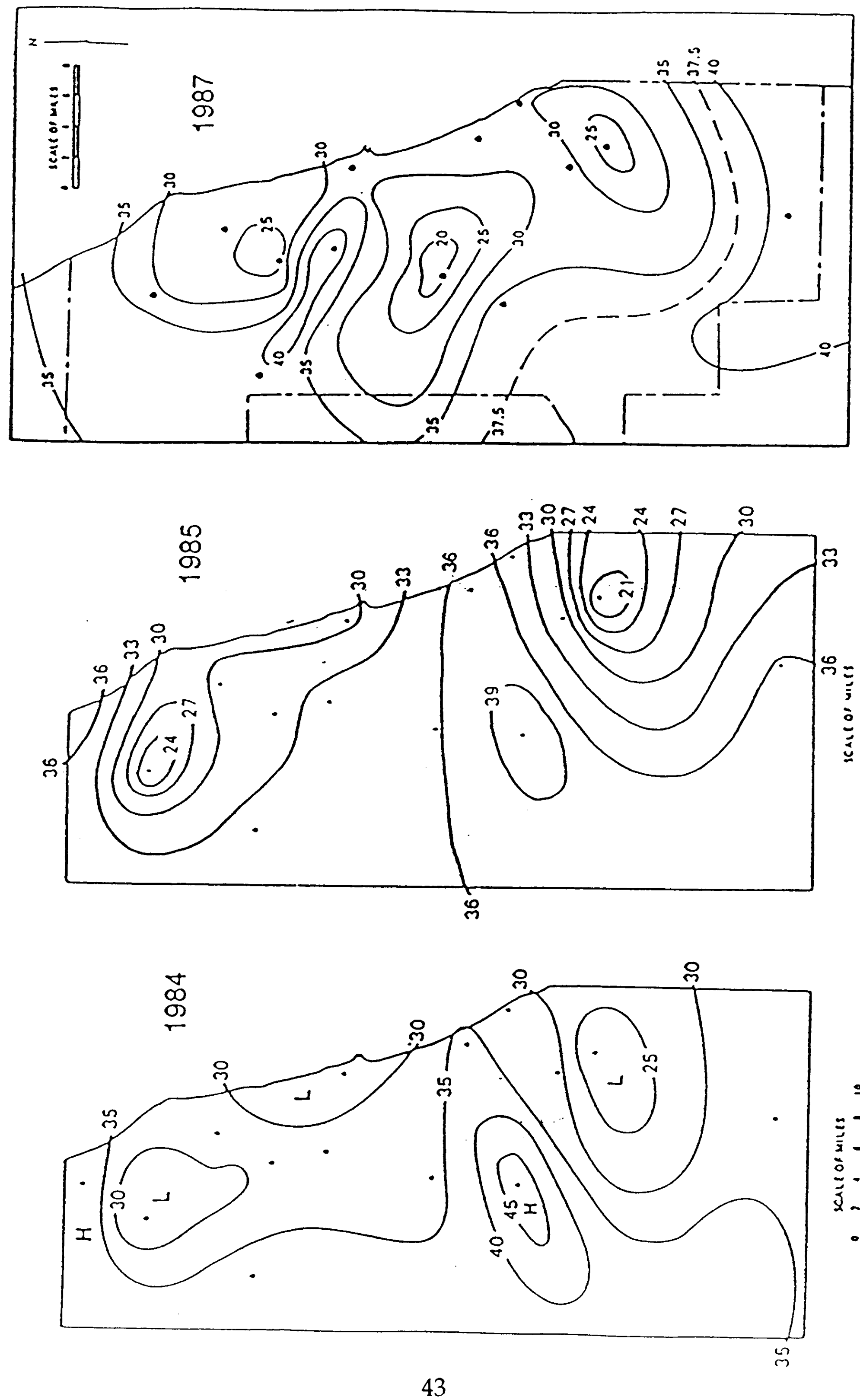
Cumulative corrections and percent changes for the gages used in the accounting procedure for the 1987 Water Year		
Rain Gage Site	**Cumulative Correction (inches)**	**Percent Change**
Glenview	+7.00	+18.1
Skokie Northside STP	+17.51	+40.7
MWRD Office	+7.15	+18.4
West Southwest STP	+19.25	+49.7
Calumet STP	+16.44	+43.4
Mayfair WPP	+19.74	+45.0
Springfield WPP	-0.39	-0.9
South WPP	+4.17	+11.3
Roseland WPP	+5.17	+13.4
Chicago O'Hare	+0.00	+0.0
Chicago University	+1.61	+4.5
Midway 3 SW	+3.67	+9.4
Park Forest	+0.68	+1.5

FIGURE 3.1



NWS, MWRDGC, and City of Chicago Rain Gage Sites in Cook County

FIGURE 3.2



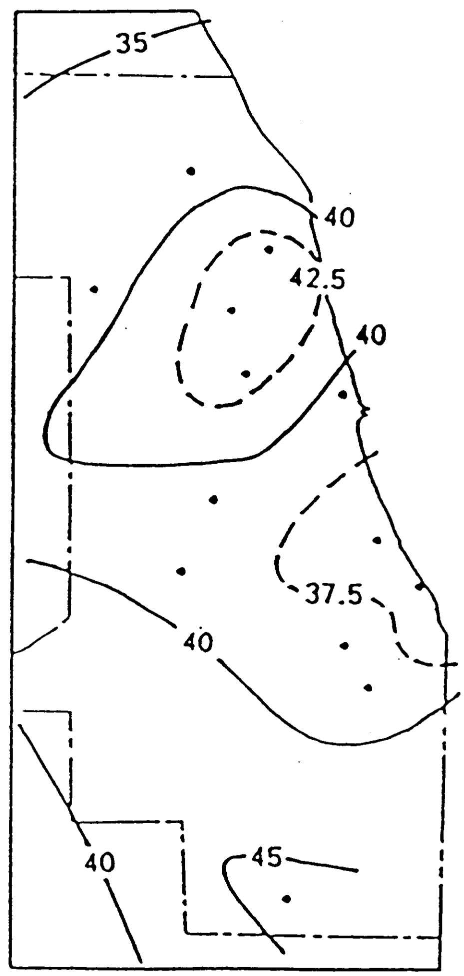
Precipitation patterns from original records (inches)

In the Summer of 1989, a new network of 25 precipitation gages was installed by the Illinois State Water Survey for the Corps of Engineers. The gages were installed on a rectangular grid with a spacing of from 5 to 7 miles between the gages. Figure 3.4 shows the location of the rainfall gages. The gages were all of a single type, a universal weighing bucket. The gages were located such that they were as free from obstructions as possible in an urban area. A quality assurance program was developed to estimate missing values and check for the consistency of the data. Figures 3.5 to 3.7 show the rainfall isohyets for 1990, 1991, and 1992 from the new rainfall gage network. The isohyets are more consistent than the results from the earlier gage network. The newer network was used for the reports for Water Year 1990 and onward.

3.2.1.2 HSPF Model

HSPF is a continuous hydrologic model which attempts to simulate the entire hydrologic cycle. The model divides the watershed into small subareas called elements. The watershed characteristics such as runoff and subsurface storage for that element are known as an interior point called a node. The model simulates the hydrologic process as a system of small reservoirs which exchange water with one another. The reservoirs simulate interception storage, upper zone storage, lower zone storage, and ground water storage. The reservoirs are linked with each other and the outside world by physical processes that are described by parametric and empirical equations. The processes are evapotranspiration, infiltration, interflow, overland flow, and deep percolation. The parameters for

FIGURE 3.3



Water Year 1987 Adjusted Precipitation Pattern

FIGURE 3.4

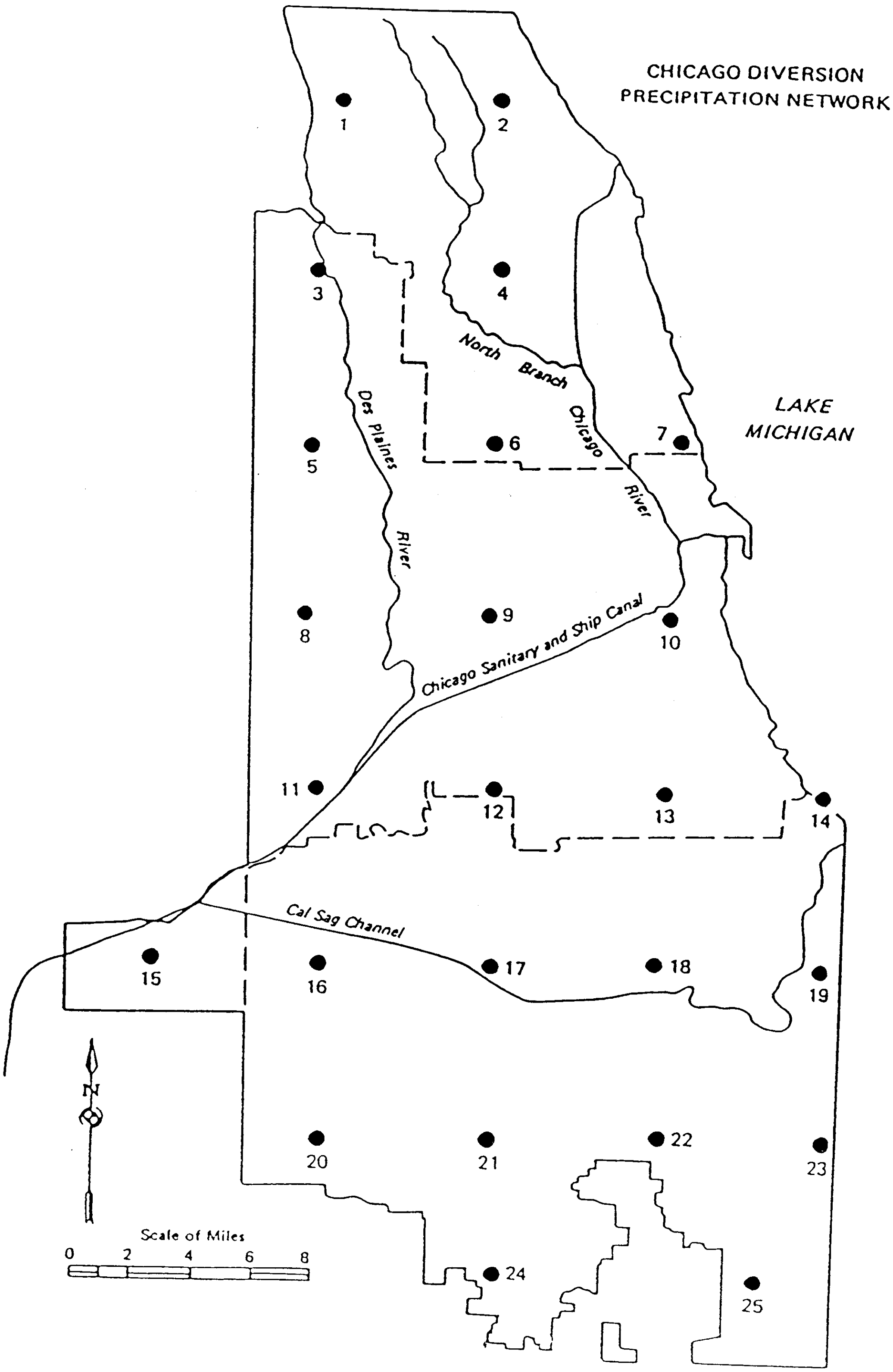
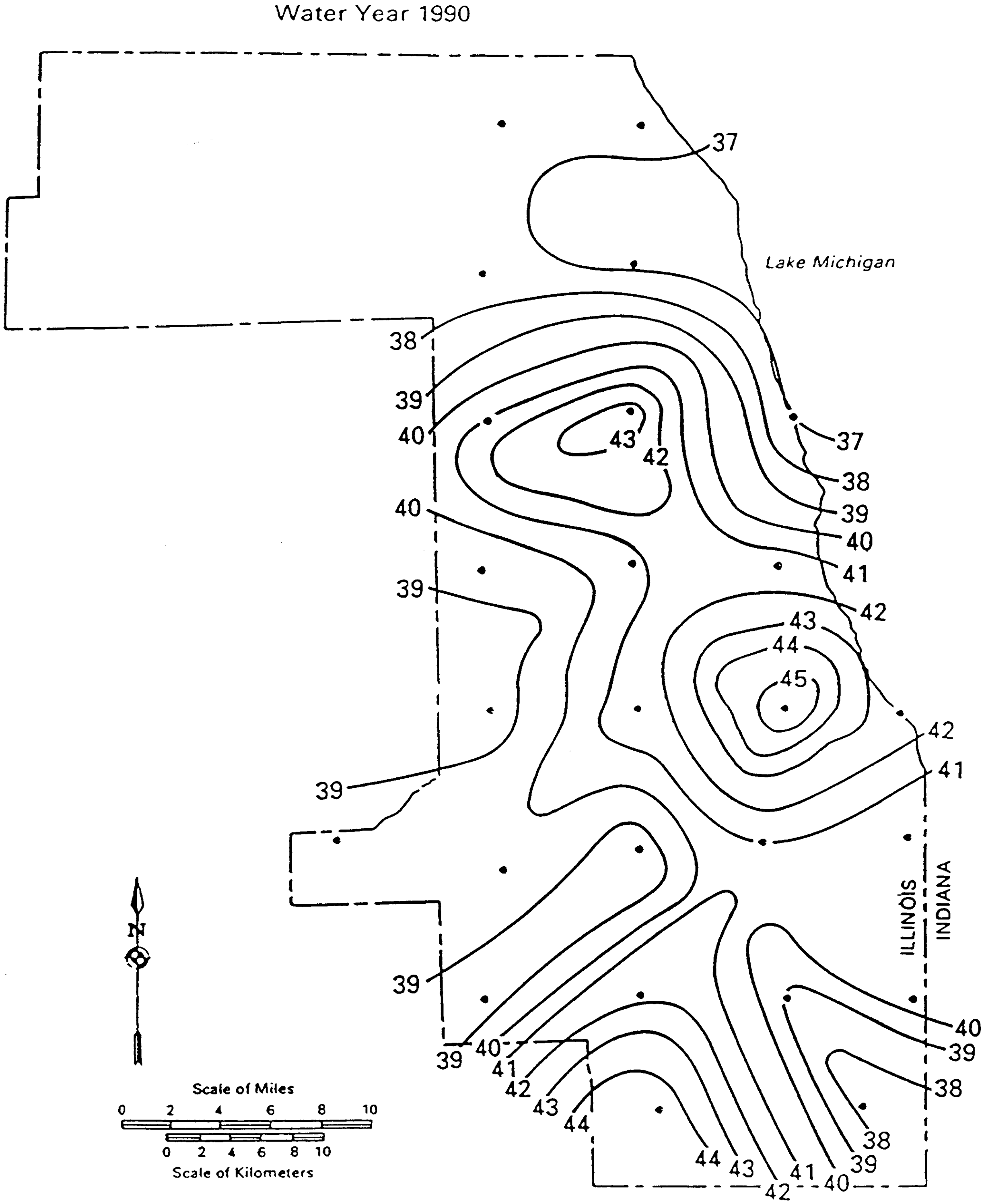

CHICAGO DIVERSION
PRECIPITATION NETWORK
LAKE
MICHIGAN
North Branch Chicago River
Des Plaines River
Chicago Sanitary and Ship Canal
Cal Sag Channel
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
N
Scale of Miles
0 2 4 6 8

FIGURE 3.5



Precipitation pattern (inches) for Water Year 1990. Dots indicate network sites.

FIGURE 3.6

Water Year 1991

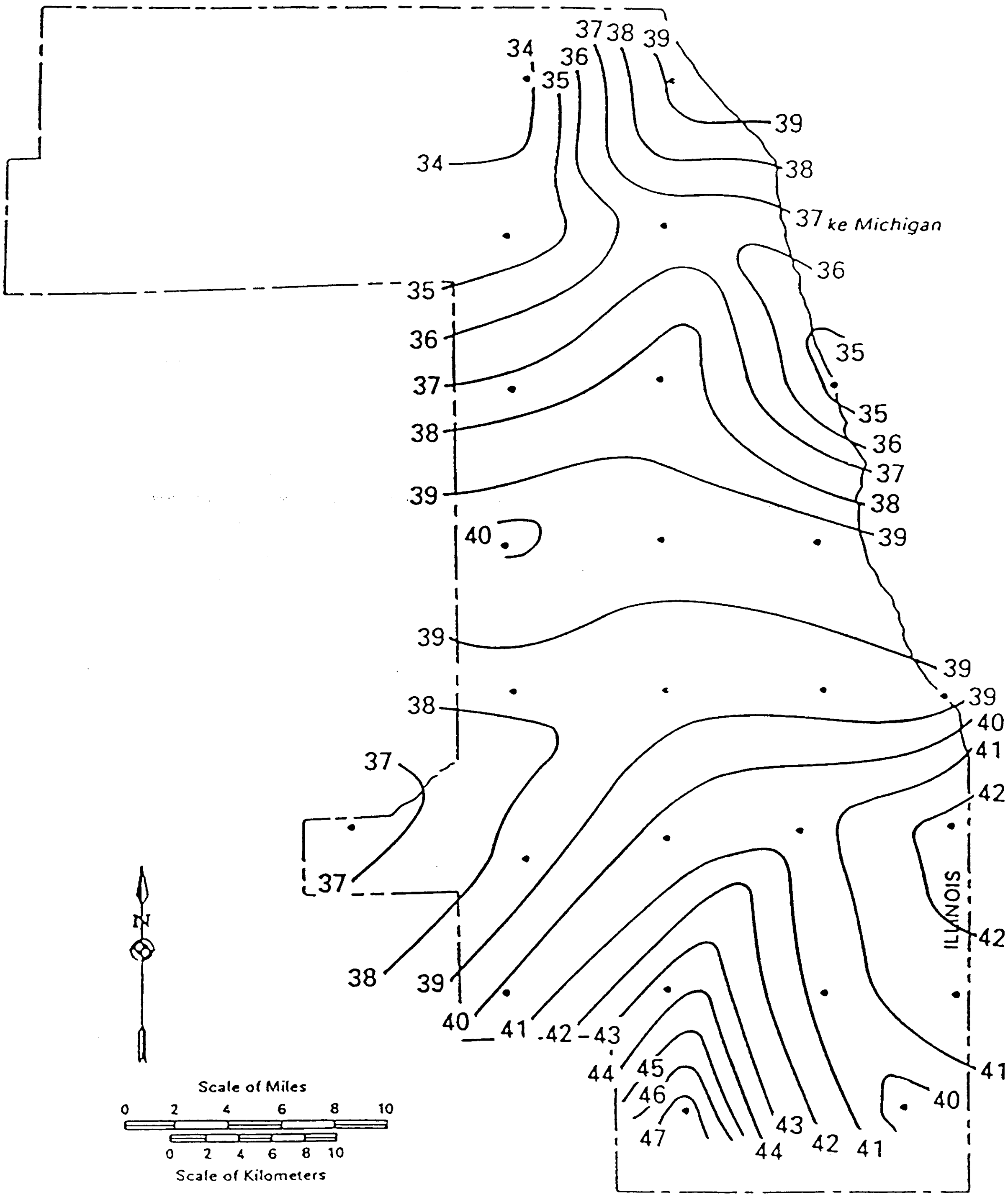
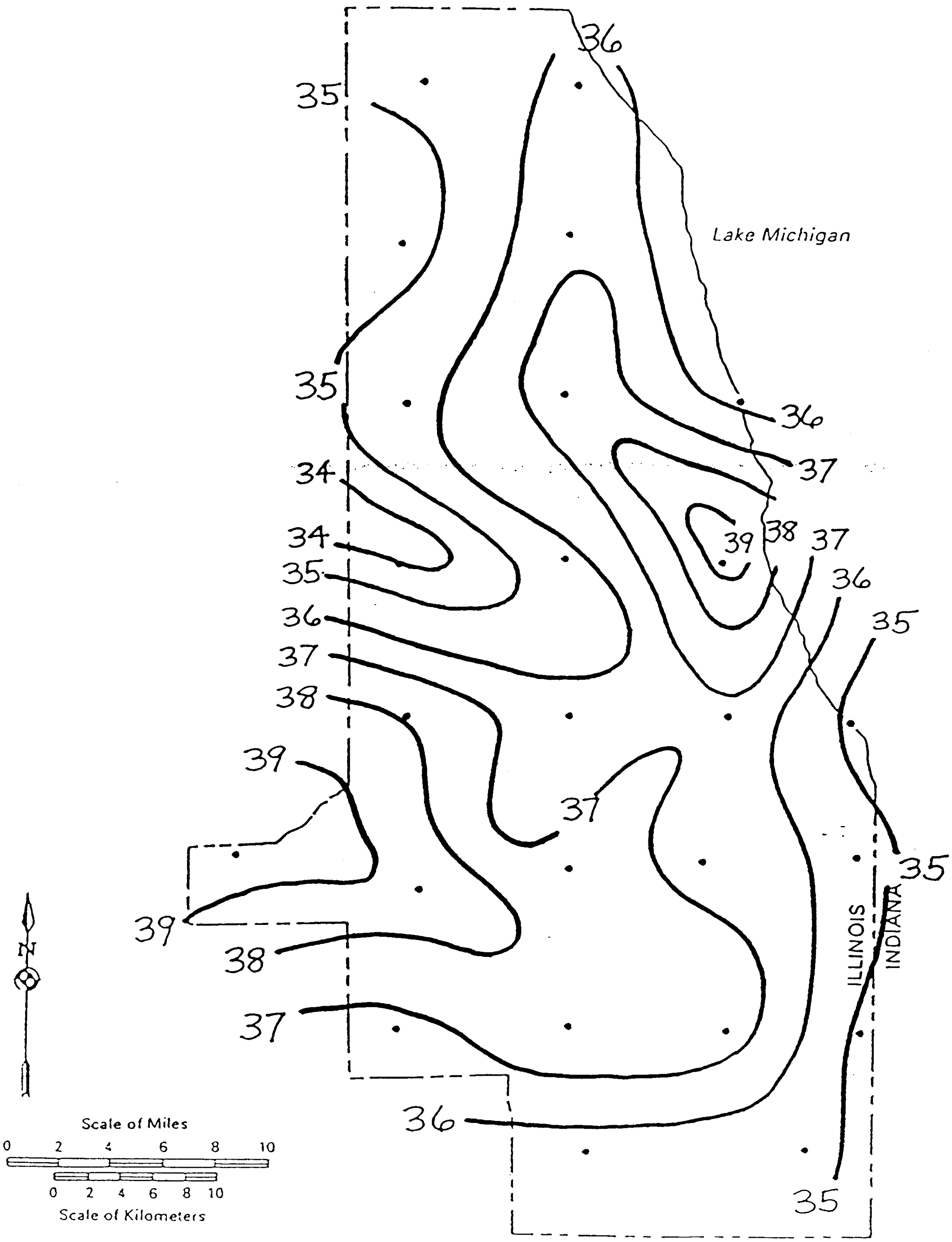


FIGURE 3.7

Water Year 1992



the equations are determined by calibration to observed data. The program, which has its roots in the Stanford Watershed Model, is an old concept, but it does represent the state-of-the-art in continuous simulation modeling.

A description of the modeling of the hydrologic cycle is as follows:

3.2.1.3 Interception Storage

Precipitation is first lost to interception - retention on leaves, branches, and stems of vegetation. The HSPF model simulations interception as a maximum storage capacity which is an input parameter. Interception continues until the interception storage is filled to capacity. Water is removed from interception storage by evapotranspiration.

3.2.1.4 Impervious Area Runoff

If the soil cover is impervious, the entire precipitation loading is assumed to be surface runoff.

3.2.1.5 Infiltration

The precipitation that falls on the pervious ground is first subject to infiltration. The fraction of the precipitation infiltrates into the lower zone storage and the excess surface runoff enters the upper zone storage. Infiltration is modeled using an empirical function whose parameters are calibrated to reproduce observed data.

3.2.1.6 Upper Zone Storage

Upper zone storage is the depression and upper soil storage of the land. The fraction of the rainfall excess retained in the upper zone is a function of the upper soil moisture and the nominal storage capacity of the upper zone. Water is lost to the upper zone through evapotranspiration, interflow, and infiltration to the lower zone.

3.2.1.7 Overland Flow

The excess precipitation after losses to interception, infiltration, and the upper zone enters overland flow detention. Water is routed from overland flow detention by an empirical relation. Water remaining in overland flow detention at the end of a time step is added to the precipitation for the next time step. This enables the residual detention volume to contribute to infiltration for the later time steps.

3.2.1.8 Lower Zone

The lower zone extends from the upper zone down to the top of the groundwater table. Water enters the lower zone as infiltration from runoff or from the upper zone. Water leaves the lower zone through evapotransporation, and percolation to the deep groundwater storage.

3.2.1.9 Interflow

Interflow is the process where flow leaves the upper zone and flows laterally to the stream channel. Interflow is assumed to be a function of the volume of storage in the upper zone.

3.2.1.10 Groundwater and Deep Percolation

Water enters groundwater storage from the lower zone. The flow is a function of the moisture level and nominal storage capacity in the lower zone.

A portion of this inflow can be diverted into deep groundwater storage where the water is completely lost to the system. Water in groundwater storage returns to the river channel according to an exponential recession.

3.2.1.11 Evapotranspiration

Evapotranspiration is the loss of moisture from plants and soil to the atmosphere. HSPF models evapotranspiration as an assumed function. For water in depression storage, the evapotranspiration is the potential rate which is rate from class A pan evaporation records. For water in the lower zone, the evapotranspiration is a function of the water in storage and an assumed index of vegetation density.

3.2.2 SCALP

The SCALP program converts the unit runoff from the HSPF model computed for each segment into flow and routes the flow through lateral, submain, and main sewers. The Chicago sewers are divided into two types - separate and combined sewers. Separately sewered areas use a linear routing technique. In the Chicago model, the main sewers are called interceptor sewers. When the capacity of an any sewer is exceeded, that sewer either overflows into the Chicago Canal System or overflows into a drop shaft of the Chicago TARP system. The SCALP model was specifically designed to calculate these overflows.

The SCALP model reads the three HSPF unit runoff files: SUBRO - subsurface runoff; IMPRO - impervious runoff; and OLFRO - overland pervious surface runoff. For each subarea, the surface runoff for each time step is computed by multiplying the pervious and impervious drainage area times the pervious and impervious unit runoff. Subsurface runoff is computed by multiplying the pervious drainage area times the unit subsurface runoff. Sanitary flow is determined by multiplying per capita loading by a population equivalent for each subarea. For both types of sewer systems, combined and separate, sanitary flow, surface runoff, and subsurface runoff is routed through the sewers.

Infiltration is the groundwater which seeps into the sewer system through joints and fissures. Inflows are unregulated connections to the sewer system. Two examples of inflows are the discharge from gutter downspouts and the discharge from basement sump pumps. For combined sewer areas, 100 percent of the infiltration (subsurface runoff) and inflow (surface runoff) is estimated as entering the sewers. For the separately sewered areas, Burke recommended (1990) that the sum of 100% of the subsurface runoff and 5% of impervious flow be assigned as infiltration and inflow.

The SCALP uses a simplified hydrologic routing technique to route flow through the sewers. Each sewer line is viewed as a small reservoir and a system of sewers is viewed as a series of cascading reservoirs. The outflow from the reservoir is a linear function of storage,

$$Q=\frac{1}{K}S \tag{3.1}$$

in which Q is the outflow; K is the linear routing factor and S is storage. This type of model does not simulate the hydraulics of the sewer lines, but, since, the goal is yearly runoff totals the model is adequate.

The output from SCALP is the routed outflow which is the inflow to the sewage treatment plant and the overflows from the sewers which are the inflow to the TNET model. The sewer flow and the overflows are both written to the Time Series Storage (TSS) database.

3.2.3 TNET

The Tunnel and Reservoir Plan consists of a dendritic network of deep tunnels underlying the City of Chicago. The tunnels collect sanitary and stormwater runoff that overflow from the interceptor sewers up to the storage capacity of the tunnels. The flow into the tunnel is controlled by gates on the drop shafts. After the gates on the drop shafts, wastewater overflows into the canal system. After the storm event, the storage of the tunnel is pumped to the Stickney Water Reclamation Plant and the Calumet Water Reclamation Plant and then discharged to the canal system. At present, the Mainstem and Calumet Tunnel Systems are in operation, and the Des Plaines tunnel system is under construction. A reservoir is being designed for the downstream end of the Mainstem Tunnel to increase the available storage.

Both tunnels are being simulated by the TNET model. The TNET program simulates both open channel and pressure flow using the open channel flow equations. The open channel flow equations are "tricked" to simulate pressure flow through the Preissmann slot (Cunge, 1980). The Preissmann slot is a slot of very small width at the top of the tunnel. The width of the slot is set such that the celerity of the waves inside the tunnel are the same as the celerity of a pressure wave. The width of the slot is generally about .001' in width which produces a wave celerity of about 4,900 fps.

The overflows, which were computed by SCALP, are input to the drop shafts. The TNET program sets the drop shaft gates according to the volume of storage in the tunnel. When the gates are closed, the overflow, which is dumped to the canal, is written to DSS.

3.2.4 Comments

Insufficient Volume at Lower Des Plaines and Other Sites

Table 3.4 shows the simulated and recorded mean flow at the gaging stations within the basin. The mean flow is the average for the entire year; therefore, errors in the temporal distribution of rainfall and routing are washed out by the lumping of the flow data. The simulated volumes for the Northside WRP and the Des Plaines PS are consistently low. The volume deficiency is of particular concern for the Des Plaines PS which, in theory, acts as is a calibration point for the Des Plaines watershed. This flow deficiency requires resolution before this site can be used as a calibration point for the Des Plaines watershed models that impact the simulated Des Plaines watershed runoff deduction contained in Calumet of the accounting report.

The Calumet WRP also shows a similar deficiency, but in the final year, 1989, the deficiency disappears. The COE analyzed the Calumet basin and

TABLE 3.4

WY 1989 SUMMARY OF SIMULATION STATISTICS

Budget No.-->	7	8	9	10	11	12	13	14
Description	Northside WRP (1)	Upper Des Plaines Pump Station (1),(3)	Mainstream TARP Pump Station (2)	Stickney WRP (1)	Calumet TARP Pump Station (2)	Calumet WRP (1)	Lemont WRP (1)	Chicago Canal System Balance (1)
Mean Recorded Flow, cfs	422.0	82.3	86.6	1152.3	31.9	421.3	2.3	3043.5
Max. Recorded Flow, cfs	682.8	179.7	359.9	2134.0	122.3	709.9	6.5	13410.0
Min. Recorded Flow, cfs	330.3	21.3	14.2	688.6	0.0	296.7	0.8	1671.7
Mean Simulated Flow, cfs	407.2	67.8	89.1	1187.7	27.5	419.0	1.8	3523.7
Max. Simulated Flow, cfs	680.8	186.0	186.8	2589.8	89.4	784.7	4.9	13754.0
Min. Simulated Flow, cfs	307.0	43.3	38.8	819.1	6.5	303.9	1.2	1877.5
Mean S/R	0.97	0.82	1.03	1.03	0.86	0.99	0.78	1.16
Max. S/R	1.42	3.79	7.30	1.66	6.14	1.53	3.67	1.56
Min. S/R	0.65	0.43	0.25	0.56	0.27	0.66	0.36	0.78
Correlation	0.80	0.47	0.55	0.74	0.68	0.72	0.72	0.95

(1) Based on daily values.
(2) Based on weekly values.
(3) Does not include days with missing records.

determined that the per capita sanitary loadings were too small. The loadings were revised and the S/R ratio was increased to its current value of 0.99.

The Second Committee also noted the deficit in flow in their report. Their concern was the infiltration and inflow was too low in the separately sewered areas. As a result, the COE retained Christopher B. Burke Engineering to review the parameters in SCALP which determine inflow and infiltration. Burke's Report (1990) was based primarily on the flow records at the Des Plaines Pumping Station. Special sewer studies at other locations were found to have significant errors, and the results of these sewer flow measurements were unusable.

Calibrating to the Des Plaines Pumping Station data, Burke suggested that the infiltration be increased to 100% of the SUBRO (subsurface unit runoff), and the inflow be increased to 5% of the IMPRO (impervious unit runoff). With the Burke parameter assignments, the simulated flow was only increased from 80% to 85% of the recorded flow for 1985, and Table 3.5 demonstrates similar results for succeeding years. These recommendations were implemented for the 1986, 1987, 1988, and 1989 diversion accounting reports for all separately sewered areas. Figures 3.8 to 3.11 compare simulated and recorded flow at the Des Plaines Pumping Station for Water Years 1986 to 1989. The hydrography show a consistent deficiency at low flow. The reproduction of high flow, while not perfect, is still acceptable. Clearly, the volume deficiency is from an inadequate reproduction during low flow periods. The COE has concluded that the deficiency in flow cannot be resolved until the measurement problems at the

Table 3.5

Upper Des Plaines Pumping Station (UDPPS)
Updated Model Simulated Flow (cfs)
(after Burke, 1990)

		WY 83	WY 84	WY 85
TOTAL	Rainfall (inches)[1]	53.5	38.6	43.1
	Recorded[2]	88.5	88.5	81.2
	Total	82.2	72.9	69.8
	Runoff	9.8	8.1	7.1
	Infiltration	28.4	20.0	17.9
	Sanitary	44.0	44.8	44.8
SEPARATE SEWER AREA	Total	33.7	28.9	27.2
	Runoff	1.2	1.0	.09
	Infiltration	18.1	13.0	11.4
	Sanitary	14.4	14.9	14.9
COMBINED SEWER AREA	Total	48.5	44.0	42.6
	Runoff	8.6	7.1	6.2
	Infiltration	10.3	7.0	6.5
	Sanitary	29.6	29.2	29.9

[1]Recorded Rainfall at O'Hare International Airport.
[2]Record flow has 176 days of missing average daily flow data.

pump station are resolved. During high flow on the Des Plaines River, the flow can be diverted around the pumping station into the Des Plaines River. The deficiency in flow may be caused by two factors: 1) sanitary inflow is underestimated, and 2) the infiltration and inflow is still underestimated. The sanitary inflow is input a per capita loading and a population equivalent into the SCALP model. Since this watershed was developed 40 to 50 years ago, the land use has changed little over the past 15 years and the population would be relatively constant. Therefore, the primary focus would be the per capita loading. Table 3.6 compares the loading factors for the Des Plaines watershed and other basins in the system. The Committee cannot specify new loading factors; instead, the committee recommends that the basin be studied and that the loading factors be adjusted, if warranted.

The Burke infiltration and inflow study raises more questions than answers. The Burke recommendation of assigning 100% of the subsurface runoff to infiltration clearly violates physical reality. This leads to a dilemma: Either the subsurface flow from HSPF is too small or the conceptual model of sewer infiltration using HSPF and SCALP is wrong.

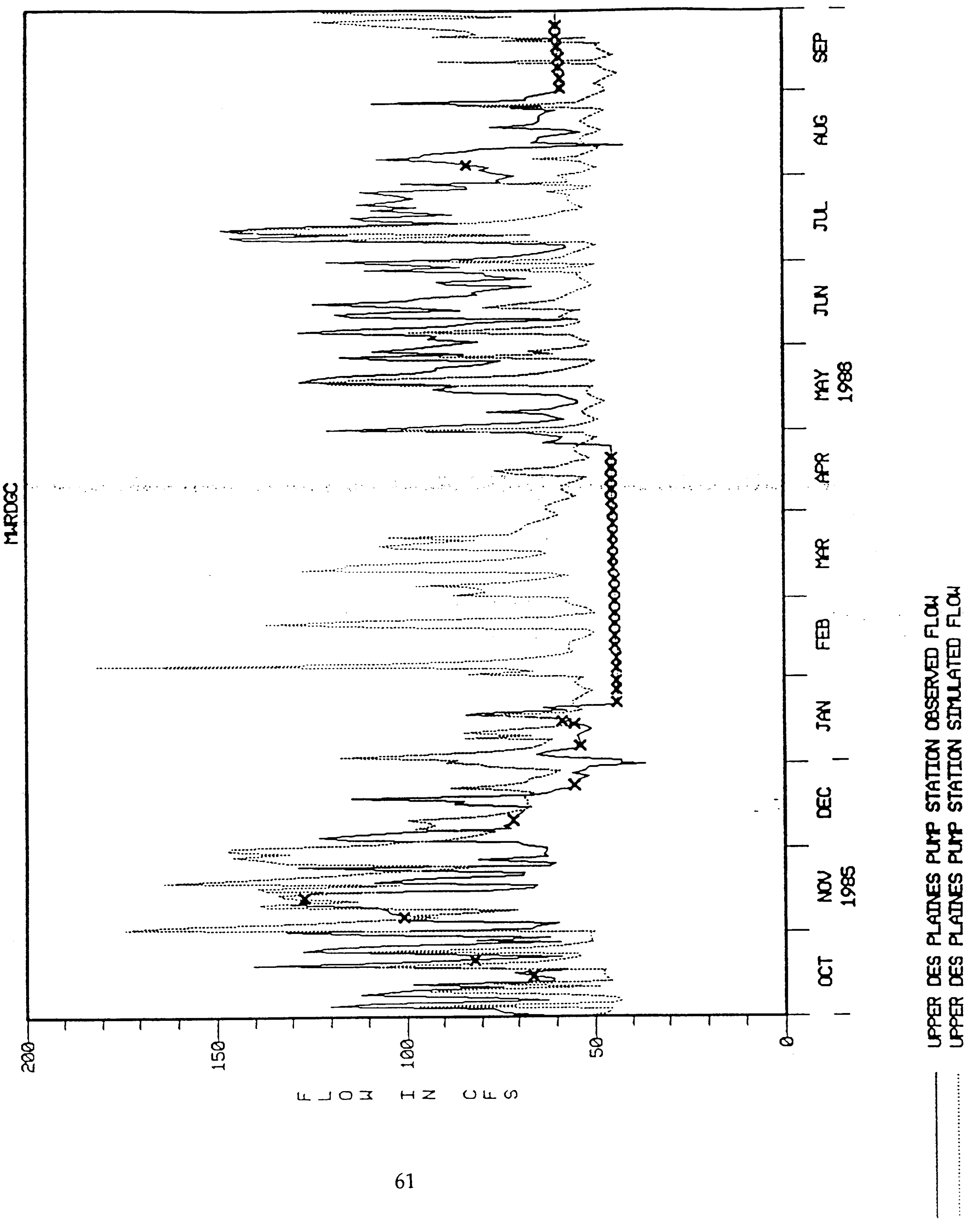
TABLE 3.6

Sanitary Flow Used in the SCALP Program for Selected Watersheds

Subarea	Type	Sanitary Flow in CFS x .0001 per Person
Upper Des Plaines	Combined	2.22
	Separate	2.22
Chicago contributing to Stickney STP	Combined	4.88
Des Plaines watershed inflowing into Tunnel 13a	Combined	1.92
	Separate	1.92
Inflow to future Des Plaines Tunnel	Combined	1.93
Lower Des Plaines	Combined	4.88
	Separate	2.08
Suburban Lake Michigan watershed contributing to Northside STP	Combined	2.55
Chicago watershed contributing to Northside STP	Combined	2.47

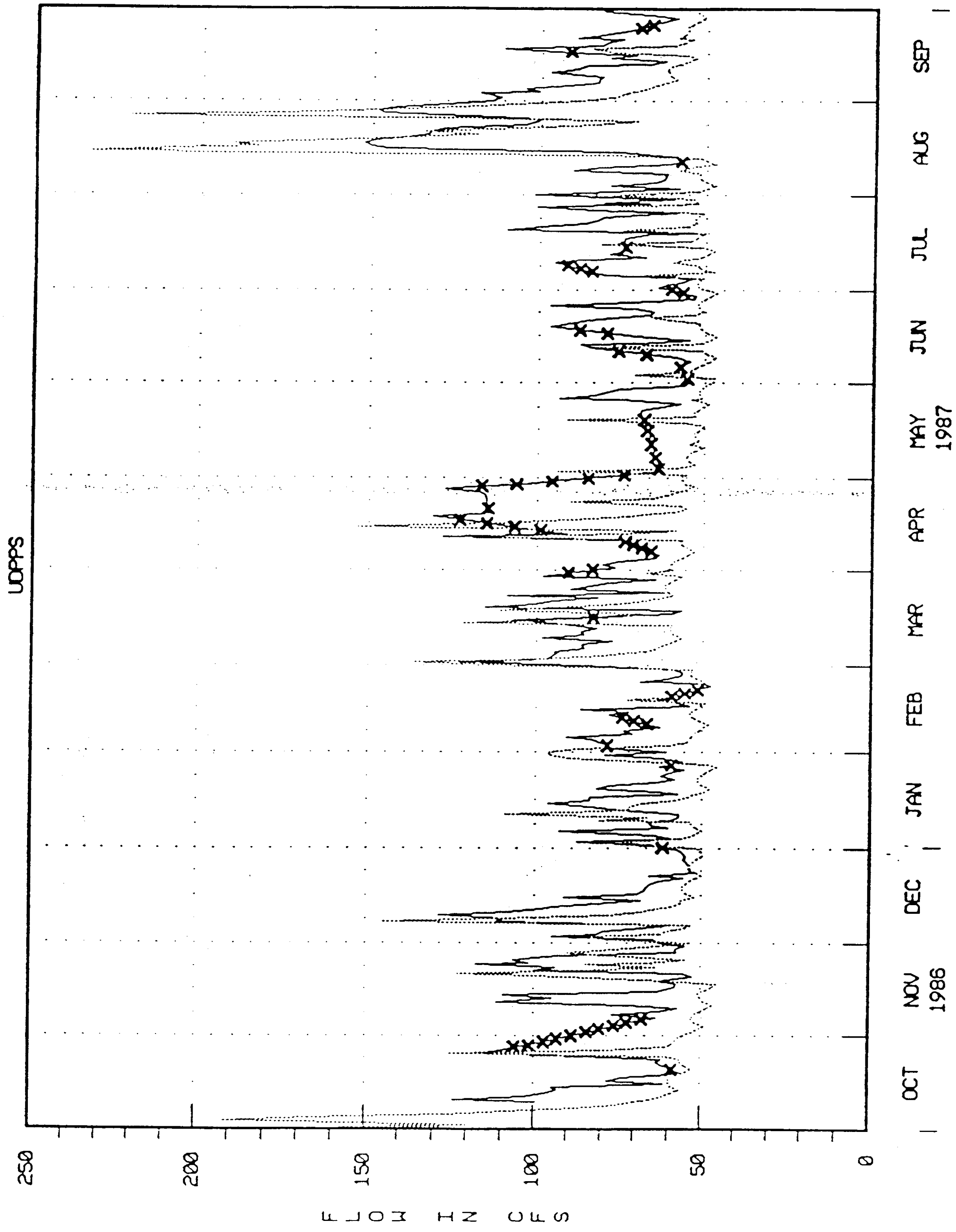
The subsurface component can be increased by either increasing the inflow through infiltration from the surface or by reducing the evapotranspiration and percolation to deep groundwater. It is unlikely that one can adjust these parameters sufficiently to compensate for the 15% shortfall. Is there any other source of inflow into the lower zone? Infiltration into the lower zone can only come from pervious areas. Can impervious areas be reassigned to the pervious category, thereby increasing the inflow into the subsurface areas? Are rooftops considered impervious area? Roofs drain through gutters onto yards which is a pervious area. Do impervious areas contribute to the lower zone through cracks in the pavement and through exfiltration from sewers under surcharge? The subsurface component of HSPF was designed to simulate the flow of water from soil storage into stream channels - thus creating base flow. This concept is similar but different from the infiltration into sewers. The infiltration into sewers is caused by a head of water forcing water through joints into the pipe. Is a different conceptual model which would simulate the pressure component needed?

FIGURE 3.8



Budget 8 - Simulation of the MWRDGC Upper Des Plaines Pump Station

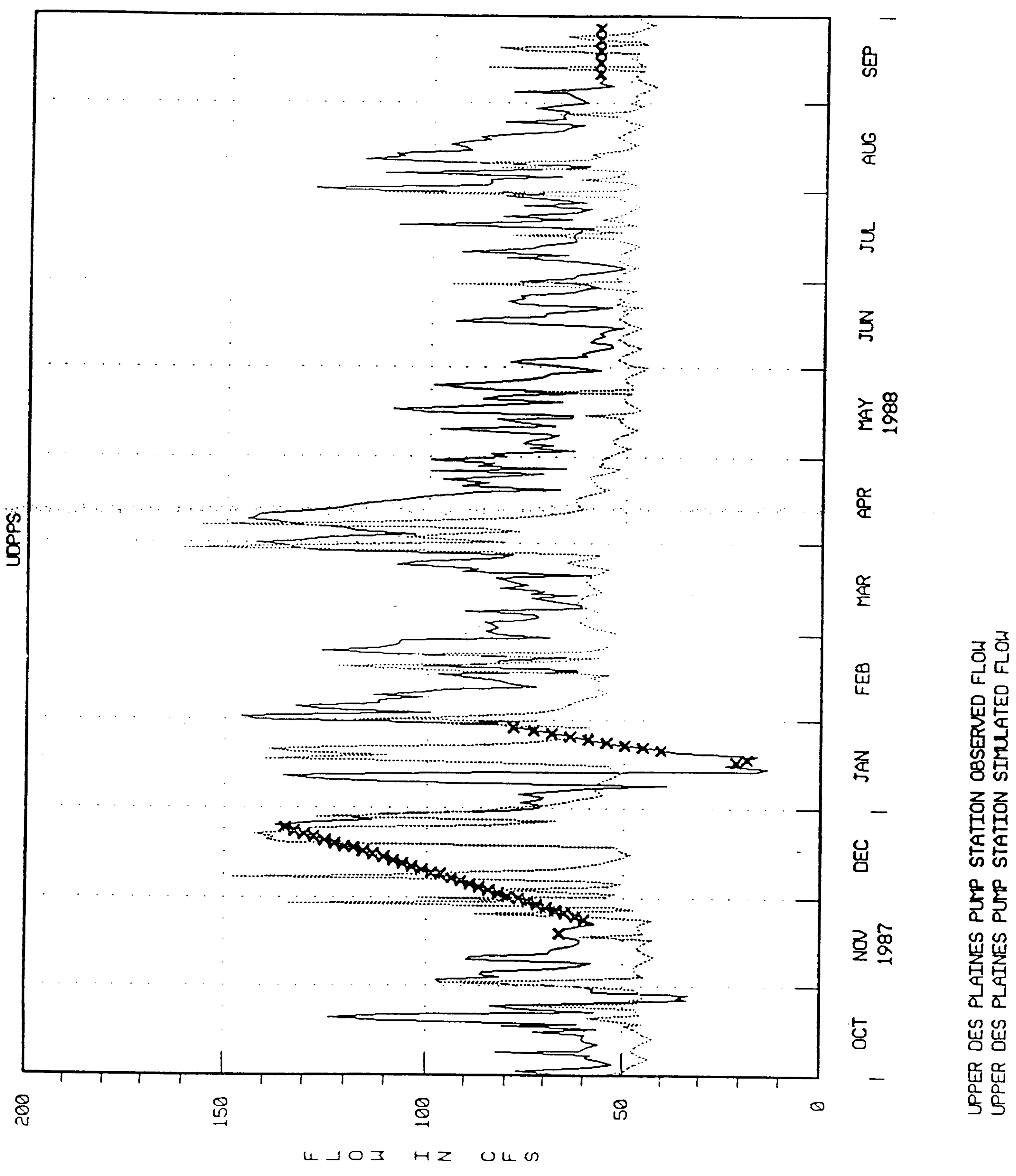
FIGURE 3.9



TOTAL PLANT FLOW OBSERVED FLOW
TOTAL PLANT FLOW SIMULATED FLOW

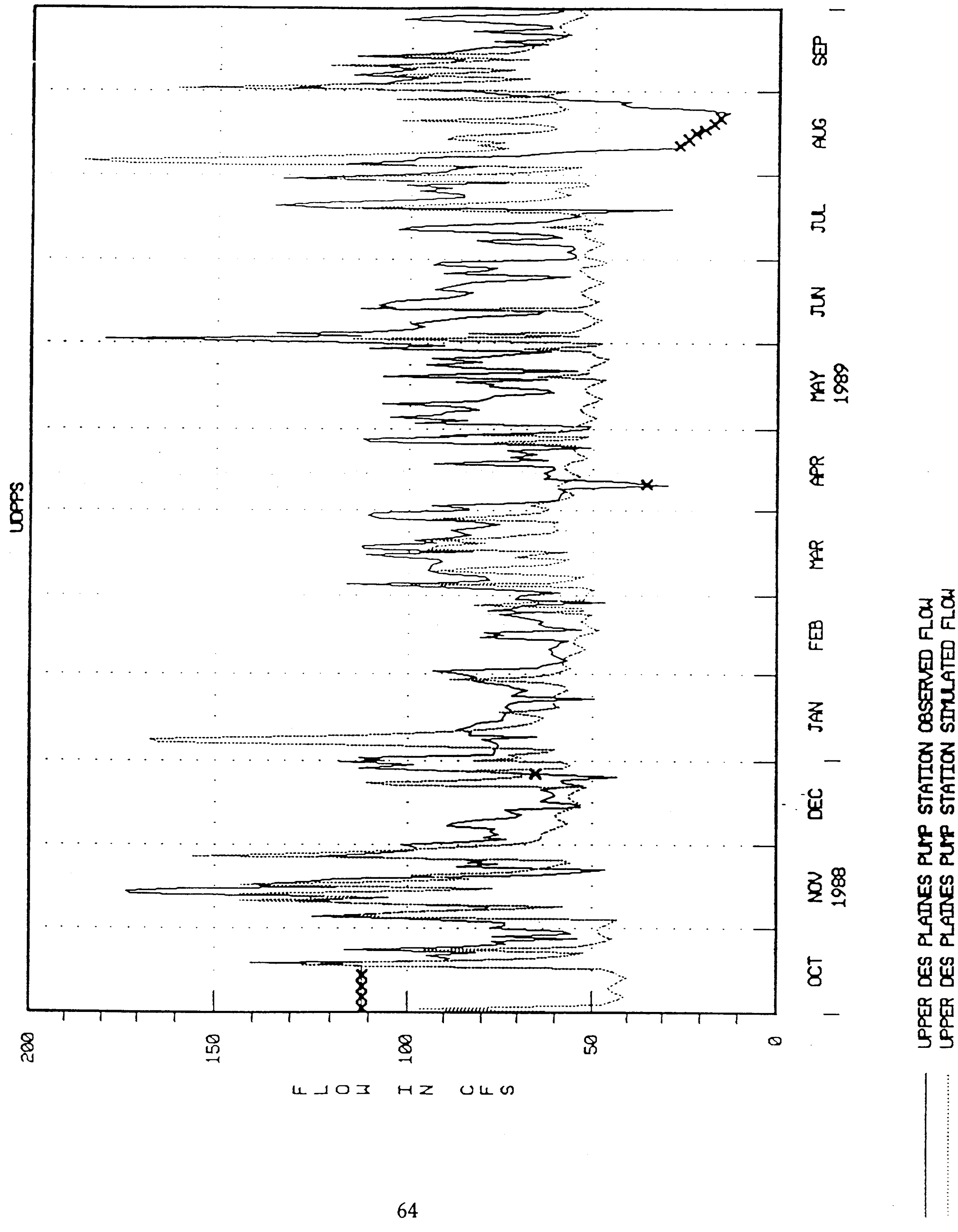
Budget 8 - Simulation of the MWRDGC Upper Des Plaines Pump Station

FIGURE 3.10



Budget 8 - Simulation of the MWRDGC Upper Des Plaines Pump Station

FIGURE 3.11



Budget 8 - Simulation of the MWRDGC Upper Des Plaines Pump Station

TABLE 7
SEWER SYSTEM EVALUATION SURVEY (S.S.E.S.)
After Burke, 1990

UPPER DES PLAINES BASIN

	COMMUNITY	STUDY DATE	CONTRACTOR	POPULATION EQUIVALENT	STUDY AREA (acres)	SANITARY SEWER LENGTH (miles)	SANITARY SEWER (in.-mi.)	SANITARY (gpcpd)	SANITARY (mgd)	FLOW INFILTRATION (gpcpd)	FLOW INFILTRATION (mgd)	INFLOW (gpcpd)	INFLOW (mgd)
1)	DES PLAINES	2/87	RJN	23,677	4,922	104.64	1033.75	86	2.04	121	2.86	1234	29.22
2)	FRANKLIN PARK	1/87	KUDRNA	16,401	800	22.98	262.1	150	2.46	61	1.00	456	7.48
3	HARWOOD HEIGHTS	4/89	MCCLURE	4,363	230	4.45	61.13	166	0.72	22	0.10	446	[illegible]
4)	LEYDEN TWSHP			11,600	1,260	30.46	352.89	60	0.71	64	0.76	339	[illegible]
5)	MELROSE PARK	11/87	SSE	8,848	768	11.87	121.92	142	1.26	111	0.98	261	[illegible]
6)	NORTHLAKE			21,071	1,666	35.6	397.05	203	4.28	133	2.80	532	11.21
7)	NORRIDGE	1/89	KUDRNA	15,954	883	26.97	272.75	8Q	1.28	53	0.85	871	[illegible]
8)	PARK RIDGE	1/87	HARZA	291	30	0.87	7.02	113	0.03	28	0.01	684	[illegible]
9)	ROSEMONT	3/88	BURKE	13,524	768	15.3	142.35	70	0.95	23	0.31	471	6.37
10)	SCHILLER PARK	11/87	SSE	11,103	960	20.97	192.66	96	1.07	111	1.23	166	[illegible]
11)	STONE PARK			4,815	218	5.8	54.71	107	0.52	40	0.19	0	0.00
	TOTAL			131,847	12,747	279.91	2898.35		15.30	23.67	11.09	17.16	78.49
	AVERAGE			11,986	1,159	25.45	263.49		1.30		1.01		7.14

4.0 AVM SYSTEM AT ROMEOVILLE

After a number of studies and detailed investigations, the first and the second Technical Committees concluded that the flow control structures and devices (i.e. turbines, sluice gates, and the upstream controlling works) at the Lockport Powerhouse are inadequate to provide acceptable and accurate accounting of the flows through the Lockport facilities.

In response to the Committee's concerns, the USACE in cooperation with the USGS installed an acoustic velocity meter (AVM), manufactured by Sarasota Automation, at Romeoville, five miles upstream from Lockport. The AVM is an accurate flow meter, which when properly calibrated, will provide more reliable and accurate accounting of the flows than those reported by the MWRDGC through the Lockport facilities. This AVM site is operated and maintained by the Illinois District of the U.S. Geological Survey and became operational on June 12, 1984 (USGS's Romeoville AVM Station Description - Appendix 3). A short time afterwards in March 1985, the AVM was damaged by barge traffic, which cut the submarine cables and rendered the AVM inoperative. Many problems were encountered while repairing the AVM including the inability to get replacement parts or service from the manufacturer. Eventually the AVM was repaired and put into operation in May 24 1988 (Station Analysis, 1989-1992; Appendix 4).

Because of the problems encountered with the AVM and the many problems in getting it repaired, a replacement system was bought from another manufacturer, ORE, Inc. This new AVM was installed in November 1988, and reliable flow records were being recorded by December 1, 1988.

To estimate flows during periods of malfunction of the AVM, a number of regression equations, relating Lockport flows to AVM flows, were developed by the Corps of Engineers, the USGS, Harza Engineering Company, and the second technical committee. A detailed discussion of the characteristics of these regression equations can be found in a report titled "Chicago Sanitary and Ship Canal at Romeoville Acoustic Velocity Meter Backup System." (USACE,1989). The regression equations that were ultimately selected and used to estimate the missing AVM flows from Water Year 1986 through Water Year 1991 were developed by the USGS. These equations are discussed in detail in a preliminary report titled "Comparison, Analysis, and Estimation of Discharge Data on the Chicago Sanitary and Ship Canal at Romeoville Illinois." This report will review the most important aspects of the AVM operation.

4.1 AVM SYSTEM

It has been demonstrated that acoustic velocity meters are particularly useful and successful in obtaining a continuous record of the discharge of rivers and canals, in sites such as Romeoville, where a simple stage-discharge relation cannot be applied satisfactorily.

When rating an AVM system a relation needs to be developed, not only between stage and cross-sectional area, but also between the line velocity measured by the AVM system and the mean velocity in the stream. At river locations with significant range in stage, a relation can be obtained also between stage and K-coefficient (the ratio of mean velocity to line velocity).

At this time, the U.S. Geological Survey does not have official guidelines for defining these relations. Nevertheless usable and pertinent information is available in papers and articles written by U.S. Geological Survey hydrologists. Particularly informative and useful among these papers is one titled "Defining the Relation Between Mean Velocity and the Line Velocity of an Acoustic Velocity Meter" prepared by A. Laenen (1992), USGS, preliminary draft copy.

This paper provides guidelines for defining a mean velocity to AVM velocity rating, explains the theory of the mean-velocity to line velocity (K-factor) relation, discusses various environmental variables that affect the AVM rating and a method to incorporate this variables into the rating, and describes velocity measurement methods that can be used to calibrate a rating.

Pertinent guidelines and information contained in the Laenen report that may be applicable to the Romeoville site have been gleaned and included in the following paragraphs. The Romeoville site will be reviewed based on these guidelines and information.

4.2 DEVELOPMENT OF A DISCHARGE RATING

Ratings for the K-factor, the mean velocity at the channel, and the cross-sectional area need to be established in order to compute discharge at an AVM location. The K-factor (ratio of mean channel velocity to AVM path velocity) is related to variables other than stage. Some of the variables are more significant than others and become more significant because of changing hydraulic or environmental conditions. Additionally, the shape of the vertical-velocity curve may vary with the magnitude of the flow and a separate velocity rating may be required. Cross-sectional area is related to the stage and this relation is subject to change due to scour and fill. Scour and fill are, however unlikely in the Sanitary and Ship Canal at Romeoville because at this location sediment loads are small and the canal is carved into bedrock.

Rating environmental variables affecting the AVM rating include ice, wind, bed roughness, and aquatic biota. One way of allowing for the influence of environmental factors is to apply a shift based on measurements of discharge. However, several of these environmental variables can be measured accurately on a real-time basis. The K-factor can be defined as a function of stage and any number of environmental factors. These relations can be summarized in tables or represented by equations defined by regression analyses:

$$K = k_1 + k_2 s + k_3 s^2 + k_4 v_1 + k_5 v_2 \ldots\ldots + k_n v_{n-3} \qquad (3.1)$$

or

$$K = k_1 * s^{x_1} * v^{x_2} * v^{x_3} \ldots\ldots v^{x_n} \qquad (3.2)$$

where:

K = line velocity to mean velocity ratio related to stage and environmental factors.
K_n = coefficient defined by regression analysis or other curve fitting technique.
xn = exponents determined by regression analysis or other curve fitting technique.
s = stage
v^{xn} = environmental variable

4.2.1 Rating Velocity

A velocity rating can be developed as a function of the magnitude of the AVM line velocity. A velocity rating can either be tabular or an equation defined by regression analyses:

$$V = k1 + k2\ Vavm + k3\ (Vavm)^2 \tag{3.3}$$

When developing a velocity rating, it is important that the vertical-velocity profile be defined as accurately as possible. The best way of defining accurate velocity distribution along the vertical is by making additional measurements of point velocities, thus defining individual vertical velocity profiles (for a range of flow conditions) that will establish relative bed roughness, shear velocity, and define local momentum changes.

4.2.2 Rating Area

Area can be a straightforward rating if the cross section remains stable or changes little. Area can be defined by depths measured when making current meter measurements of discharge or by bathymetric survey. For locations where channel fill and scour make changes in the cross-section continually, provisions need to be made to define these changes. Periodic measurements can provide a shift which can be applied to the rating. Area ratings can be defined by measurements of depth and be presented in tabular form or equations defined by regression analyses:

$$A = k_1 + k_2 s + k_3 s^2 + k_4 d \quad (3.4)$$

or

$$A = k_1 * s^{x_1} + k_2 * d^{x_2} \quad (3.5)$$

where:
A = area rating
d = depth change from channel fill or scour.

Discharge is computed by multiplying K, V and A ratings, which have been defined by an adequate number of discharge measurements:

$$Q = K\ A\ V \quad (3.6)$$

where Q = discharge in cfs.

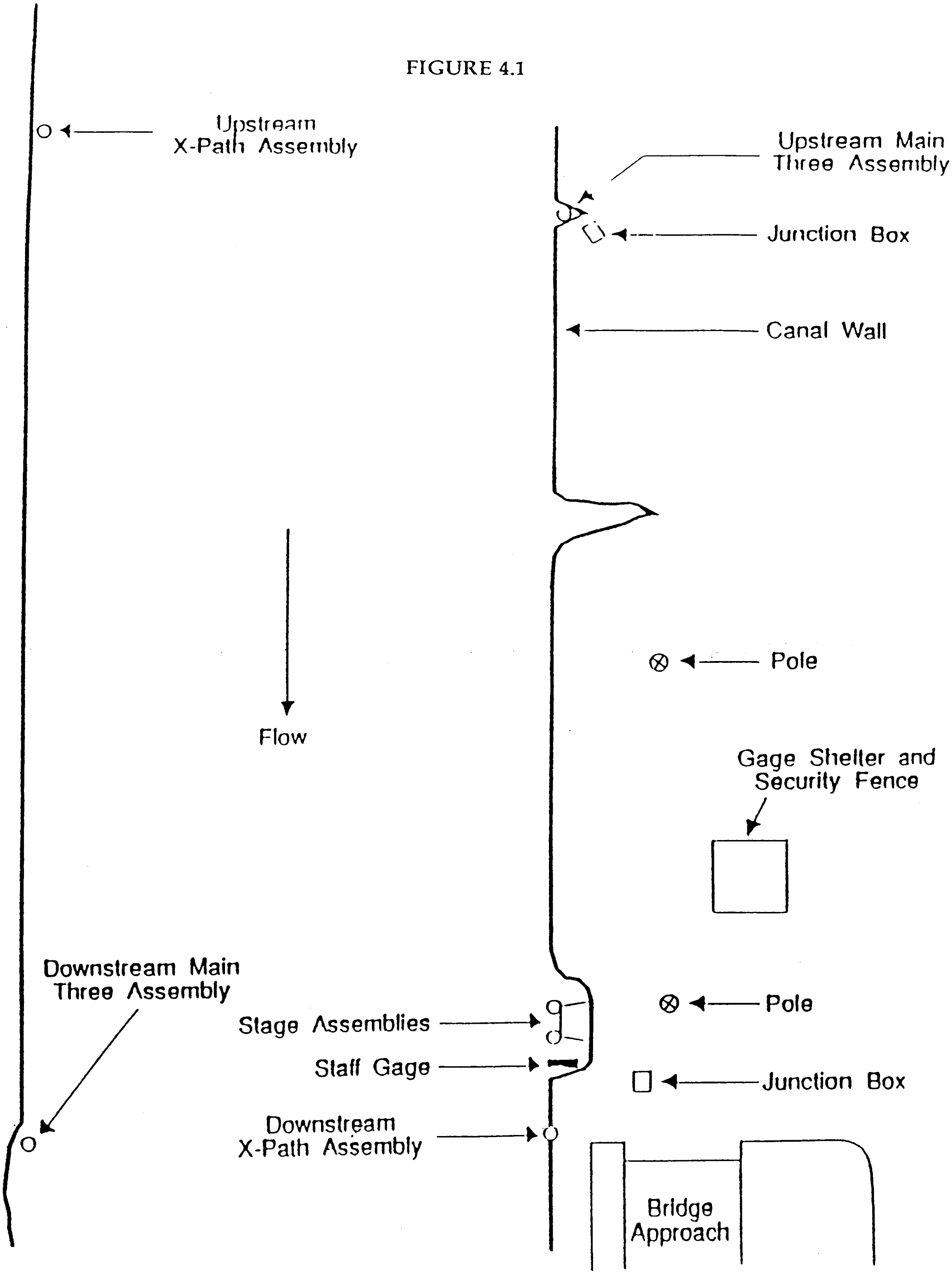
4.3 ROMEOVILLE AVM STATION

The gage is located on the left bank 40 feet upstream from the Romeoville Road (135th Street) bridge over the canal at Romeoville, Illinois 5.2 miles upstream from Lockport Lock and Dam.

The instrumentation includes a four-path Ferranti ORE 7410 Acoustical Velocity Meter (AVM), DecWriter printer, Campbell Scientific CR-10 dataloger with a temperature thermocouple, Handar SDI-12 shaft encoder, a manometer, equipped with a 10-turn potentiometer, and a telemetry system within an 8 ft x 8 ft x 8 ft concrete block shelter.

Eight velocity transducers are installed at four locations along the canal walls with two locations on each bank approximately 170 apart and 162 feet across from the other bank (Figure 4.1). The velocity transducers are installed in or attached to 3 or 6 inch plastic pipes. One set of three transducers (upper, middle, and lower paths) is located along the east (left) bank approximately 130 feet upstream of the gage. The other set of three transducers is located along the west (right) bank near the upstream side of the bridge. The remaining pair of transducers make up the cross-path. The upstream cross-path transducer is located approximately 170 feet upstream from the bridge on the west bank and the downstream transducer is located on the east bank near the upstream side of the bridge. Each pair (path) of transducers is at approximately the same elevation across the canal from one another at approximately a 45 degree angle to the canal sides, and at different vertical locations within the cross-section. Each pair forms a velocity path. One stage transducer is attached to the east canal wall near the gage house and is pointed at the water surface. All transducers are linked to the AVM by individual electrical wires.

FIGURE 4.1



Sketch of Acoustic Velocity Meter, Chicago Sanitary and Ship Canal at Romeoville, Il.

A PVC stilling well is mounted next to the stage transducer on the same mounting bracket that is attached to the east canal wall. A float operated SDI-12 shaft encoder is linked to CR10 datalogger by buried cable.

An outside staff gage is bolted to the east canal wall, in the same natural crevice as the uplooker transducer and the manometer orifice.

Elevation of prominent features, in feet above gage datum are as follows:

Velocity path No. 1 (top = t) transducers	16.51
Velocity path No. 2 (middle = m) transducers	12.26
Velocity path No. 3 (cross = x) transducers	13.16
Velocity path No. 4 (bottom = b) transducers	8.28
Stage transducer	15.75
Orifice	18.00

AVM transducer path lengths and angles are as follows:

Length of velocity paths 1,2 and 4	236. feet
Length of velocity paths	3235. feet
Angle of velocity paths 1,2 and 4	44.5°
Angle of velocity path 3	44.0°

The gage datum is 551.89 ft. NGVD of 1929.

For a more detailed description of this installation see Appendix 3.

4.4 REVIEW OF THE ROMEOVILLE AVM RATINGS

Data for this review were supplied by the U.S. Geological Survey (USGS). These data were compiled from discharge measurements made at the Romeoville site. Selected data compiled from USGS data forms are shown in Table 4.1. Measurements 1-41 were made during the time when the Sarasota AVM was in operation, and measurements 42-73 were made during the ORE AVM operation.

TABLE 4.1

Discharge Measurement Data at Romeoville

Meas No.	Date	Width	Gage Height	Area	Measured Discharge	AVM Discharge	Observed Velocity
1	22-Mar-84	163	25.50	4190	6400	6310	1.53
2	12-Jun-84	164	25.20	4170	3710	3591	0.89
3	29-Jun-84	164	24.60	4088	3400	2436	0.83
4	16-Oct-84	164	22.20	3660	7670	8477	2.10
5	25-Feb-85	164	23.40	3830	5770	6117	1.51
6	04-Mar-85	164	22.20	3640	17700	17908	4.86
7	04-Apr-85	164	22.40	3680	17900	17842	4.86
8	29-Aug-85	164	24.90	4110	3460	2685	0.84
9	17-Oct-85	164	25.00	4090	2550	1486	0.62
10	19-Nov-85	164	23.20	3800	6660	6383	1.75
11	20-Nov-85	163	22.20	3650	8510	8230	2.33
12	20-Dec-85	164	25.10	4160	2920	2675	0.70
13	10-Jan-86	164	25.00	4280	1360	944	0.32
14	04-Apr-86	164	25.10	4210	1880	1392	0.45
15	01-Jul-86	164	24.30	3970	5100	4827	1.28
16	14-Jul-86	164	24.70	4150	3050	2678	0.73
17	07-Aug-86	164	24.70	4090	4720	4134	1.15
18	22-Sep-86	164	24.70	4150	4400	2541	1.06
19	25-Sep-86	164	24.80	4080	4460	4389	1.09
20	03-Oct-86	164	21.80	3660	15800	15725	4.32
21	12-Dec-86	164	25.00	4170	3430	3275	0.82
22	26-Jan-87	164	25.00	4190	2850	2903	0.68
23	Mar/16/87	164	25.10	4180	1950	2180	0.47
24	07-Apr-67	164	25.00	4170	2430	2383	0.58
25	15-May-87	164	25.10	4190	3120	3114	0.74
26	19-Jun-87	164	24.30	4080	7300	6838	1.79
27	24-Jul-87	164	24.70	4110	3970	3992	0.97
28	17-Aug-87	164	20.90	3450	14700	14325	4.26
29	09-Oct-87	164	24.90	4140	2670	2689	0.64
30	15-Oct-87	164	24.80	4160	2930	2837	0.70
31	15-Oct-87	164	24.90	4170	2460	2116	0.59
32	15-Oct-87	164	25.10	4160	2660	2271	0.64
33	19-Oct-87	164	25.20	4180	2320	1983	0.56
34	19-Oct-87	164	25.20	4170	2550	1983	0.61
35	03-Nov-87	164	25.10	4150	2020	1993	0.49
36	23-Nov-87	164	24.90	4150	2810	2847	0.68
37	30-Dec-87	164	25.00	4140	2840	3803	0.69
38	12-Feb-88	164	25.50	4220	2080	2181	0.49
39	10-Jun-88	164	25.00	4160	4110	4181	0.99
40	27-Jul-88	164	25.20	4150	3010	2942	0.73
41	15-Sep-88	164	24.80	4100	5230	5228	1.28
42	18-Nov-88	164	25.10	4210	4510	3810	1.07
43	13-Jan-89	164	25.30	4210	2580	2677	0.61
44	03-Mar-89	164	25.50	4220	2250	2401	0.53
45	05-Apr-89	164	25.60	4230	2560	2634	0.61
46	03-May-89	164	25.40	4140	2070	2233	0.50
47	01-Jun-89	164	21.20	3530	14400	14323	4.08
48	01-Jun-89	164	21.10	3550	15100	14209	4.25
49	18-Jul-89	164	24.70	4140	5480	5330	1.32
50	04-Aug-89	164	25.10	4140	4040	4090	0.98
51	12-Sep-89	164	24.70	4200	6010	5932	1.43
52	21-Nov-89	163	25.60	4170	2690	2804	0.65
53	21-Nov-89	163	25.60	4190	2890	2705	0.69
54	11-Jan-90	164	25.20	4200	2070	2319	0.49
55	11-Jan-90	164	25.10	4140	1990	2241	0.48
56	06-Mar-90	164	25.60	4260	2270	2046	0.53
57	06-Mar-90	164	25.50	4250	2700	2929	0.64
58	24-Apr-90	164	25.70	4220	2730	2746	0.65
59	11-Jul-90	164	25.60	4160	5450	5467	1.31
60	11-Jul-90	164	25.40	4180	5310	5362	1.27
61	20-Jul-90	164	20.70	3400	14400	13942	4.24
62	22-Aug-90	164	25.30	4150	5250	5082	1.27
63	14-Nov-90	164	25.60	4360	1920	2068	0.44
64	04-Dec-90	164	25.40	4380	4330	4848	0.99
65	08-Feb-91	164	25.50	4270	2560	2596	0.60
66	11-Mar-91	164	25.60	4390	2210	2152	0.50
67	15-Apr-91	176	21.90	4410	16900	16706	3.83
68	20-May-91	162	25.60	4430	2370	2542	0.53
69	18-Jul-91	162	25.20	4440	3780	3879	0.85
70	17-Oct-91	162	25.40	4460	2700	2772	0.61
71	17-Oct-91	162	25.50	4460	2590	1997	0.58
72	13-Jan-92	162	25.50	4460	2300	2289	0.52
73	23-Mar-92	162	25.50	4470	2620	2738	0.59

Measurements 1 through 62 were made from the upstream side of the Romeoville Road bridge. Measurements 63 through 73 were made at a section half way between the upstream and downstream transducers. Measurement 67 was made 4.3 miles upstream at Lemont Road.

4.4.1 Methods for Daily Discharge Computations.

Three methods for the computation of daily discharges, developed by the U.S. Geological Survey, were used during the 1986-1991 period:

1. During periods of normal AVM operation discharges were computed using AVM velocity records and manometer gage height records and a set of discharge equations developed for this purpose.
2. For periods of missing AVM record discharges were estimated from the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) records for Lockport which are adjusted using regression equations developed by the U.S. Geological Survey.
3. Beginning with the 1991 water year, daily discharges for periods of normal AVM operation, are computed using the Index Velocity method through the Automatic Data Processing System (ADAPS). The system consists of a velocity-velocity rating, and a stage-area rating.

4.4.2 Discharge Equations

The original set of discharge equations developed for use during periods of normal AVM operation are listed in Table 4.2.

TABLE 4.2

Discharge Equations for the AVM at Romeoville

Paths Working	EQUATION
b,m,x,t	Q = 1697*Vb + 205*Vm + 335*Vx + (Gh-14.67)*164*Vt
b,m,x	Q = 1697*Vb + 205*Vm + (Gh-12.63)*164*Vt
b,m, t	Q = 1697*Vb + 515*Vm + (Gh-14.52)*164*Vt
b, x,t	Q = 1722*Vb + 515*Vx + (Gh-14.67)*164*Vt
m,x,t	Q = 1867*Vm + 335*Vx + (Gh-14.67)*164*Vt
b,m	Q = 1697*Vb + (Gh-11.38)*164*Vm
b, x	Q = 1722*Vb + (Gh-11.53)*164*Vx
b, t	Q = 2032*Vb + (Gh-13.42)*164*Vt
m,x	Q = 1867*Vm + (Gh-12.63)*164*Vx
m, t	Q = 2177*Vm + (Gh-14.52)*164*Vt
x,t	Q = 2196*Vx + (Gh-14.67)*164*Vt
b	Q = 674*Vb + (Gh-5.14)*164*Vb
m	Q = 819*Vm + (Gh-6.24)*164*Vm
x	Q = 838*Vx + (Gh-6.39)*164*Vx
t	Q = 1086*Vt + (Gh-8.28)*164*Vt

These equations assumed that the channel was 164 feet wide and that the bottom was at elevation 0.0 foot. However, based on a bathymetric survey made in June 1991, the width was revised to 162 feet and the bottom elevation to -1.55 feet. A diagram of the revised channel is shown in Figure 4.2 and the revised equations are listed in Table 4.3. The revised equation listed in Table 4.3 were used to recompute the discharge record from November 18, 1988 to November 2, 1990. After November 2, 1990, the index velocity method was applied to estimate discharge of Romeoville, whereas prior to November 3, 1988 discharge at Romeoville was calculated internally by the Sarasota AVM.

FIGURE 4.2

Diagram of Channel at Romeoville

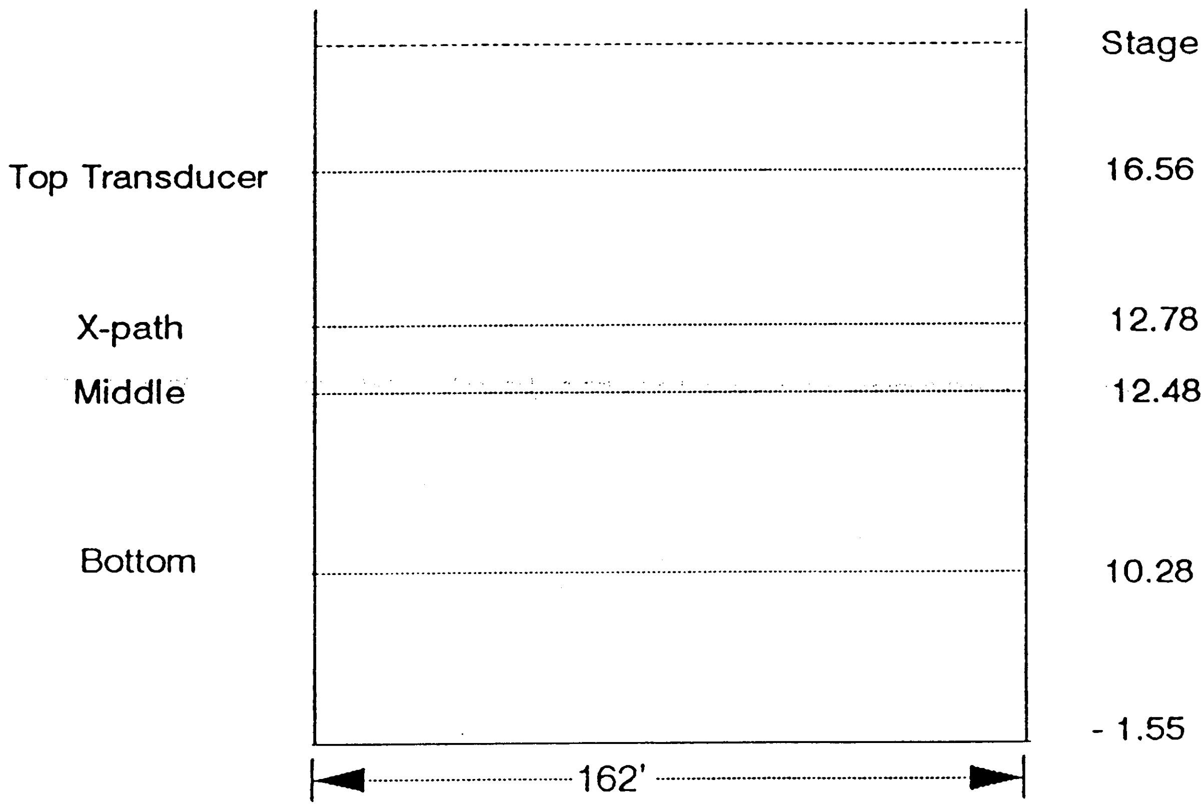


FIGURE 4.3

Comparison Between AVM and Measured Discharges (1-41) - Sarasota AVM

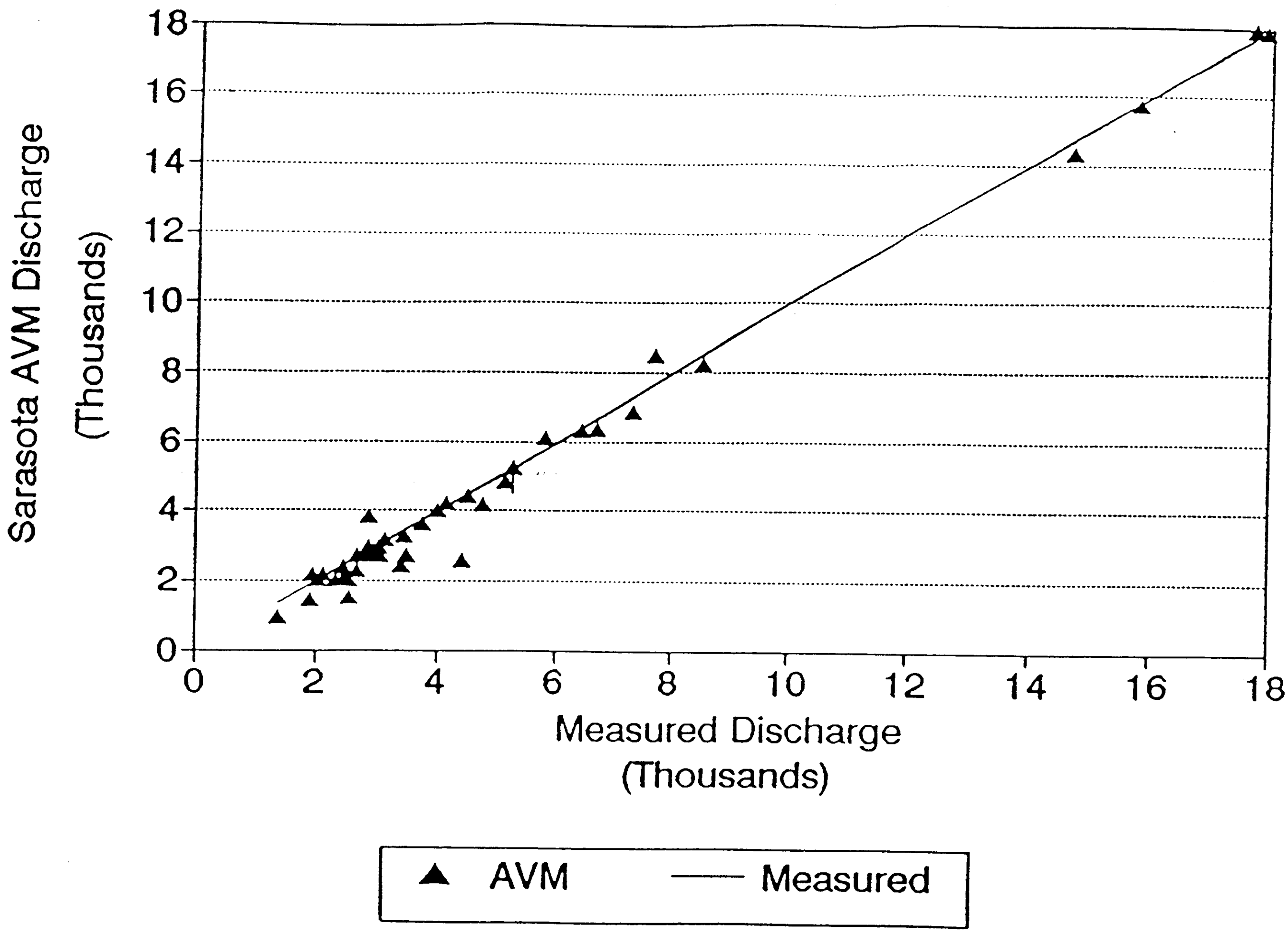


TABLE 4.3

Discharge Equations for the AVM at Romeoville

For the Period November 17, 1989 to November 2, 1990

Paths Working	EQUATION
b,m,x,t	Q = 1903*Vb + 202*Vm + 330*Vx + (Gh-14.67)*162*Vt
b,m,x	Q = 1903*Vb + 202*Vm + (Gh-12.63)*162*Vx
b,m, t	Q = 1903*Vb + 509*Vm + (Gh-14.52)*162*Vt
b, x,t	Q = 1927*Vb + 509*Vx + (Gh-14.67)*162*Vt
m,x,t	Q = 2070*Vm + 330*Vx + (Gh-14.67)*162*Vt
b,m	Q = 1903*Vb + (Gh-11.38)*162*Vm
b, x	Q = 1927*Vb + (Gh-11.53)*162*Vx
b, t	Q = 2234*Vb + (Gh-13.42)*162*Vt
m,x	Q = 2070*Vm + (Gh-12.63)*162*Vx
m, t	Q = 2376*Vm + (Gh-14.52)*162*Vt
x,t	Q = 2396*Vx + (Gh-14.67)*162*Vt
b	Q = 767*Vb + (Gh-4.36)*162*Vb
m	Q = 909*Vm + (Gh-5.46)*162*Vm
x	Q = 929*Vx + (Gh-5.62)*162*Vx
t	Q = 1174*Vt + (Gh-7.50)*162*Vt

4.4.2.1 Measured Discharge Vs. Sarasota AVM Discharge

Measurements 1 through 41 were made to verify the Sarasota AVM calibration. The AVM discharge data as well as the measured discharges are listed in Table 4.1. A plot of these data, Figure 4.3, shows that during the period when the AVM was working properly, the calibration remain reasonable constant throughout the period, and the AVM discharge records compared fairly well with the measured discharges.

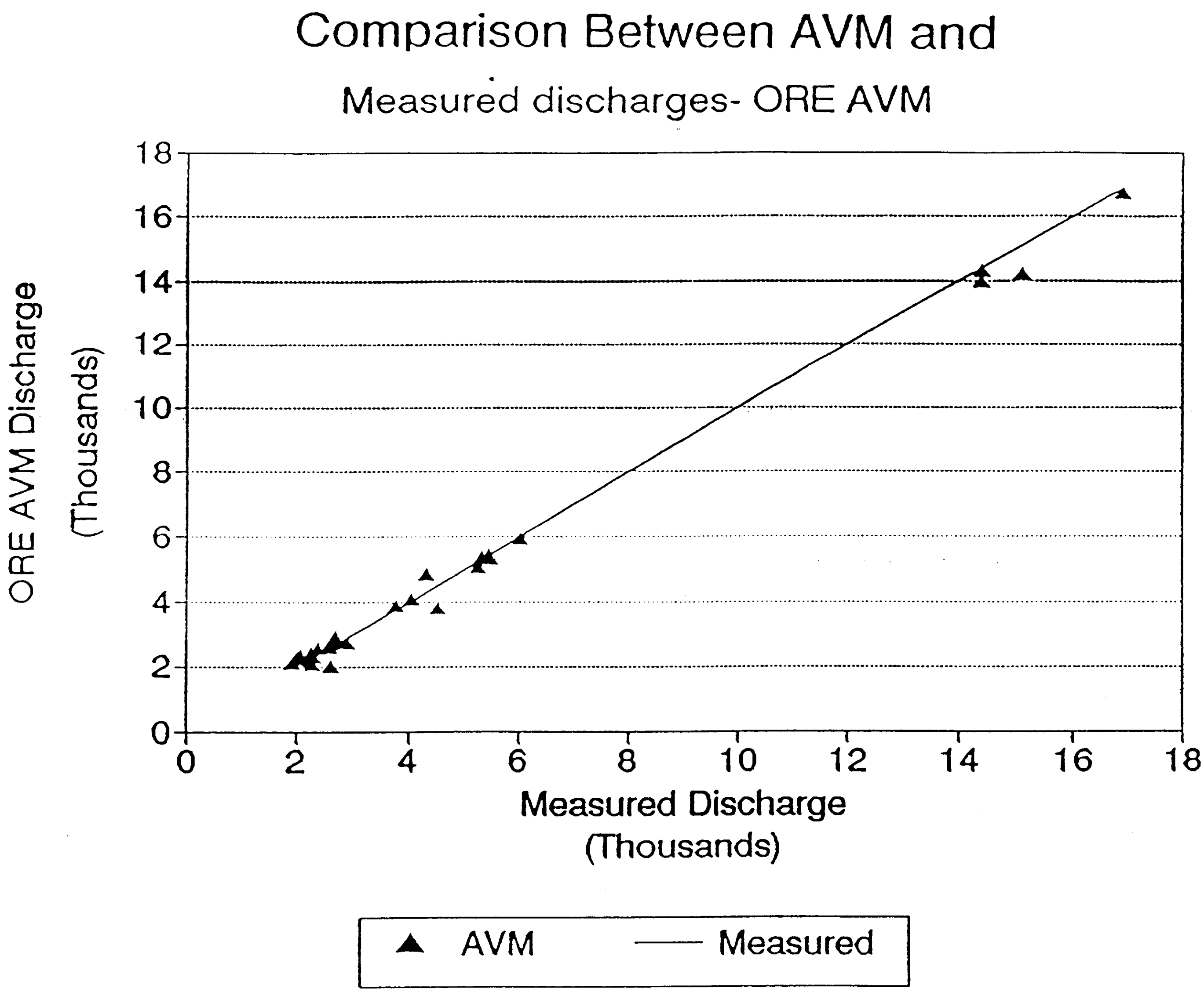
4.4.2.2 Measured Discharge Vs. ORE AVM Discharge

Measurements 42 to 73 were made to verify the calibration of the ORE AVM. Pertinent data are listed in Table 4.1, and for the purpose of comparison are plotted in Figure 4.4. The data in Table 4.1, as well as the plot in Figure 4.4, show that during periods of normal operation the ORE AVM discharge records compare reasonably well with the measured discharges.

Based on the above observations it is evident that the equations yield acceptable results. However, evaluating the equations according to guidelines (Laenen, 1992), the equations are theoretically incomplete, because the velocities are not adjusted as a function of stage. The guidelines suggest that including K factor, as defined by equations 1 or 2, in the discharge equations, would provide a tool for developing ratings where stage is a significant rating factor.

It appears that the reason why K is not included in the discharge equations, is because not enough data is available to develop a sound relationship between K and stage. The data that is needed for developing reliable values of K, are well defined velocity profiles. Collecting these type of data by current conventional methods is time consuming and expensive. However, the U.S. Geological Survey is now using a BroadBand Acoustic Doppler Current Profiler (ADCP) which is a new generation instrument that is able to measure with considerable improved precision. This improved precision allows finer vertical velocity resolution. Furthermore, measurements can be completed in minutes instead of hours. It is expected that the availability of this new technology will improve considerably the reliability and accuracy of the discharge computations at Romeoville.

FIGURE 4.4



Comparison Between AVM and
Measured discharges- ORE AVM
ORE AVM Discharge
(Thousands)
Measured Discharge
(Thousands)
0
2
4
6
8
10
12
14
16
18
AVM
Measured

4.5 BACKUP SYSTEM Regression Equations.

The need for developing a backup system for estimation of discharges at times when the AVM is inoperative has been well documented, justified, and recommended by the second technical committee. The task of developing such a system was assigned to the Illinois District of the U.S. Geological Survey. A description of the analysis and documentation of this system was made available to the committee in a report titled "Comparison, Analysis, and Evaluation of Discharge Data on the Chicago Sanitary and Ship Canal at Romeoville, Illinois".

Briefly, the analysis involved: (1) checking the consistency of the discharges estimated by two different AVMs installed at Romeoville for consecutive time periods by statistical and regression analyses; (2) adjusting the discharge record to account for corrections to the width and depth of the canal determined by field measurements; and, (3) development of equations for estimating discharges on days when the AVM was inoperative using discharge estimates made by the Metropolitan Water Reclamation District of Greater Chicago at the lock, powerhouse, and controlling works at Lockport, Illinois.

The Committee reviewed this report with particular emphasis on the quality of the basic data, on the statistical techniques used to develop the model, and on the efficiency and reliability of the regression equations. Based on this review, the committee reached the following conclusion:

a. The data compiled from October 1, 1986 through May 31, 1992 is of acceptable quality. U.S Geological Survey hydrologists reviewed the validity and consistency of discharge estimates by the Sarasota and ORE

AVMs and found no significant difference between these two sets of data. This conclusion was reached based on statistical as well as hydrological considerations. The Committee agrees with this assessment of the data.

b. The estimating equations were developed using current and accepted statistical methods. The resulting equations exhibit excellent regression coefficients and explain over 95% of the total variance.

c. The report received a comprehensive technical review by highly qualified personnel at the Office of Surface Water, Water Resources Division, of the U.S. Geological Survey and has been published in a report titled "Comparison, Analysis, and Estimation of Discharge Data from Two Acoustic Velocity Meters on the Chicago Sanitary and Ship Canal at Romeoville, Illinois", U.S. Geological Survey, Water-Resources Investigations Report 93-4048.

The Committee is gratified to see this project is commanding the attention and support that is appropriate not only at the District level but at the Division level as well. The report constitutes a valuable and useful tool for computation of discharges for periods of AVM failure.

The estimating equations published in the report are:

When flows at Lockport are through the turbines only,

$$Q_{AVM} = (1.1270 \times Q_{TLL}) + 75.48 \quad (3.7)$$

When flows at Lockport are through the turbines and powerhouse sluice gates with sluice gate flow less than 5,000 cfs.

$$Q_{AVM} = (1.1270 \times Q_{TLL}) + (0.6842 \times Q_{PHSG}) + 219.7 \quad (3.8)$$

When flows at Lockport are through the turbines, powerhouse sluice gates, and controlling works or when flow through the powerhouse sluice gates is greater than 5,000 cfs.

$$Q_{AVM} = (1.1270 \times Q_{TLL}) + (0.4361 \times Q_{PHSG}) + (0.3228 \times Q_{CW}) + 1086 \quad (3.9)$$

Where:

Q_{AVM} = Estimated AVM discharge

Q_{TLL} = MWRDGC reported flow through the Lockport turbines and locks plus leakage.

Q_{PHSG} = MWRDGC reported flow through the Lockport powerhouse sluice gates.

Q_{CW} = MWRDGC reported flow through the Lockport controlling works.

4.5.1 Index Velocity Method

Beginning with the 1991 water year the discharge records are computed using the Index-Velocity method. This method consists of a velocity-velocity rating and stage area rating, given by the following equations:

Channel Flow Area = (Gh * 162) + 251 **(3.10)**
Mean Channel Velocity = 0.92*(Mean AVM velocity) **(3.11)**

Where:

Gh = Gage height in feet
Mean AVM velocity = (Vel_t+ Vel_m + Vel_x + Vel_b)/4 if all paths are working

If all paths are not working, then the mean AVM velocity is computed by first correcting each working path velocity by the appropriate (Mean AVM Vel)/(Path velocity) ratio and then taking their arithmetic mean. These corrections ratios are listed below:

(Mean AVM Vel)/(Vel_t) = 0.964
(Mean AVM Vel)/(Vel_m) = 0.989
(Mean AVM Vel)/(Vel_x) = 1.000
(Mean AVM Vel)/(Vel_b) = 1.053

The mean AVM velocity computed using the above procedure appears to be a reliable index of the mean channel velocity.

4.5.2 Area Rating

Analysis of discharge measurements made at the upstream side of bridge from 1984-1990 indicated that the mean bottom elevation of the channel at the upstream side of the bridge fluctuated between about -0.20 feet to -0.9 feet below the zero of the gage.

This fluctuation appears to be primarily due to varying amounts of debris that from time to time accumulated and later transported away from the vicinity of the measuring section.

Beginning with discharge measurement #63 (November 14, 1990), the measuring site was moved to its present location, midway between the upstream and downstream transducers. Based on the results of a bathymetric survey of this new site, made in June 1991, the mean bottom elevation of the channel was found to be at 1.55 feet below the zero of the gage. It seems that the mean bottom elevation at this location remained nearly constant through the 1992 water year.

Based on the results obtained from studying the stability of the mean bottom elevation at the upstream side of the bridge (Appendix 5), the Committee was concerned about the stability of the mean bottom elevation of the channel at this new location. In response to this concern, and through a series of discussions and written communication, the U.S. Geological Survey informed the Committee (Appendix 6) that they plan to measure the cross section annually, and if needed, the stage-area rating will be revised or shifted as necessary to account for any significant changes in cross-section that may be detected.

To check the validity of the discharges computed using the index-velocity method, the U.S. Geological Survey maintains an updated table of equations for the AVM. These updated equations are compiled in Tables 4.4 and 4.5.

TABLE 4.4

Discharge Equations for the AVM at Romeoville

For the Period November 2, 1990 to May 16, 1991

Paths Working	EQUATION
b,m,x,t	Q = 1756*Vb + 364*Vm + 344*Vx + (Gh-14.64)*162*Vt
b,m,x	Q = 1756*Vb + 364*Vm + (Gh-12.52)*162*Vx
b,m, t	Q = 1756*Vb + 667*Vm + (Gh-14.38)*162*Vt
b, x,t	Q = 1798*Vb + 667*Vx + (Gh-14.64)*162*Vt
m,x,t	Q = 2056*Vm + 344*Vx + (Gh-14.64)*162*Vt
b,m	Q = 1756*Vb + (Gh-10.27)*162*Vm
b, x	Q = 1798*Vb + (Gh-10.53)*162*Vx
b, t	Q = 2100*Vb + (Gh-12.40)*162*Vt
m,x	Q = 2056*Vm + (Gh-12.52)*162*Vx
m, t	Q = 2358*Vm + (Gh-14.38)*162*Vt
x,t	Q = 2391*Vx + (Gh-14.64)*162*Vt
b	Q = 637*Vb + (Gh-3.36)*162*Vb
m	Q = 895*Vm + (Gh-5.36)*162*Vm
x	Q = 929*Vx + (Gh-5.62)*162*Vx
t	Q = 1170*Vt + (Gh-7.48)*162*Vt

TABLE 4.5

Discharge Equations for the AVM at Romeoville

For the Period May 16, 1991 to Present

Paths Working	EQUATION
b,m,x,t	Q = 1756*Vb + 395*Vm + 344*Vx + (Gh-14.84)*162*Vt
b,m,x	Q = 1756*Vb + 395*Vm + (Gh-12.71)*162*Vx
b,m, t	Q = 1756*Vb + 667*Vm + (Gh-14.38)*162*Vt
b, x,t	Q = 1828*Vb + 667*Vx + (Gh-14.84)*162*Vt
m,x,t	Q = 2086*Vm + 344*Vx + (Gh-14.84)*162*Vt
b,m	Q = 1756*Vb + (Gh-10.27)*162*Vm
b, x	Q = 1828*Vb + (Gh-10.72)*162*Vx
b, t	Q = 2100*Vb + (Gh-12.40)*162*Vt
m,x	Q = 2086*Vm + (Gh-12.71)*162*Vx
m, t	Q = 2358*Vm + (Gh-14.38)*162*Vt
x,t	Q = 2416*Vx + (Gh-14.84)*162*Vt
b	Q = 637*Vb + (Gh-3.36)*162*Vb
m	Q = 895*Vm + (Gh-5.36)*162*Vm
x	Q = 953*Vx + (Gh-5.80)*162*Vx
t	Q = 1170*Vt + (Gh-7.48)*162*Vt

A general evaluation of the work concerning the direct measurement of discharge can be summarized by saying that the U.S. Geological Survey has done a commendable work. They have acquired and are using state-of-the-art equipment and instrumentation for measuring stream flow, have developed and continue to improved computational techniques which conform with the latest scientific knowledge and engineering practice. They have developed a reliable backup computational procedure to be used at times of

AVM failure, and maintain and updated set of AVM discharge equations to be used for quality control of the discharges computed using the current Index-Velocity method.

Chapter 5

5.0 LEAKAGE AT LAKE MICHIGAN CONTROL STRUCTURES

The State of Illinois has requested leakage through two federally owned and operated lakefront facilities at Chicago River Controlling Works (CRCW) (Figure 5.1) and O'Brien Lock and Dam (O'Brien) (Figure 5.2) be considered a deduction from the total flow charged against the State of Illinois diversion. The Corps of Engineers requested the U.S. Geological Survey to make field measurements to determine the amount of leakage at each of the three lakefront structures (CRCW and O'Brien), including Wilmette Pumping Station (WPS). The Chicago District requested that the Committee observe the field measurements and review the preliminary results. The U.S. Geological Survey used two techniques for measuring leakage through the lakefront control structures. The first technique used was a BroadBand Acoustic Doppler Current Profiler (ADCP) from a moving boat. The second was a dye-dilution measuring technique, which was used to verify the measurements made with the ADCP at CRCW. ADCPs are state-of-the-art instruments which measure current velocity profiles. Recently, the U.S. Geological Survey began to use the ADCP system (a system developed by RD Instruments, Inc. and funded partially by the U.S. Geological Survey) to measure streamflow, especially in rivers or canals where standard discharge measurement techniques were either very difficult because of low velocities or very expensive. The use of an ADCP system to measure streamflow is described by Gordon (1989), and further documented by Simpson (1986), and Simpson and Oltman (1991).

Figure 5.1

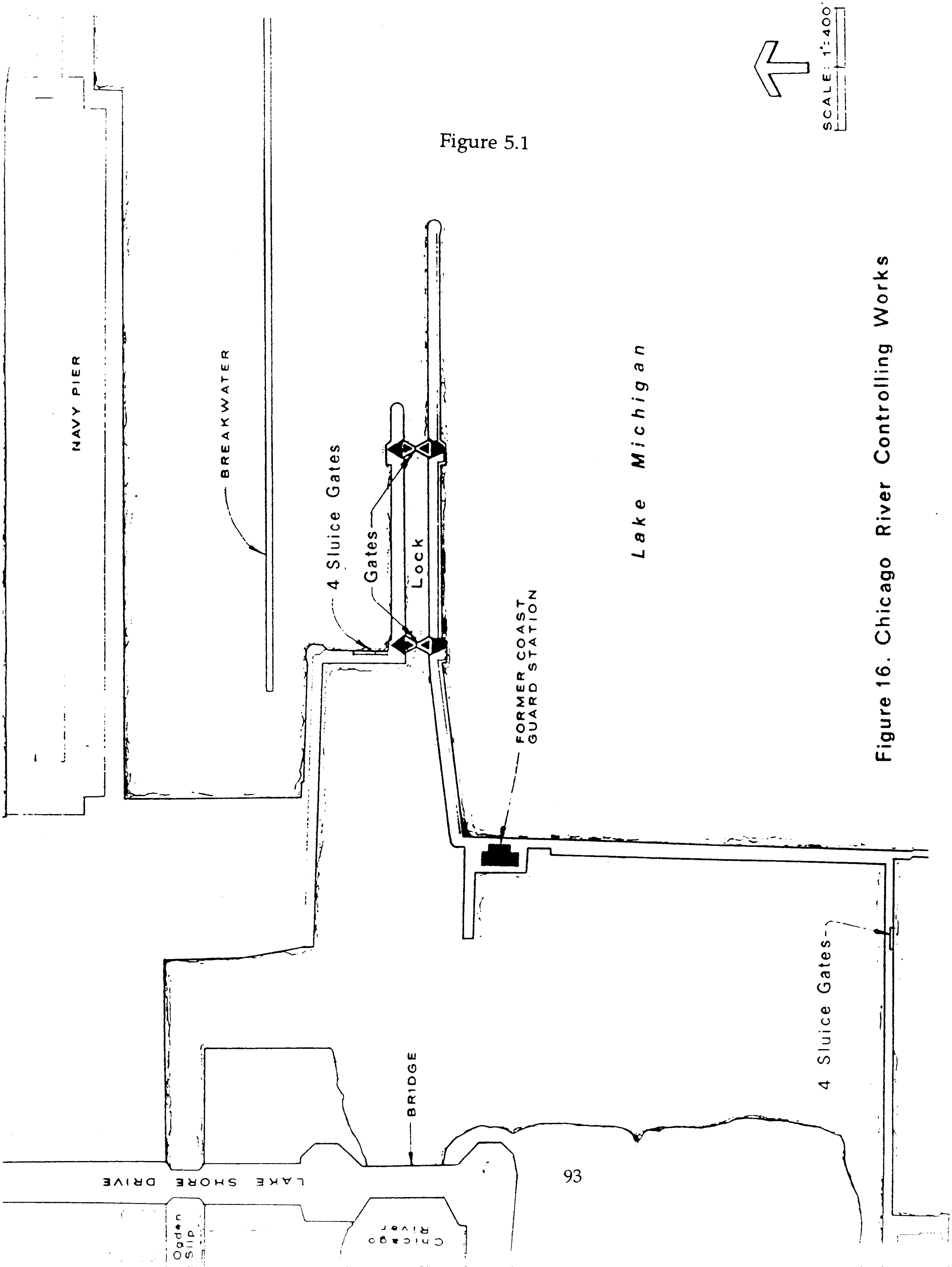
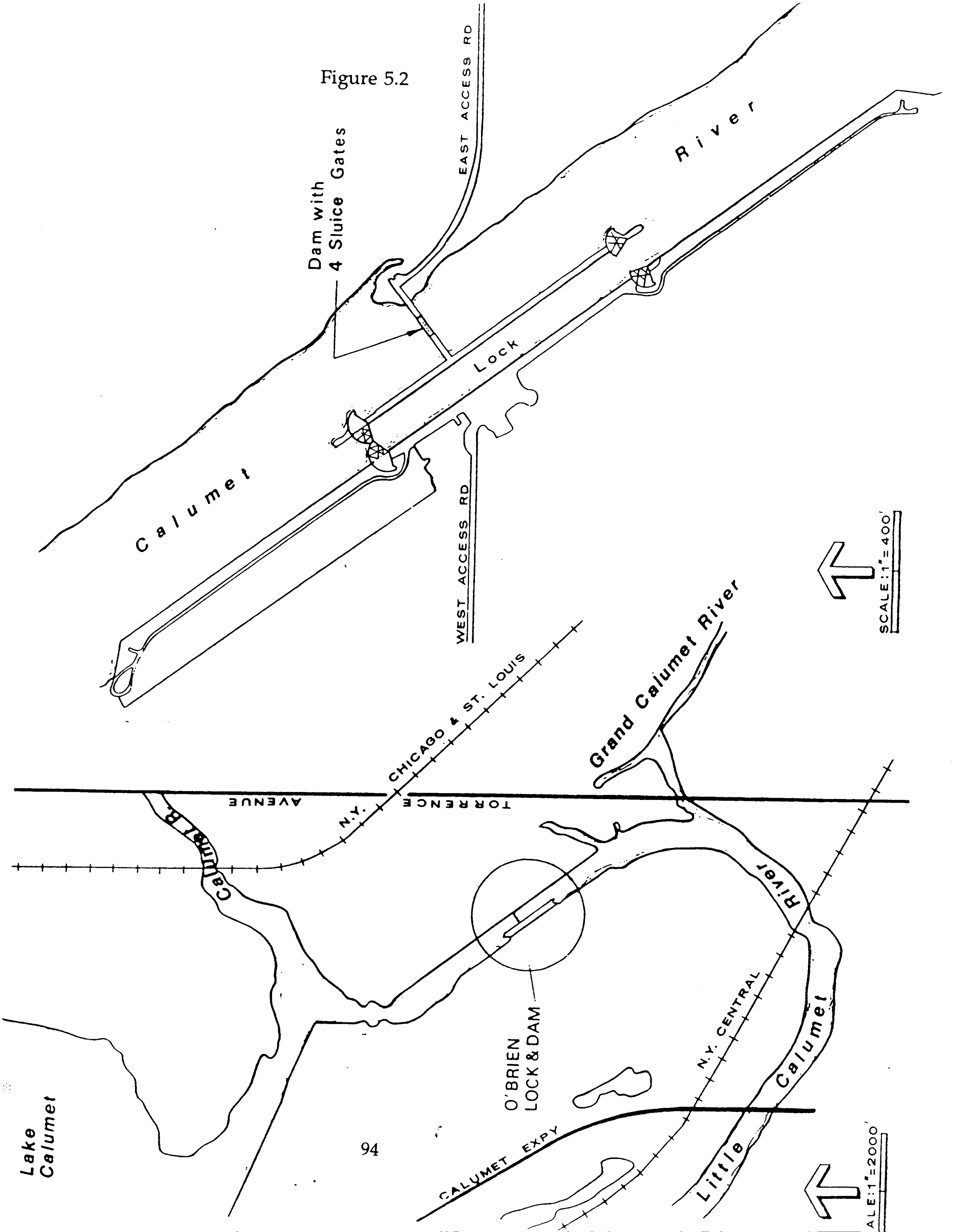


Figure 16. Chicago River Controlling Works

Figure 5.2


Calumet River
Lock
Dam with
4 Sluice Gates
EAST ACCESS RD
WEST ACCESS RD
SCALE: 1" = 400'
Grand Calumet River
N.Y. CHICAGO & ST. LOUIS
TORRENCE AVENUE
Calumet R.
O'BRIEN
LOCK & DAM
N.Y. CENTRAL
CALUMET EXPY
Little Calumet River
Lake
Calumet
ALE: 1" = 2000'

Dye-dilution discharge measuring techniques are described by Kilpatrick and Cobb (1985), Rantz, and others (1982). This technique was used to verify ADCP measurements. Dye-dilution and ADCP measurements were made simultaneously.

The U.S. Geological Survey completed a series of measurements at the Chicago River Controlling Works (CRCW), Wilmette Pumping Station (WPS), and O'Brien Lock and Dam (O'Brien). Table 5.1 summarizes the dates during which measurements were made at each location, the number of measurements made that day, and the mean measured discharge for a given location and date.

A summary description of these measurements and a discussion of the limitations of the discharge measurements are contained in a preliminary progress report letter (October 16, 1993) from the U.S. Geological Survey prepared by Kevin Oberg. Key portions of this progress report are summarized in this section.

Accurate measurements of very low velocities (such as in this study) require the speed of the boat as it moves across the section being measured be similar to the flow velocity. This concept was not fully appreciated in the April/May 1993 measurements. Even in the later measurements, the combination of water and boat velocities being measured are so small that the precision limits of the ADCP are approached. Several dye-dilution measurements were also made in order to compare results with those of the ADCP. The final results of the ADCP and dye-dilution measurements will be documented in a final U.S.

TABLE 5.1

Preliminary Results of Measurements of Leakage Through Chicago Lakefront Control Structures (Months) 1993

Month	(Date, N, Discharge)	Chicago Lock					Chicago River at Lake Shore Drive			WSP	O'Brien Lock
		East-gate		West-gate							
April	Date	6	-	5	-	-	7	-	-	6	7
	N	19	-	5	-	-	5	-	-	12	4
	Discharge	825	-	106	-	-	194	-	-	58	(*)
May	Date	5	-	4	6	-	10	-	-	-	-
	N	6	-	23	18	-	4	-	-	-	-
	Discharge	867	-	142	127	-	178	-	-	-	-
July	Date	-	-	13	14	-	14	15	26	-	-
	N	-	-	10	4	-	5	4	2	-	-
	Discharge	-	-	140	195	-	355	213	200	-	-
September	Date	-	-	-	-	-	20	21	-	22	17
	N	-	-	-	-	-	6	7	-	5	10
	Discharge	-	-	-	-	-	359	334	-	(*)	53.2
October	Date	-	-	-	-	-	4	5	6	-	-
	N	-	-	-	-	-	3	2	4	-	-
	Discharge	-	-	-	-	-	310	210	204	-	-

Date = Day of measurement
N = Number of measurements
Discharge = Mean of all discharge measurements
WPS = Wilmette Pumping Station

Geological Survey report that is in preparation. Because the data are preliminary, they should be used with caution. The mean discharges shown are, in some cases, based on only a few measurements. Additional quality assurance review of the measurements will be made by U.S. Geological Survey and RD Instruments, Inc. prior to publication of the final report.

The following information regarding the limitations of the data should also be considered. During May 1993, both gates at the Chicago Lock underwent extensive repair by the Corps of Engineers. As a result, leakage through these gates has been changed considerably. In addition, it appears the Metropolitan Water Reclamation District sealed off the pump bays at the WSP sometime during the Summer of 1993. This could be the reason no leakage could be measured there in September. The April and May ADCP measurements in the Chicago River are probably less accurate than those made later in the year because of the following: (1) the April measurements were intended as reconnaissance measurements only and are not as accurate as later measurements; (2) U.S. Geological Survey measurement techniques and procedures improved during the later measurements as a result of the experience gained during the April and May measurements.

Tentative results of the preliminary measurements of leakage are encouraging, primarily because it appears the U.S. Geological Survey is on the right track to solving the difficult problem of measuring low velocity streams where unsteady flow patterns may be present or where the flow may be affected by rapidly changing tide or backwater conditions.

The U.S. Geological Survey's objective to validate the ADCP measurements using dye-dilution as an alternative method was good. However, after evaluating the physical characteristics of the site and taking into account the accuracy with which the major components of the dye-dilution need to be measured, the Committee believes that using the dye-dilution technique at this particular location may be more difficult, costly, and possibly less accurate than using the ADCP system. After reviewing the final report on ADCP and dye-dilution measurements for lake front leakage, which currently is being prepared by the U.S. Geological Survey, the Committee will be able to comment on this issue.

It is reasonable to assume the rate of leakage flow does not remain constant for long periods of time, but increases and decreases as the gates are damaged and repaired, and the seals deteriorate and are replaced. For a given set of conditions, the rate of leakage also changes as a function of the surface elevation of Lake Michigan. This will become a significant factor, particularly in those years within the accounting period, where the elevation of Lake Michigan reached record height.

From late 1984 to about February 1987, Lake Michigan exceeded its previously recorded high levels (Figure 5.3). The highest annual average level in 90 years of record (1903-1993) was reached in 1986. In fact, every monthly mean in 1986 was the highest in record, except for January which reached its highest average level in 1987. The highest monthly average elevation for the period of record was 582.38 feet (October 1986). During 1986, the monthly mean water levels of Lake Michigan were more than 2 feet above their respective long-term

Long-term fluctuation in the

water levels of Lake Michigan 1950-90

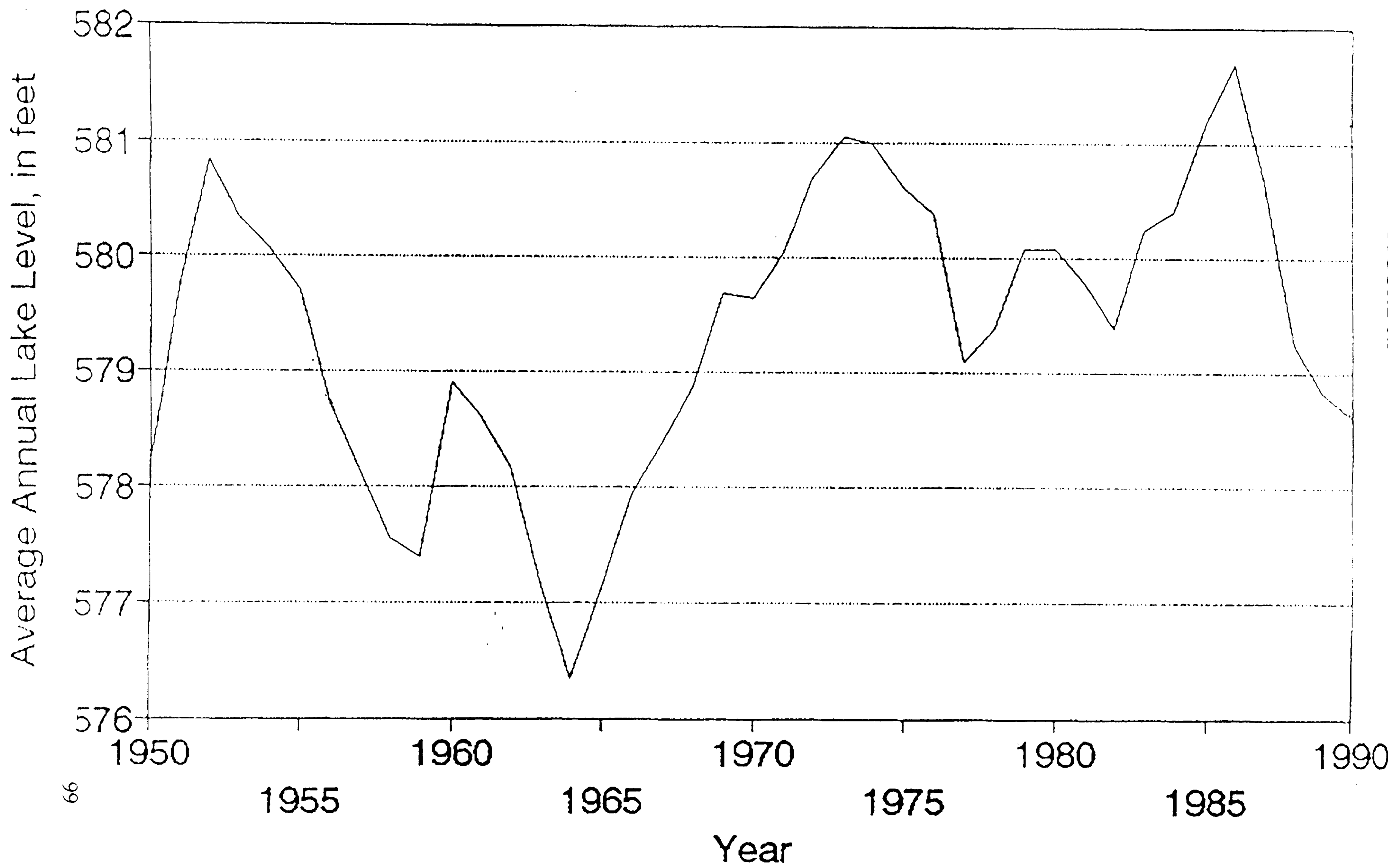


FIGURE 5.3

averages and over 3 feet during October and November (Table 5.2). For this reason, it is important to define, if at all possible, a relation between the rate of leakage flow vs. lake elevation.

Table 5.2

Summary of Average and Extreme Levels - Lake Michigan

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
	Monthly and Annual Average lake Levels for Period 1903 - 1990												
	578.41	578.44	578.57	578.83	579.16	579.36	579.42	579.33	579.16	578.93	578.70	578.54	578.93
	Highest Monthly and Annual Lake Levels for Period 1903 - 1990												
	581.56	581.26	581.16	581.62	581.72	581.89	582.02	582.02	581.98	582.38	581.79	581.46	581.69
	2.85	2.82	2.59	2.79	2.56	2.53	2.59	2.69	2.82	3.45	3.08	2.92	2.76
Year	1987	1986	1986	1986	1986	1986	1986	1986	1986	1986	1986	1986	1986

U.S. Department of Commerce - Lake Water Levels

6.0 TURBINE DISCHARGE RATING

Water Year 1984 was the first year in which the AVM was used to measure the flow in the canal system. As reported in the 1989 Annual Report, for Water Year 1984 the AVM measured flow was 314 cfs greater than the Lockport measured flow and in Water Year 1985, the AVM flow was 229 cfs greater than the Lockport flow. The First Technical Committee in evaluating the various measurement elements at the Lockport gage estimated the probable error of the turbines as a minus 15 percent. Corresponding relative of error percentage was 71.5 percent with respect to diversion computation. Based on the annual flow at Lockport for the period 1961 through 1969, turbine flow represent an average of approximately 78 percent of the average annual flow at Lockport (Espey et al, 1982). The Sarasota AVM system was installed March 18 - 23, 1984. This was the second AVM system, the first being an experimental Westinghouse system which was installed in the channel early in the 1970s and subsequently abandoned. The diversion accounting for Water Years 1984 and 1985 were the first water years which utilized the Sarasota AVM system. The 1981, 1982, and 1983 Water Years were still based on Lockport measurements. The Second Technical Committee analyzed the difference between the AVM and Lockport flows and determined the difference in the AVM and Lockport flow scan be attributed to a series of errors in the rating for one or more of the various Lockport flow components, that is, turbines, lockage, leakage, powerhouse, service gates, and controlling work gates. The Second Technical Committee reported (Espey et al, 1987) that on March 4, 1985 a high rate of flow was sustained for a period of about 9 hours when all power house and controlling work gates were opened. During this 9-hour period, the discharge at the AVM site in Romeoville varied gradually from about 18,000 to 16,500 cfs while the reported MSD discharge varied from 35,000 to 35,200 cfs. The MSD reported discharge included about 12,000 cfs through the controlling work and about 21,000 cfs through the Lockport power house sluice gates. It was concluded the discharge through the controlling works was more likely to have been 5,000 to 6,000 cfs than the reported 12,000 cfs. The Second Technical Committee concluded that the MSD flows versus AVM flows in the lower flow range which is normally controlled by the turbines, lock operations, and leakage, the flow reported at Lockport was consistently under reported (Figure 6.1c - 6.1d and Figure 6.2). Conversely, the MSD flows are over reported when all gates for the powerhouse and controlling works are open. Controlling works flow are significantly affected by downstream submergence which leads to over reporting of the flow with five or more gates are opened.

The Second Technical Committee developed regression equations for MSD Lockport flow records for the periods June 12, 1984 - March 20, 1985 and September 23 - December 31, 1986 for turbine only flow conditions only:

$$Q_{AVM} = 1.10\ Q_{MSD} + 84. \qquad (6.1)$$

The flow record used to develop Equation 1 contains a period of record for which MSD turbine-only flow is unique because the navigation lack was closed for repairs from July 7 to September 28, 1984. Consequently, both lock leakage and daily lockage flow were zero, and all flow was discharged through the turbines. A regression of the flow data for this period is:

$$Q_{AVM} = 1.08\ Q_{MSD} + 207. \qquad (6.2)$$

for MSD flows ranging from 2,457 to 4,221 cfs. Discharges estimated using Equations 6.1 and 6.2 agree within 2 percent.

Assuming Equation 6.2 is adequate for correcting under reported turbine flow and that approximately 78 percent of historical reported diversion is turbine flow, the "adjusted diversion flows" for 1981, 1982, and 1983 are presented in Table 6.1.

Table 6.1

Revised Water Years 1981, 1982, and 1983

Year	Reported	Corrected	Increase
1981	3106	3506	+400
1982	3087	3487	+400
1983	3612	4045	+433

6.1 THIRD COMMITTEE

The data available to the Third Technical Committee is longer and reliable. In addition, the MWRDGC installed an ORE AVM system at the Lockport Powerhouse turbines and began operating on March 19, 1992. This is a significant step towards achieving reliable technical quality in the direct measurement of diversion flow at the turbines at Lockport. This information will be very valuable in establishing correct turbine flows for historical record. Future regression equations will use the turbine AVM flows as one independent variable.

A sample of the data now available is listed in Table 6.2 and 6.3, these data were supplied by the U.S. Geological Survey, and the tables contain typical mean daily discharges for Lockport (turbines, lockage, and leakage) and concurrent AVM discharges recorded at Romeoville for selected periods in 1990 and 1991. These data show the Lockport estimates are consistently low by 400 cfs on the average for the sample period in 1990 (Figure 6.3) and about 373 cfs for the period in 1991 (Figure 6.4) roughly an 11 percent bias overall. The data in Table 6.2 is a typical sample mean daily discharges recorded concurrently at AVMs in Lockport and Romeoville. It should be pointed out the Lockport discharges do not include the lockage discharge. The Lockport discharges, adjusted for the number of reported lockages are listed in the next to last column of Table 6.4. These adjusted AVM discharges recorded at Lockport compare reasonably well with the Romeoville AVM discharges.

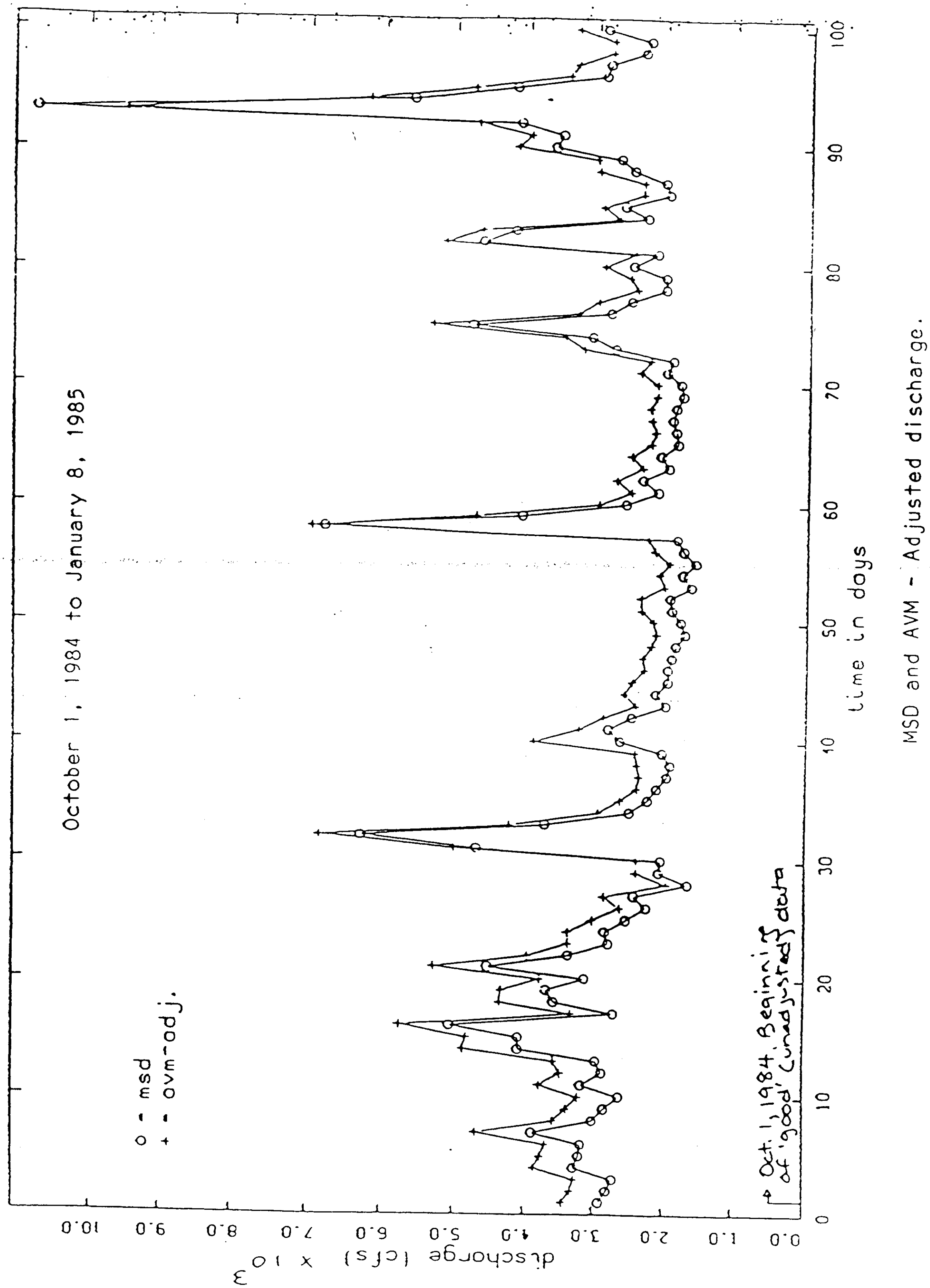
6.2 Recommendation

It has been shown, by the First and Second Technical Committees, and confirmed by current data, that turbine flow components at the Lockport facility are biased. For this reason, this Committee supports the recommendation made by the Second Technical Committee that the reports for Water Years after 1980 should be revised as necessary, in order to account for the errors in the Lockport discharge ratings used during the 1981-85 Water Years. The Third Technical

Committee believes that revising past records to reflect present knowledge and standards would remove a potential source of controversy, and most importantly would bring undeniable credibility to the diversion accounting process.

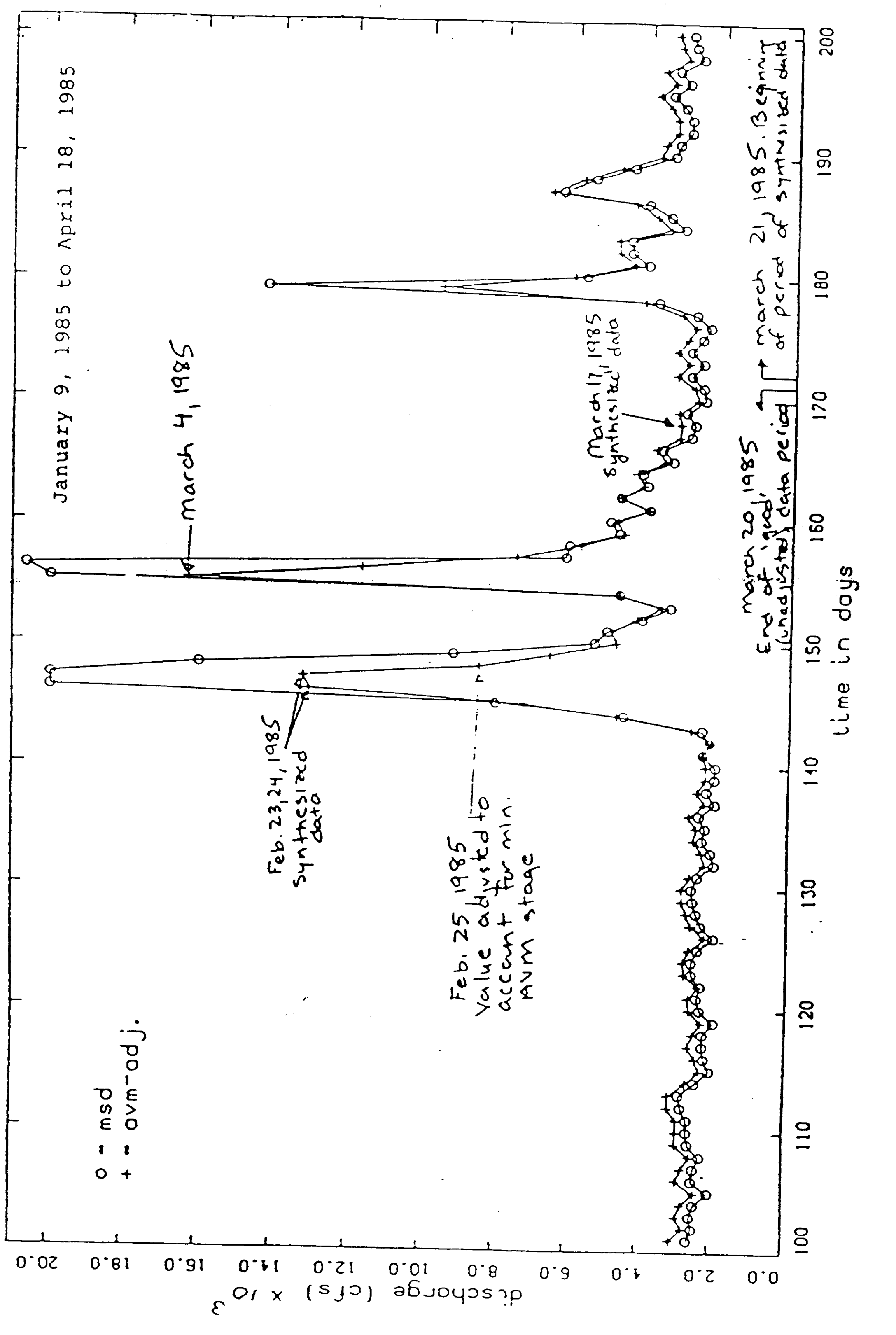
The Third Technical Committee commends the State of Illinois, the MWRDGC, and the U.S. Army Corps of Engineers for acquiring state-of-the-art equipment for the direct measurement of the diversion flow.

FIGURE 6.1a



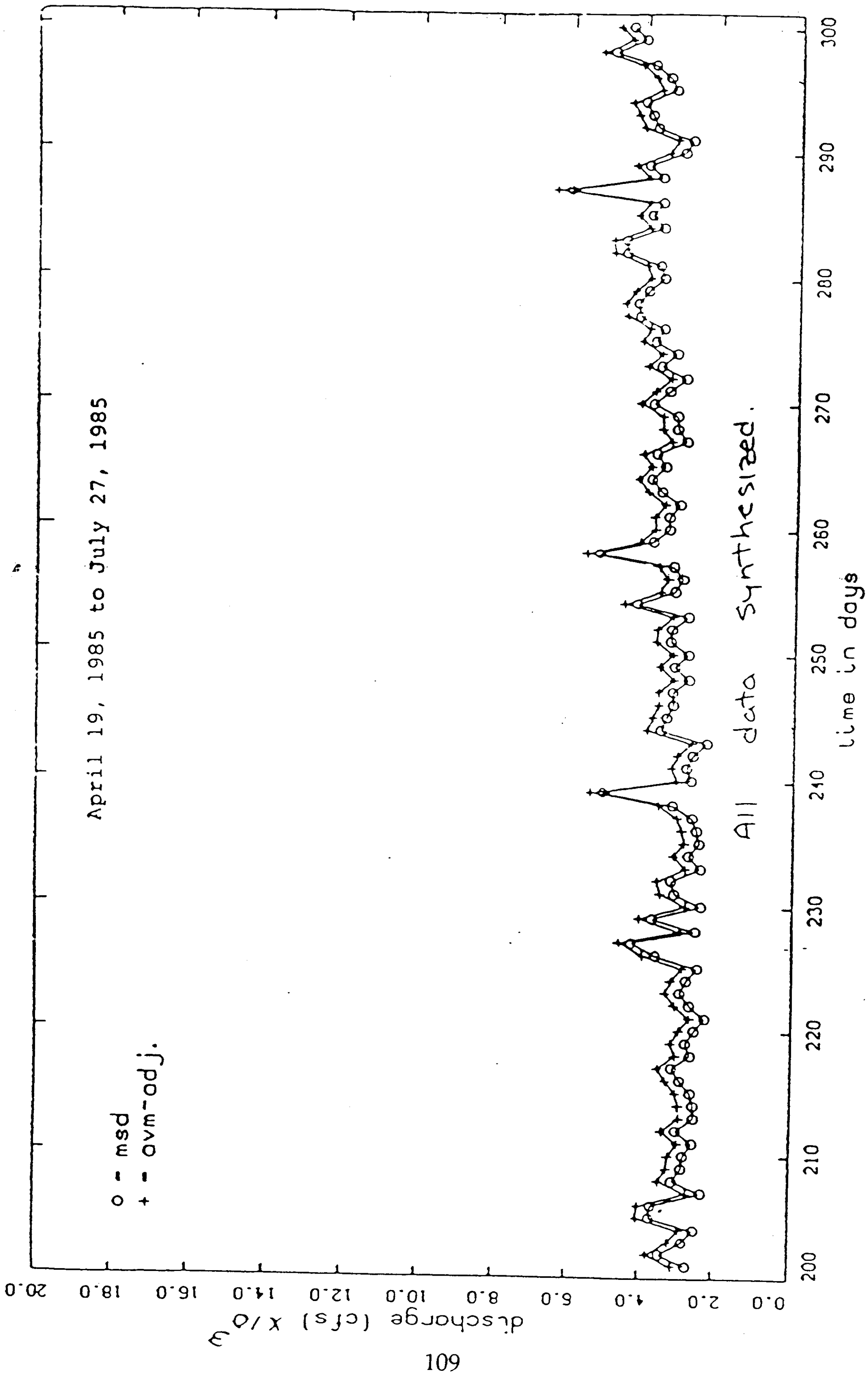
October 1, 1984 to January 8, 1985
o - msd
+ - avm-adj.
Oct. 1, 1984, Beginning of 'good' (unadjusted) data
time in days
discharge (cfs) x 10³
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
0
10
20
30
40
50
60
70
80
90
100
MSD and AVM - Adjusted discharge.

FIGURE 6.1b



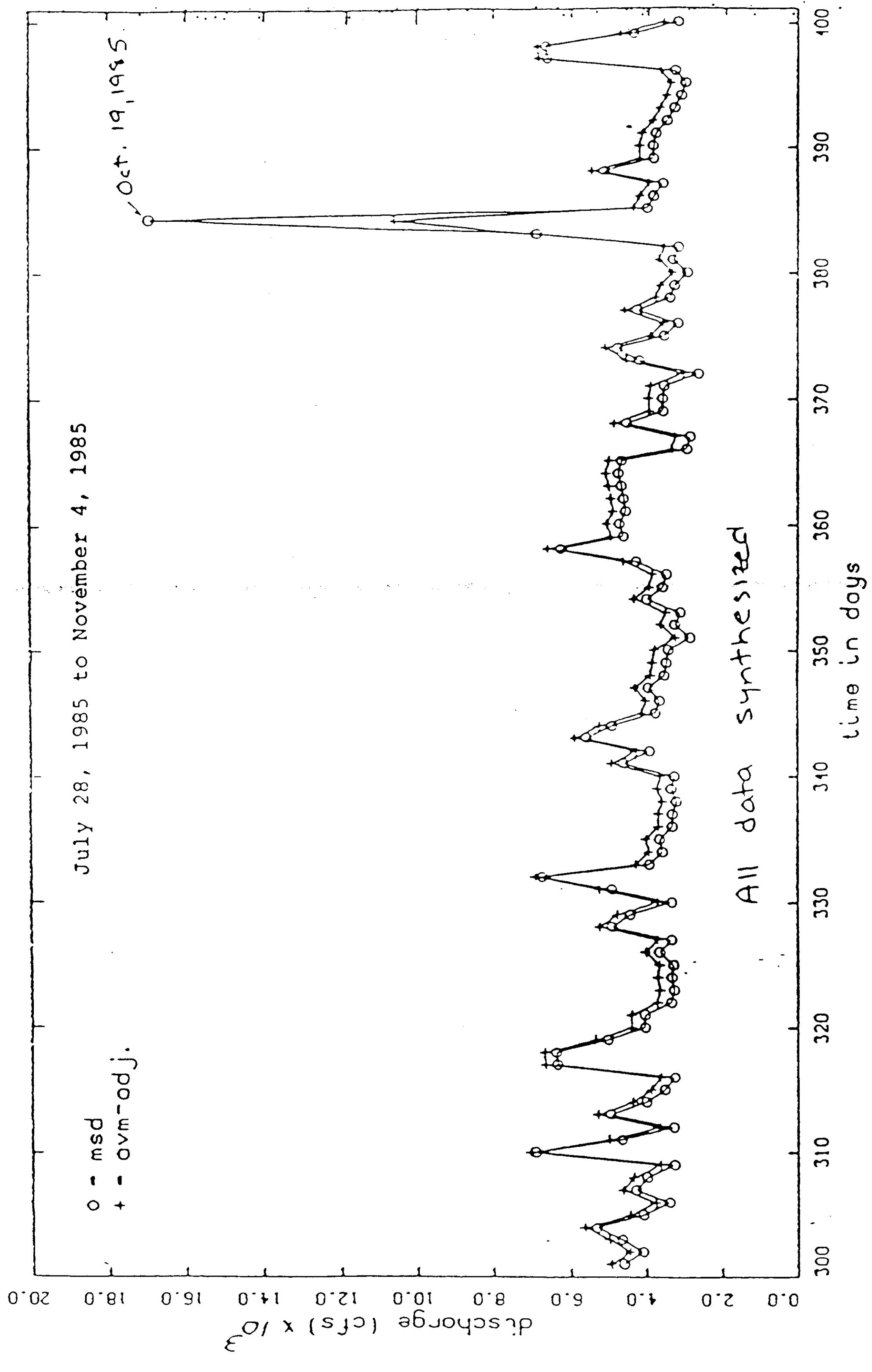
MSD and AVM - Adjusted discharge (cont'd)

FIGURE 6.1c



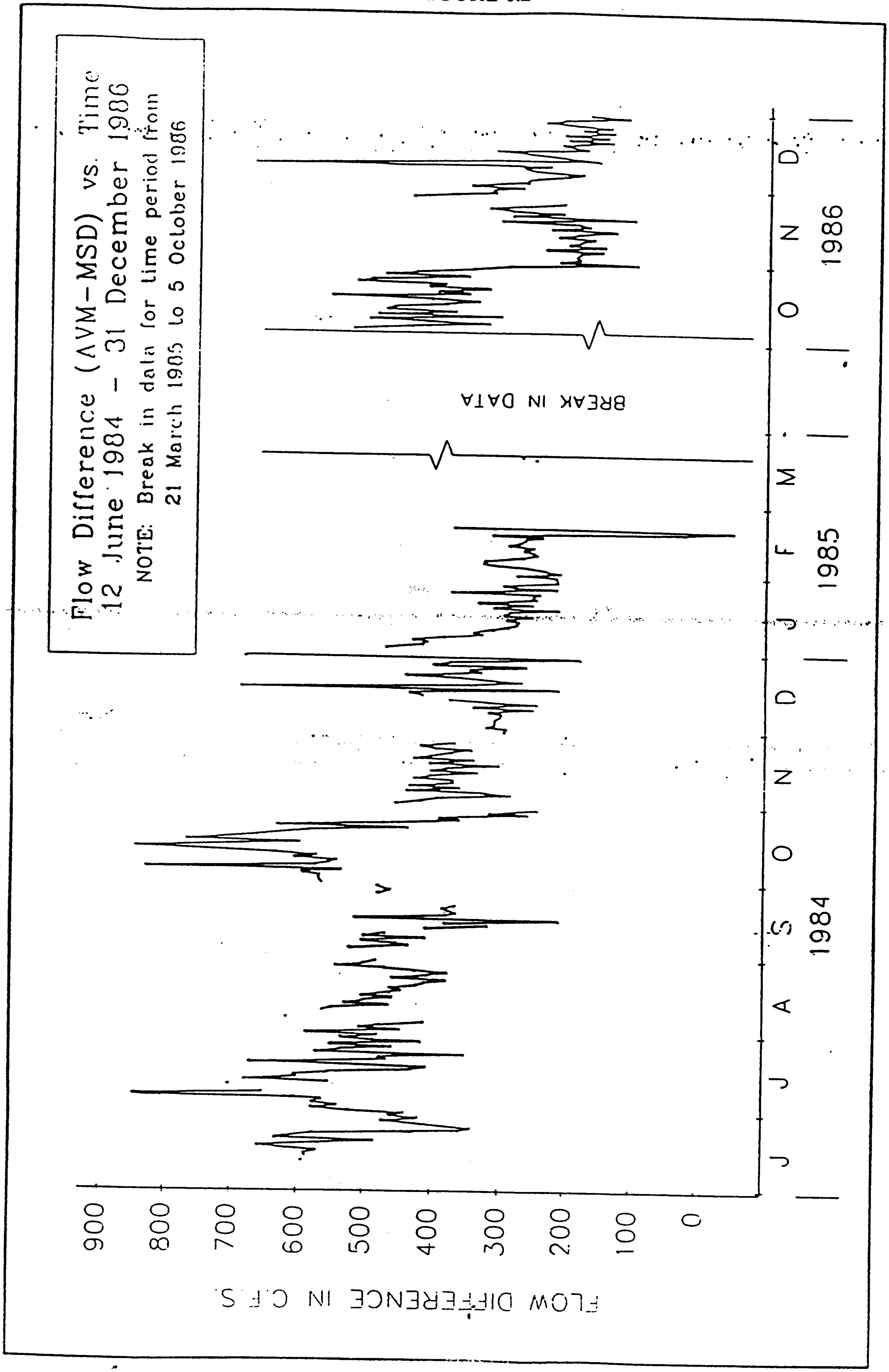
MSD and AVM - Adjusted discharge (cont'd)

FIGURE 6.1d



MSD and AVM - Adjusted discharge (cont'd)

FIGURE 6.2



Flow Difference (AVM-MSD) vs. Time
12 June 1984 - 31 December 1986
NOTE: Break in data for time period from
21 March 1985 to 5 October 1986
BREAK IN DATA
FLOW DIFFERENCE IN C.F.S.
900
800
700
600
500
400
300
200
100
0
J
J
A
S
O
N
D
J
F
M
O
N
D
1984
1985
1986

TABLE 6.2

Mean daily discharges for Romeoville AVM and Lockport. October - December, 1990

Date	Turbine	Lockage	Leakage	Sluice gate	Control works	Lockport total	Romeoville AVM	Absolute Difference	Percent Difference
	Mean daily discharge, in cubic feet per second								
10/1/90	1235	396	100	0	0	1731	2063	332	16.09%
10/2/90	1330	330	100	0	0	1760	2157	397	18.41%
10/3/90	2248	297	100	0	0	2645	2949	304	10.31%
10/4/90	2757	297	100	0	0	3154	3466	312	9.00%
10/5/90	1649	330	100	0	0	2079	2458	379	15.42%
10/6/90	1679	297	100	0	0	2076	2456	380	15.47%
10/7/90	1888	330	100	0	0	2318	2619	301	11.49%
10/12/90	3420	297	100	0	0	3817	4276	459	10.73%
10/13/90	3147	297	100	0	0	3541	4013	499	12.34%
10/14/90	2826	495	100	0	0	3421	3867	446	11.53%
10/15/90	2812	297	100	0	0	3209	3599	390	10.84%
10/16/90	1927	396	100	0	0	2423	2827	404	14.29%
10/17/90	2532	396	100	0	0	3028	3449	421	12.21%
10/18/90	2864	396	100	0	0	3360	3757	397	10.57%
10/19/90	2133	396	100	0	0	2629	3028	399	13.18%
10/20/90	2249	396	100	0	0	2745	3253	508	15.62%
10/21/90	1569	462	100	0	0	2131	2457	326	13.27%
10/22/90	1797	297	100	0	0	2194	2546	352	13.83%
10/23/90	1708	231	100	0	0	2039	2441	402	16.47%
10/24/90	1925	396	100	0	0	2421	2713	292	10.76%
10/25/90	1660	297	100	0	0	2057	2422	365	15.07%
10/26/90	2861	363	100	0	0	3324	3678	354	9.62%
10/27/90	2519	330	100	0	0	2949	3326	377	11.33%
10/28/90	3151	429	100	0	0	3680	4013	333	8.30%
10/29/90	3775	264	100	0	0	4139	4479	340	7.59%
10/30/90	4216	363	100	0	0	4679	5319	640	12.03%
10/31/90	4050	297	100	0	0	4447	5051	604	11.96%
11/1/90	1669	330	100	0	0	2099	2500	401	16.04%
11/2/90	1399	396	100	0	0	1895	2287	392	17.14%
11/3/90	1484	396	100	0	0	1980	2333	353	15.13%
11/8/90	3371	99	100	0	0	3570	4174	604	14.47%
11/9/90	2708	264	100	0	0	3072	3589	517	14.41%
11/10/90	2384	297	100	0	0	2781	3249	468	14.40%
11/11/90	1862	363	100	0	0	2325	2728	403	14.77%
11/12/90	1728	363	100	0	0	2191	2584	393	15.21%
11/13/90	1631	264	100	0	0	1995	2383	388	16.28%
11/14/90	1425	330	100	0	0	1855	2320	465	20.04%
11/15/90	1847	363	100	0	0	2310	2685	375	13.97%
11/16/90	1578	297	100	0	0	1975	2355	380	16.14%
11/17/90	1518	363	100	0	0	1981	2409	428	17.77%
11/18/90	1403	297	100	0	0	1800	2277	477	20.95%
11/19/90	1535	264	100	0	0	1899	2305	406	17.61%
11/20/90	1322	297	100	0	0	1719	2205	486	22.04%
11/21/90	2812	264	100	0	0	3176	3538	362	10.23%
11/22/90	1965	297	100	0	0	2362	2813	451	16.03%
11/23/90	1877	165	100	0	0	2142	2542	400	15.74%
11/24/90	1511	396	100	0	0	2007	2434	427	17.54%

TABLE 6.2 (continued)

Mean daily discharges for Romeoville AVM and Lockport. October - December, 1990

Date	Mean daily discharge, in cubic feet per second								Percent Difference
	Turbine	Lockage	Leakage	Sluice gate	Control works	Lockport total	Romeoville AVM	Absolute Difference	
11/25/90	1199	330	100	0	0	1629	2082	453	21.76%
11/26/90	1737	264	100	0	0	2101	2518	417	16.56%
12/1/90	3953	297	100	0	0	4350	5160	810	15.70%
12/2/90	3802	429	100	0	0	4331	4992	661	13.24%
12/4/90	3680	330	100	0	0	4110	4701	591	12.57%
12/5/90	3096	330	100	0	0	3526	4288	762	17.77%
12/6/90	2724	396	100	0	0	3220	3775	555	14.70%
12/7/90	2200	363	100	0	0	2663	3007	344	11.44%
12/8/90	2293	198	100	0	0	2591	2983	392	13.14%
12/9/90	2195	264	100	0	0	2559	2878	319	11.08%
12/10/90	1890	264	100	0	0	2254	2552	298	11.68%
12/11/90	2110	264	100	0	0	2474	2791	317	11.36%
12/12/90	2044	396	100	0	0	2540	2825	285	10.09%
12/13/90	1699	396	100	0	0	2195	2472	277	11.21%
12/14/90	1701	363	100	0	0	2164	2461	297	12.07%
12/15/90	2150	330	100	0	0	2580	2876	296	10.29%
12/16/90	1900	363	100	0	0	2363	2701	338	12.51%
12/17/90	2051	231	100	0	0	2382	2750	368	13.38%
12/18/90	1964	330	100	0	0	2394	2732	338	12.37%
12/19/90	2153	231	100	0	0	2484	2815	331	11.76%
12/20/90	2087	165	100	0	0	2352	2618	266	10.16%
12/21/90	2698	231	100	0	0	3029	3354	325	9.69%
12/22/90	2110	264	100	0	0	2474	2798	324	11.58%
12/23/90	2208	132	100	0	0	2440	2718	278	10.23%
12/24/90	1965	363	100	0	0	2428	2580	152	5.89%
12/25/90	1448	264	100	0	0	1812	2157	345	15.99%
12/26/90	1635	330	100	0	0	2065	2344	279	11.90%
12/27/90	1733	264	100	0	0	2097	2453	356	14.51%
12/28/90	1826	264	100	0	0	2190	2569	379	14.75%
12/31/90	3662	330	100	0	0	4092	4461	369	8.27%

TABLE 6.3

Mean daily discharges for Romeoville AVM and Lockport. July- September, 1991

Date	Mean daily discharge, in cubic feet per second								
	Turbine	Lockage	Leakage	Sluice gate	Control works	Lockport total	Romeoville AVM	Absolute Difference	Percent Difference
7/1/91	2949	297	100	0	0	3346	3760	414	11.01%
7/2/91	3310	330	100	0	0	3740	4055	315	7.77%
7/3/91	3488	264	100	0	0	3852	4219	367	8.70%
7/4/91	3002	429	100	0	0	3531	3960	429	10.83%
7/5/91	3031	429	100	0	0	3560	3965	405	10.21%
7/6/91	3166	363	100	0	0	3629	4001	372	9.30%
7/8/91	3011	165	100	0	0	3276	3650	374	10.25%
7/9/91	3490	297	100	0	0	3887	4303	416	9.67%
7/10/91	2940	363	100	0	0	3403	3718	315	8.47%
7/11/91	3236	297	100	0	0	3633	3948	315	7.98%
7/12/91	2968	363	100	0	0	3431	3787	356	9.40%
7/13/91	3243	429	100	0	0	3772	4115	343	8.34%
7/14/91	2935	495	100	0	0	3530	3877	347	8.95%
7/15/91	2896	297	100	0	0	3293	3760	467	12.42%
7/16/91	3295	231	100	0	0	3626	4002	376	9.40%
7/17/91	3023	297	100	0	0	3420	3783	363	9.60%
7/18/91	3481	330	100	0	0	3911	4244	333	7.85%
7/19/91	3261	297	100	0	0	3658	4021	363	9.03%
7/20/91	3644	330	100	0	0	4074	4527	453	10.01%
7/21/91	2999	429	100	0	0	3528	3878	350	9.03%
7/22/91	3225	297	100	0	0	3622	3995	373	9.34%
7/23/91	3225	297	100	0	0	3622	3887	265	6.82%
7/24/91	3291	297	100	0	0	3688	4066	378	9.30%
7/25/91	3185	330	100	0	0	3615	3931	316	8.04%
7/26/91	3282	330	100	0	0	3712	4032	320	7.94%
7/27/91	3169	330	100	0	0	3599	3924	325	8.28%
7/28/91	3316	495	100	0	0	3911	4212	301	7.15%
7/29/91	2767	363	100	0	0	3230	3580	350	9.78%
7/30/91	3079	330	100	0	0	3509	3956	447	11.30%
7/31/91	2969	363	100	0	0	3432	3728	296	7.94%
8/1/91	3341	231	100	0	0	3672	3985	313	7.85%
8/2/91	3112	396	100	0	0	3608	3895	287	7.37%
8/3/91	3393	297	100	0	0	3790	4175	385	9.22%
8/4/91	3393	297	100	0	0	3790	4192	402	9.59%
8/10/91	3599	495	100	0	0	4194	4614	420	9.10%
8/11/91	3360	396	100	0	0	3856	4162	306	7.35%
8/12/91	3281	396	100	0	0	3777	4150	373	8.99%
8/13/91	3001	330	100	0	0	3431	3834	403	10.51%
8/14/91	3081	396	100	0	0	3577	3941	364	9.24%
8/15/91	3201	297	100	0	0	3598	3945	347	8.80%
8/16/91	3382	429	100	0	0	3911	4178	267	6.39%
8/17/91	2877	330	100	0	0	3307	3646	339	9.30%
8/18/91	3155	330	100	0	0	3585	3952	367	9.29%
8/19/91	3768	363	100	0	0	4231	4736	505	10.66%
8/20/91	4188	330	100	0	0	4618	5090	472	9.27%
8/21/91	3125	231	100	0	0	3456	3883	427	11.00%
8/22/91	3284	132	100	0	0	3516	3883	367	9.45%

TABLE 6.3 (continued)

Mean daily discharges for Romeoville AVM and Lockport. July- September, 1991

Date	Mean daily discharge, in cubic feet per second								
	Turbine	Lockage	Leakage	Sluice gate	Control works	Lockport total	Romeoville AVM	Absolute Difference	Percent Difference
8/24/91	3225	363	100	0	0	3688	3956	268	6.77%
8/25/91	3358	297	100	0	0	3755	4091	336	8.21%
8/26/91	3048	297	100	0	0	3445	3828	383	10.01%
8/27/91	2954	231	100	0	0	3285	3595	310	8.62%
8/28/91	3312	264	100	0	0	3676	4042	366	9.05%
8/29/91	3097	330	100	0	0	3527	3920	393	10.03%
8/30/91	3205	462	100	0	0	3767	4212	445	10.57%
8/31/91	3120	495	100	0	0	3715	4145	430	10.37%
9/1/91	3456	429	100	0	0	3985	4429	444	10.02%
9/2/91	2462	363	100	0	0	2925	3680	755	20.52%
9/4/91	3079	297	100	0	0	3476	3876	400	10.32%
9/5/91	3328	330	100	0	0	3758	4148	390	9.40%
9/6/91	3131	330	100	0	0	3561	3929	368	9.37%
9/7/91	2969	462	100	0	0	3531	3985	454	11.39%
9/8/91	3119	495	100	0	0	3714	4051	337	8.32%
9/10/91	3025	330	100	0	0	3455	3940	485	12.31%
9/11/91	3346	363	100	0	0	3809	4210	401	9.52%
9/14/91	3504	396	100	0	0	4000	4510	510	11.31%
9/15/91	3882	363	100	0	0	4345	4875	530	10.87%
9/16/91	2956	264	100	0	0	3320	3764	444	11.80%
9/20/91	1619	330	100	0	0	2049	2428	379	15.61%
9/24/91	1365	396	100	0	0	1861	2216	355	16.02%
9/25/91	1310	396	100	0	0	1806	2146	340	15.84%
9/26/91	1552	429	100	0	0	2081	2283	202	8.85%
9/27/91	1398	297	100	0	0	1795	2009	214	10.65%
9/28/91	1644	297	100	0	0	2041	2281	240	10.52%
9/29/91	1583	396	100	0	0	2079	2328	249	10.70%
9/30/91	1504	231	100	0	0	1835	2087	252	12.07%

FIGURE 6.3

oct-90

--Difference in mean daily Lockport discharge and Romeoville AVM discharge, October-December 1990

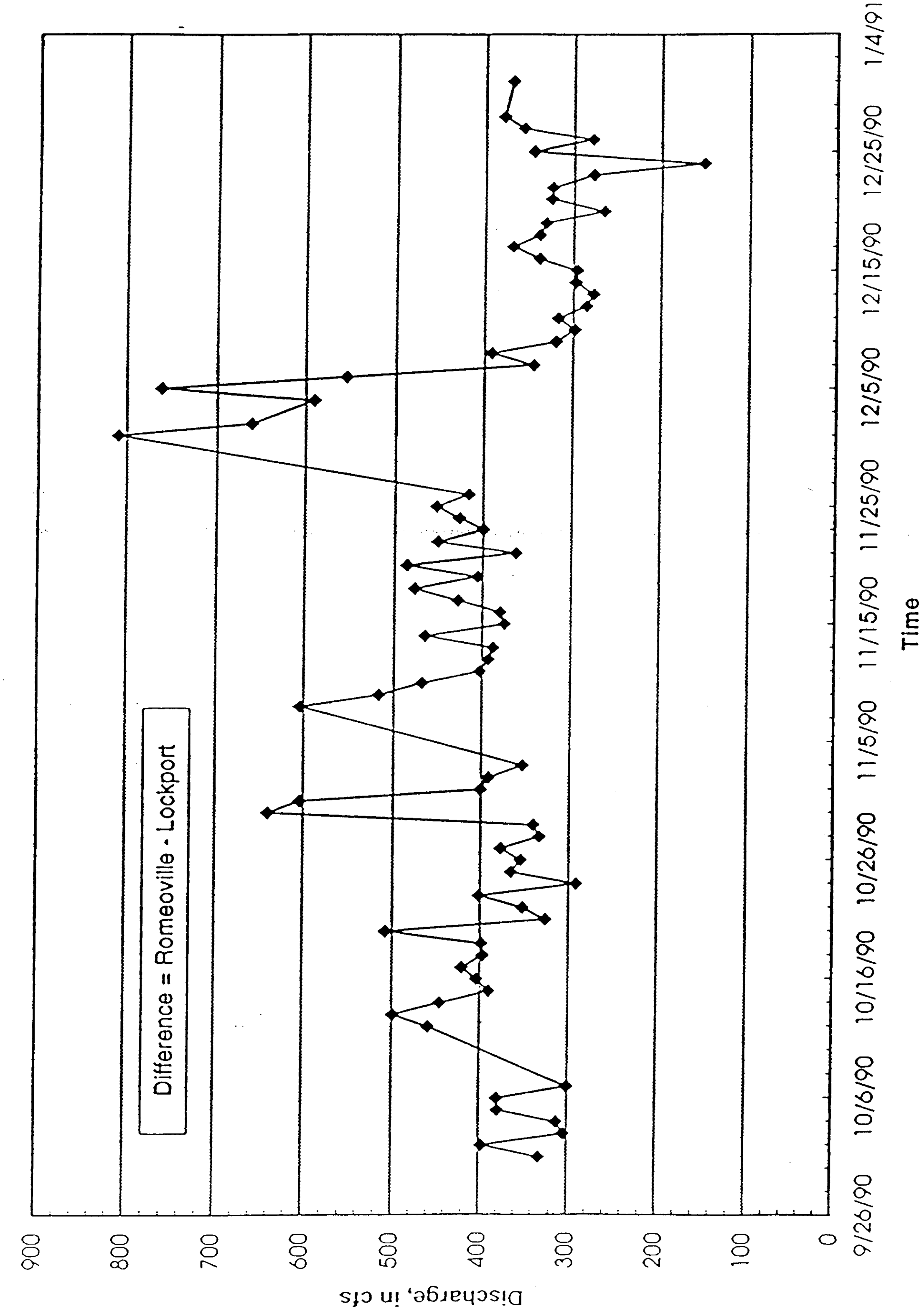


FIGURE 6.4

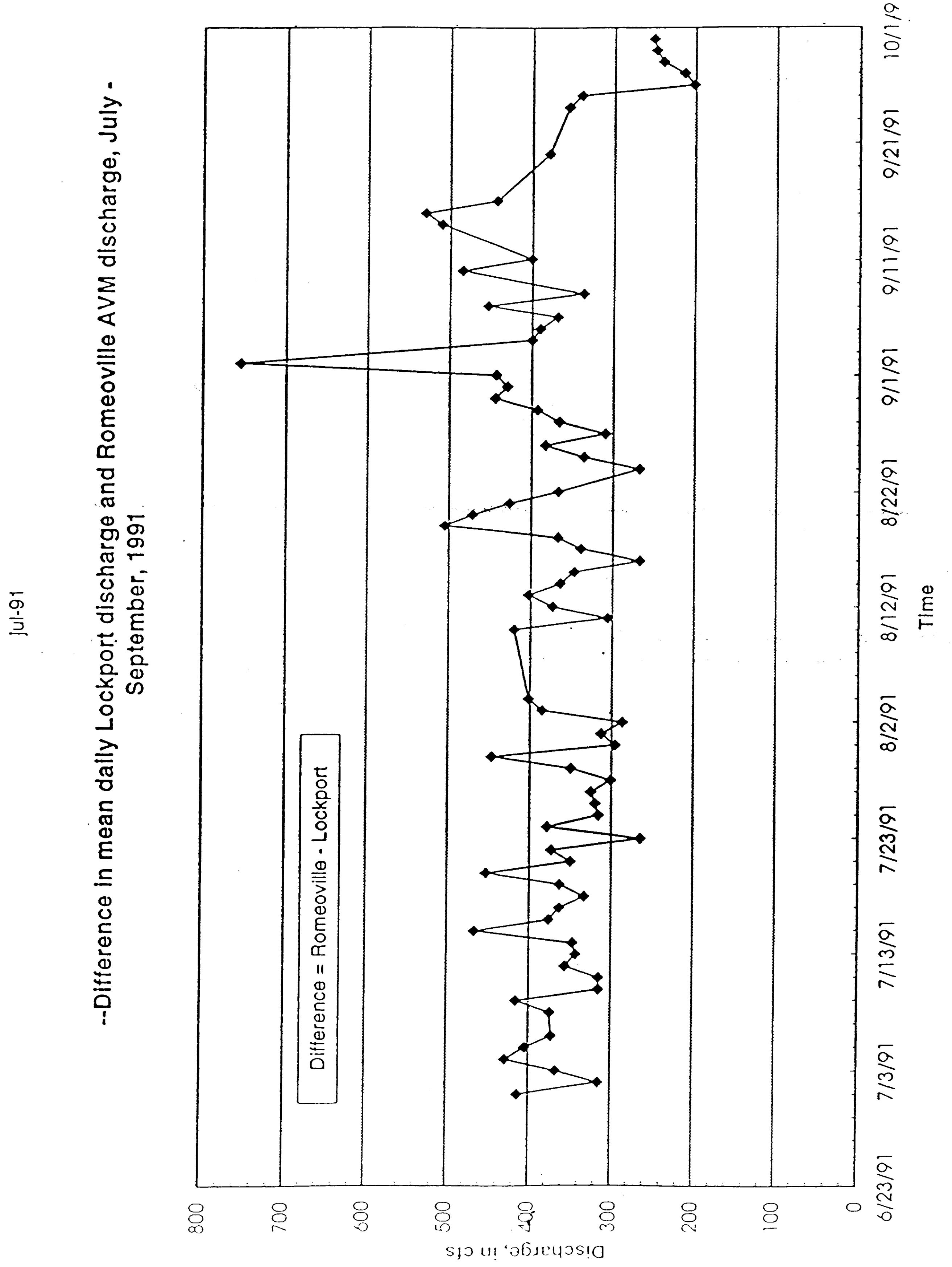

Jul-91
--Difference in mean daily Lockport discharge and Romeoville AVM discharge, July - September, 1991
Difference = Romeoville - Lockport
Discharge, in cfs
800
700
600
500
400
300
200
100
0
6/23/91
7/3/91
7/13/91
7/23/91
8/2/91
8/12/91
8/22/91
9/1/91
9/11/91
9/21/91
10/1/91
Time

TABLE 6.4

Selected Mean Daily Lockport and Romeoville AVM Discharges August and October 1992

Year	Mean Daily Discharge, in cfs			Difference in cubic feet	Lockages		Lockport Adj for Lockage	Percent Difference
	Lockport	Romeoville	Difference		Compute	Reported		
24-Aug-92	3,010	3465	455	39,312,000	15.7	133	3416	-1.40%
25-Aug-92	3,273	3606	333	28,771,200	11.5	14	3650	1.23
26-Aug-92	3,949	4022	73	6,307,200	2.5	10	4239	5.40
04-Oct-92	3,118	3439	321	27,734,400	11.1	18	3641	5.86
05-Oct-92	2,628	2988	360	31,104,000	12.4	16	3092	3.50
06-Oct-92	2,595	2943	348	30,067,200	12.0	14	3001	1.98

Lock Width	110 feet
Lock Length	600 feet
Normal Head	38 feet
Volume per Lockage	2,508,000 cubic feet
Total lockage time	20 minutes

7.0 RECOMMENDATIONS

This Committee is gratified by the improvement achieved in the accounting procedure, particularly in the quality of the AVM records. The U.S. Army Corps of Engineers, U.S. Geological Survey, and the State of Illinois should be commended for assigning to this project highly qualified personnel and supplying state-of-the-art instrumentation and technical support. The primary reason for the diversion exceeding the flow limits of the Supreme Court decree is the improved accuracy of the accounting procedures. A major part of this improved accuracy can be attributed to the AVM system at Romeoville. This Committee is in general agreement with the findings and recommendations made by the Second Technical Committee. In most instances, actions have been taken to comply with the recommendations and significant progress has been made.

Some of the recommendations made by the Second Technical Committee are still current and may be repeated here to emphasize their importance.

7.1 FIRST AND SECOND COMMITTEE RECOMMENDATIONS

The Committee is in agreement with the findings and recommendations of the Second Committee (Espey, et al, 1987).

7.2 MASTER PLAN

7.2.1 The draft of the Master Plan for Lake Michigan Diversion Accounting Program should be finalized.

7.2.2 The Master Plan should include an "Operational Procedures Manual" documenting technical procedures and methods used in the Lake Michigan diversion computations.

7.3 QUALITY ASSURANCE PLAN

The draft Quality Assurance Plan (draft - October 1988) should be updated and finalized based on the present status (1994) of Lake Michigan diversion computational procedures and measurements. Basic elements of the plan are as follows:

- Develop documentation for measurements;
- Develop documentation for methods of data collection;
- Develop "Standard Operation Procedure" for calibration and verification of measurement components;
- Measurement site field evaluation schedule;
- Establish methods of verifying the accuracy of data used in diversion computation; and
- Maintain permanent records of measurements, verification tests, and other sources of diversion data.

7.4 AVM SYSTEM RECOMMENDATIONS

7.4.1 Update the AVM Quality Assurance Plan to include:

7.4.1.1 Uniform guidelines for the operation of AVM installations and development of discharge ratings.

7.4.1.2 Policy and technical guidance on Broadband Acoustic Doppler Current Profilers, including discharge-measurement procedures.

7.4.2 A technical review of the Romeoville AVM discharge ratings and flow records should be conducted annually.

7.4.3 The AVM discharge ratings and flow records at Lockport should also be reviewed annually using the technical guidelines described in the Quality Assurance Plan.

7.4.4 The mean bed elevation of the canal at the AVM measuring reach should be surveyed periodically to detect any changes in the mean bottom elevation and to determine if a correction or shift to the area rating is needed.

7.4.5 An examination of the range of discharge measurements indicates that about 80 percent of the measurements were made at gage heights between 24.7 and 25.7 feet. If at all possible, it would be very useful in the development of discharge ratings to obtain more discharge measurements at the 21 to 24 foot range.

7.4.6 The ACDP (Broadband) system should be used to calibrate and verify the AVM Romeoville system operations. The ACDP can be a valuable tool for measurement during low flow and/or unsteady flow conditions.

7.5 LAKEFRONT MEASUREMENTS

Investigate the feasibility of developing ratings between the leakage flow through the gates at the lakefront and the water surface elevation of the lake.

7.6 LOCKPORT/ROMEOVILLE REGRESSION EQUATIONS

7.6.1 Use the AVM turbine (August 1992) and Romeoville AVM data to revise the turbine rating.

7.6.2 Based on results of recommendation 7.6.1, review and revise, if appropriate, USGS regression equations.

7.6.3 Based on the 7.6.2, recalculate the Lake Michigan diversion for the 1981, 1982, 1983, and 1984 Water Years.

7.7 ANNUAL DIVERSION REPORT

Annual Lake Michigan diversion results should be published in a more timely fashion.

7.8 DES PLAINES PUMPING STATION

Field investigation of flow characteristics of the Des Plaines pumping station, including bypass flow, be conducted to improve the accuracy of inflow and infiltration characteristics used in the hydrologic simulation.

7.9 GRAND CALUMET RIVER

Based on the measured flows of the current Grand Calumet River gage, if the regression equation that estimates Grand Calumet River flow results in a significant error in the deductible water supply from Indiana (contained in column 5), the impact on the historical diversion record should be reviewed.

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REFERENCES

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APPENDIX 1

COLUMN 4

GROUNDWATER PUMPAGE DISCHARGED INTO THE CANAL

\+ LMW GW REACHING CANAL (NOT INCLUDING INDIANA)

\+ DPW GW REACHING CANAL (NOT INCLUDING O'HARE TRANSFER)

\+ O'HARE FLOW TRANSFER (GW PORTION OF SANITARY COMPONENT)

- SANITARY % BASED ON UDPPS
- GW % OF WATER SUPPLY COMPUTED ON INDIVIDUAL COMMUNITY BASIS

\+ MAINSTREAM TARP GW INFILTRATION

\+ CALUMET TARP GW INFILTRATION

\- SUBTRACT 10 % OF SANITARY PORTION OF THE DPW CSO's NOT REACHING CANAL

- 10% GW ASSUMED (MAY REVISE TO MATCH O'HARE GW %)
- COMPUTED BY SUMMING SCA's THAT OVERFLOW TO WATERWAYS NOT TRIBUTARY TO CANAL.

COLUMN 5

WATER SUPPLY PUMPAGE FROM INDIANA REACHING CANAL

COMPONENTS

1 - WATER SUPPLY FROM - DYER DISCHARGE
- SCHERERVILLE TO HART DITCH
- ST. JOHN (LITTLE CALUMET)

2 - GRAND CALUMET WATER SUPPLY DEDUCTION

- LESSER VALUE OF:

A. GRAND CALUMET FLOW FROM REGRESSION EQNS.
B. SUM OF WATER SUPPLY PUMPAGE FOR
- EAST CHICAGO
- WHITING
- HAMMOND (INCLUDES PUMPAGE TO MUNSTER, HIGHLAND, AND GRIFFITH)

GRAND CALUMET FLOW FROM REGRESSION EQUATIONS

IF LM STAGE $\leq$ 1.0 CCD GC FLOW = 23 CFS

IF LM STAGE > 1.0 CCD

$$\text{GC FLOW} = 29.9\,(\text{LMS})^{5/3} + 0.13\,(\text{HDR})^{2/3} - 9.6$$

WHERE LMS = LAKE MICHIGAN STAGE @ CALUMET HARBOR
HDR = HART DITCH RUNOFF AS INDICATOR OF GC RUNOFF

COLUMN 6

RUNOFF FROM DES PLAINES WATERSHED REACHING THE CANAL

COMPONENTS		MODEL
NORTHSIDE WRP	- DPW INFLOW - DPW INFILTRATION	SCALP
WSW WRP	- DPW INFLOW - DPW INFILTRATION	SCALP
CALUMET WRP	- DPW INFLOW - DPW INFILTRATION	SCALP
LEMONT WRP	- INFLOW - INFILTRATION	SCALP
DPW CSO's TO CANAL	- INFLOW - INFILTRATION	SCALP & TNET
O'HARE TRANSFER	- INFLOW - INFILTRATION	SCALP FOR UDPPS
WSW TARP PUMPAGE	- DPW INFLOW - DPW INFILTRATION	TNET
CALUMET TARP PUMPAGE	- DPW INFLOW - DPW INFILTRATION	TNET
SUMMIT CONDUIT RUNOFF (I/I) LDP UNGAGED WATERSHED RUNOFF		HSPF SIMULATION

COLUMN 7

LAKE MICHIGAN PUMPAGE BY FEDERAL FACILITIES DISCHARGING TO CANAL

COMPONENTS:

- HINES HOSPITAL
- FORT SHERIDAN
- GLENVIEW NAVAL AIR STATION
- U.S. ARMY CORPS EMERGENCY NAVIGATION MAKEUP

COLUMN 9

LAKE MICHIGAN PUMPAGE NOT DISCHARGED TO CANAL

COMPONENTS:

+ LINCOLNSHIRE
+ RIVERWOODS
+ LIBERTYVILLE
+ WAUKEGAN --- GURNEE, PARK CITY

+ N.W. SUBURBAN JOINT ACTION WATER AGENCY
  - ELK GROVE VILLAGE, HOFFMAN ESTATES, MOUNT PROSPECT, SCHAUMBURG, HANOVER PARK, ROLLING MEADOWS, AND STREAMWOOD

+ N.W. WATER COMMISSION
  - ARLINGTON HEIGHTS, BUFFALO GROVE, PALATINE, WHEELING.

+ LAKE CO. PUBLIC WATER DISTRICT
  - KNOLLWOOD - ROUNDOUT, VERNON HILLS, WILDWOOD - GAGES LAKE

+ LAKE CO. PUBLIC WORKS - BRADLEY ROAD
+ 38.2% DES PLAINES (38.2% TO O'HARE STP)
+ 76% NORTH CHICAGO (76% TO GURNEE STP) MINUS LAKE CO. PUBLIC WKS (FROM NORTH CHICAGO)
+ 90% DPW SANITARY PORTION CSO NOT TO CANAL (90% LM WATER 10% GW ASSUMED)
  - MAY REVISE TO MATCH O'HARE LM & GW %'s

- (SUBTRACT) 95.4% SANITARY PORTION O'HARE FLOW TRANSFER (95.4% LM WATER , 4.6% GW)

- MOST WATER SUPPLY DATA SUPPLIED BY IDOT DIVISION OF WATER RESOURCES ON LMO-3 FORMS

- COMPUTATIONS BASED ON LM WATER SUPPLY DISTRIBUTION NETWORK DIAGRAM FROM IDOT. (DYNAMIC IN NATURE)

COLUMN 11

LAKE MICHIGAN PUMPAGE ACCOUNTABLE TO ILLINOIS

COMPONENTS:

+ CHICAGO	
+ EVANSTON	
+ GLENCOE	
+ HIGHLAND PARK	
+ HIGHWOOD	
+ KENILWORTH	
+ LAKE FOREST	
+ LANSING	(PURCHASED FROM HAMMOND, IN)
+ CHICAGO HEIGHTS	(PURCHASED FROM HAMMOND, IN)
+ NORTH CHICAGO	
+ NORTHBROOK	
+ WAUKEGAN	
+ WILMETTE	
+ WINNETKA	
+ ACME STEEL	
+ LAKE CO. PUBLIC WATER DISTRICT	
+ LTV STEEL	
+ REPUBLIC STEEL	
+ U.S. STEEL SOUTH WORKS	

(SUBTRACT) - GLENVIEW NAVAL AIR STATION (SUPPLIED BY WILMETTE)
(SUBTRACT) - HINES HOSPITAL (SUPPLIED BY CHICAGO)

WATER SUPPLY DATA FROM LMO-3 FORMS SUPPLIED BY IDOT. PUMPAGE RECORDS ON LMO-3 FORMS INCLUDE PUMPAGE TO SECONDARY USERS

COLUMN 12

RUNOFF FROM THE DIVERTED LAKE MICHIGAN WATERSHED

COMPONENTS:

- NORTH BRANCH CHICAGO RIVER @ NILES RUNOFF (FROM BUDGET 3)
- LITTLE CALUMET RIVER @ STATE LINE RUNOFF (FROM BUDGET 4)
- THORN CREEK @ THORNTON RUNOFF (FROM BUDGET 5)
- LITTLE CALUMET RIVER @ S. HOLLAND RUNOFF (FROM BUDGET 6)

SCALP STP:

- NORTH SIDE WRP - LMW INFLOW
  - LMW INFILTRATION
- WSW WRP - LMW INFLOW
  - LMW INFILTRATION
- CALUMET WRP - LMW INFLOW
  - LMW INFILTRATION

TNET:

- WSW TARP PUMPAGE - LMW INFLOW
  - LMW INFILTRATION
- CALUMET TARP PUMPAGE - LMW INFLOW
  - LMW INFILTRATION

SCALP & TNET:

- INFLOW PORTION CSO's FROM UNGAGED SCA's
- INFILTRATION PORTION CSO's FROM UNGAGED SCA's

- UNGAGED CALUMET RUNOFF
  - DETERMINED BY MULTIPLYING UNIT RUNOFF FILES IMPRO, OLFRO, SUBRO (HSPF) BY THE APPROPRIATE DRAINAGE AREAS FOR IMPERVIOUS, GRASSLAND , AND FOREST LAND

- GRAND CALUMET RIVER RUNOFF
  - CRUDE ESTIMATION
  - SUBTRACT WATER SUPPLIES OF EAST CHICAGO, WHITING, AND HAMMOND FROM ESTIMATED GRAND CALUMET RIVER FLOW (REGRESSION EQUATIONS)

COLUMN 13

DIRECT DIVERSIONS
ACCOUNTABLE TO ILLINOIS

COMPONENTS:

+ CHICAGO RIVER CONTROLLING WORKS
+ O'BRIEN LOCK
+ WILMETTE CONTROLLING WORKS

LOCKAGE,
LEAKAGE,
NAVIGATION MAKEUP,
& DISCRETIONARY

- CRCW BACKFLOWS
- O'BRIEN BACKFLOWS
- WILMETTE BACKFLOWS

BUDGET & COLUMN INTERACTIONS

	BUDGET	COLUMN	
DIVERTED LM PUMPAGE	1	11	
GROUNDWATER DISCHARGED TO CSSC	2	4	GW FROM IL DISCHARGED TO CSSC
		5	GW FROM IN DISCHARGED TO CSSC
N. BRANCH CHGO. RIV. @ NILES	3	12	RUNOFF FROM LMW TRIBUTARY TO GAGE
LIT. CAL RIV. @ ST. LINE	4	12	
THORN CRK @ THORNTON	5	12	
LIT. CAL RIV. @ S. HOLLAND	6	12	
NORTHSIDE WRP	7	6	DPW I/I TO N.SIDE WRP
		12	LMW I/I TO N. SIDE WRP
MWRDGC UDPPS	8	6	CALIBRATES UDPPS SCALP MODEL
MAINSTREAM TARP	9	4	GW PORTION OF DPW CSO NOT IN CSSC
		6	DPW I/I TO WSW WRP & DPW I/I PORTION CSO
		9	LM PORTION OF SANITARY CSO DISCHARGED TO DPR
		12	LMW I/I TO WSW WRP & LMW I/I PORTION CSO
WSW WRP	10	6	DPW I/I TO WSW WRP
		12	LMN I/I TO WSW WRP
CALUMET TARP	11	4	GW PORTION DPW CSO NOT TO CSSC
		6	DPW I/I TO CAL WRP & DPW I/I PORTION CSO TO CSSC
		12	LMW I/I TO CAL WRP & LMW I/I PORTION
CALUMET WRP	12	6	DPW I/I TO CALUMET WRP
		12	LMW I/I TO CALUMET WRP
LEMONT	13	6	DPW I/I TO LEMONT WRP
CANAL BALANCE	14		

Lake Michigan Diversion Accounting
Data Sources and Problems

Precipitation Network

- Original 13 gages, (4 NWS, 4 City of Chicago, and 5 MWRDGC) gages, through Water Year 1989
- MWRDGC gages are digitized from circular charts, Chicago City gages from tabulations, and four NWS gages from EarthInfo CD-ROM
- Data through Water Year 1989 adjusted by Illinois State Water Survey
- ISWS 25 gage network began WY 1990
- ISWS delivered data on disk as hourly data

Problems with precipitation data

- For 13 gage network include rain shadows at some locations, differing equipment and differing techniques
- MWRDGC circular charts could have digitizing errors
- For both networks include missing data and damaged gages

Meteorological Data

- Includes wind run, dew point, maximum and minimum temperatures, and cloud cover
- Temperatures from four NWS gages, and other meteorological data from O'Hare
- Solar radiation and evapotranspiration simulated by HSPFPREP
- Read from climatilogic reports as daily values

Water Supply Pumpage from Lake Michigan

- Lake Michigan withdrawals reported by Illinois Dept. of Transportation and Indiana Dept of Natural Resources

- Monthly Illinois report of daily pumping from lake (primary use) and monthly pumping to secondary users in form LMO-3, and annual distribution network

- Flows are based on pump ratings

Water Supply Pumpage from Groundwater

- Groundwater pumpage reported by Indiana Dept of Environmental Management, and Illinois State Water Survey and USGS Illinois office annual
- Annual and monthly totals are converted to average daily flows
- Flows are based on pump ratings and are averaged rather than daily flows

Waste Treatment Plant Pumpage

- Four plants used to check runoff and tunnel flows to treatment plant (Calumet, O'Hare, Northside, and Stickney)
- Eight plants used to check simulations of runoff at stream gages (IL - Nile, Deerfield, Plum Creek, University Park, Willowbrook, and Homewood; IN - Dyer and Schererville)
- Delivered on paper as pump time charts, or daily or monthly tabulations
- Based on pump ratings and digitized or averaged flows

Pump Station Data

- Sewer pumps at Calumet, Mainstream, O'Hare, and Upper Des Plaines
- Calumet, Mainstream, and O'Hare pump water from respective TARP tunnels
- Upper Des Plaines pumps water from upper Des Plaines River watershed
- Data is from weekly circular pump records with some missing data, multiple weeks on same chart
- Flow based on pump ratings and digitizing of charts
- Upper Des Plaines does not measure overflows

Streamflow Data from USGS

- Flows at:
  - Grand Calumet River at Hammond
  - Hart Ditch at Munster
  - Little Calumet River at Munster
  - Little Calumet River at South Holland
  - North Branch of Chicago River at Niles
  - Romeoville Acoustic Velocity Meter (AVM)
  - Thorn Creek at Thornton

- Flows are received direct from USGS on disk or read from Earthinfo CD-ROM

Possible Errors in USGS Data

- Possible errors in ratings, gage breakdowns, and AVM data replacement based on Lockport flows

- Hammond flow before WY91 simulated from Hart Ditch at Munster and Lake Michigan elevations

Streamflow Data from Metropolitan Water Reclamation District of Greater Chicago

- Canal flows (lockage, leakage, navigation makeup, direct diversion, backflows) at:
  - O'Brien Lock and Dam
  - Chicago River Controlling Works
  - Lockport (turbine, sluice, and Controlling Works flows)
  - Wilmette Controlling Works
- Flows are recieved on paper as daily values
- Leakage assumed to be constant and is not measured
- Flow calculations for navigation makeup, direct diversions, backflows, sluice and Lockport Controlling Works are of dubious accuracy
- Turbine flows now measured with AVMs since March 1992, of dubious accuracy before then
- Lockage flows derived by Corps of Engineers, Chicago District based on lock usage

Data from Industry

- Withdrawals from canal, Lake Michigan (by industry or other entity), groundwater, or storm runoff
- Discharges to canal or to sewers
- Data from:

  Acme Steel at Chicago and Riverside

  Argonne Laboratories

  LTV Steel

  Material Service

  Republic Steel

  Rhone-Doulenc Basic Chemical

  Texaco Oil

  Uno-ven Corporation

  Underwriter's Laboratory
- Variations in data collection techniques and in data quality

APPENDIX 2

Description of the Diversion Accounting Computational Budgets

Budget No.	Title	Description
1	Diverted Lake Michigan Pumpage	This budget sums Lake Michigan water diverted by the State of Illinois in the form of municipal and industrial water supply. The results of this budget are used in Column 11.
2	Groundwater Discharged to the CSSC	This budget sums groundwater pumpages that are discharged to the CSSC. The results of this budget are used in Column 4.
3	North Branch Chicago River at Niles, IL	This budget performs a simple separation of stream flow into sanitary and runoff portions. The results this budget are used in Budget 13 and Column 12.
4	Little Calumet River at the IL-IN State Line	This budget performs a simple separation of stream flow into sanitary and runoff portions. The results this budget are used in Budget 13 and Column 12.
5	Thorn Creek at Thornton, IL	This budget performs a simple separation of stream flow into sanitary and runoff portions. The results this budget are used in Budget 13 and Column 12.
6	Little Calumet River at South Holland, IL	This budget performs a simple separation of stream flow into sanitary and runoff portions. The results this budget are used in Budget 13 and Column 12.
7	MWRDGC Northside Water Reclamation	This budget performs hydrologic and hydraulic simulation of the service basin tributary to the MWRDGC Northside Water Reclamation Facility. The simulations estimates the runoff from portions of the Lake Michigan and Des Plaines River watersheds within the Northside service basin that is diverted to the CSSC in the form of inflow-infiltration. The budget provides an internal verification of the accounting procedures. The results of this budget are used on Budget 13 and Columns 6 and 12.

Table 2 (cont)

Description of the Diversion Accounting Computational Budgets

Budget No.	Title	Description
8	MWRDGC Upper Des Plaines Pumping Station	This budget performs hydrologic and hydraulic simulation of the MWRDGC Upper Des Plaines Pumping Station. This budget provides a calibration point to verify models of the Des Plaines River watershed
9	MWRDGC Mainstream TARP Pumping Station	This budget performs hydrologic and hydraulic simulation of the MWRDGC Mainstream TARP Pumping Station. The results of this simulation are used in Budgets 10 and 13 and Columns 6 and 12. The budget also provides internal verification of the accounting procedures.
10	MWRDGC Stickney Water Reclamation Facility	This budget performs hydrologic and hydraulic simulation of the service basin tributary to the MWRDGC Stickney Water Reclamation Facility. The simulations estimates the runoff from portions of the Lake Michigan and Des Plaines River watersheds within the Stickney service basin that is diverted to the CSSC in the form of inflow-infiltration. The budget provides an internal verification of the accounting procedures. The results of this budget are used in Budget 13 and Columns 6 and 12.
11	MWRDGC Calumet Water Reclamation Facility	This budget performs hydrologic and hydraulic simulation of the service basin tributary to the MWRDGC Calumet Water Reclamation Facility. The simulations estimates the runoff from portions of the Lake Michigan and Des Plaines River watersheds within the Calumet service basin that is diverted to the CSSC in the form of inflow-infiltration. The budget provides an internal verification of the accounting procedures. The results of this budget are used in Budget 13 and Columns 6 and 12.

Table 2 (cont)

Description of the Diversion Accounting Computational Budgets

Budget No.	Title	Description
12	MWRDGC Lemont Water Reclamation Facility	This budget performs hydrologic and hydraulic simulation of the service basin tributary to the MWRDGC Lemont Water Reclamation Facility. The simulations estimates the runoff from portions of the Des Plaines River watershed within the Lemont service basin that is diverted to the CSSC in the form of inflow-infiltration. The budget provides an internal verification of the accounting procedures. The results of this budget are used in Budget 13 and Column 6.
13	Chicago Canal System	This budget performs a water balance of the Chicago Canal System which includes the CSSC and adjoining channels. This budget provides a verification point for the accounting procedures.

APPENDIX 3

Enclosure 1

ROMEOVILLE AVM STATION DESCRIPTION REV. 05/19/93

Quadrangle - Romeoville, 7.5' series

STATION NUMBER 05536995

WRITTEN BY: D.A. Stedfast, 08/14/91
CHECKED BY: D.P. Morgan, 08/14/91
REVISED BY: D.P. Morgan, 05/19/93

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Description of Gaging Station on Chicago Sanitary & Ship Canal at Romeoville, IL

Location.--Lat 41 38' 26", long 88 03' 38", in SE1/4SW1/4 sec. 35, T.37 N., R.10 E., Will County, Hydrologic Unit 07120004, on the left bank 40 feet upstream from Romeoville Road (135th Street) bridge over the canal, at Romeoville, 5.2 miles upstream from Lockport Lock and Dam, and at river mile 6.2.

To reach gage.-- Exit from I80 at Richards Street in Joliet, IL. Drive north on Richards Street approximately 0.9 miles to Jefferson Street (just past RR Viaduct). Proceed right on Jefferson Street which turns north and becomes Collins Street and later route 171 for 5.5 miles to New Avenue (0.9 miles north of route 171 and route 7 intersection). Turn left onto New Avenue and proceed 2.8 miles to 135th Street. At 135th Street turn left and drive 0.6 miles to the Romeoville Road Bridge over the canal. Turn right between the bridge and the railroad tracks, and proceed 150 ft north to gage.

Establishment and history.--April 1974 to September 19, 1977, water-temperature records were collected at a site on the right downstream side of the bridge. Water quality samples have been collected at the site from 1974-77 and from 1987 to the current year. The first acoustical velocity meter and the wire-weight gage were installed during the week of March 18-23, 1984, by A. W. Noehre, G. G. Fisk, J. K. LaTour, and personnel from Sarasota Automation, W. Buck and A. Rouse. A manometer and digital water-stage recorder were installed on April 3, 1984, by G. G. Fisk. The Sarasota AVM was replaced by a Ferranti O.R.E. Inc. AVM during the week of November 7-11, 1988. The O.R.E. AVM was installed by M. P. DeVries, D. P. Morgan, J. J. Duncker, S. M. Robinson, and a representative from O.R.E.. At the time of the O.R.E. AVM installation the downstream set of three transducers (upper, middle, and lower paths) was relocated 20 feet downstream from the original location. On November 2, 1990 the left upstream set of three transducers (upper, middle, and lower paths) was relocated approximately 20 feet downstream to a natural crevis in the canal wall. A staff gage was installed on November 2, 1990, by D. P. Morgan and L. J. Mansue. A PVC stilling well with a Handar SDI-12 shaft encoder were installed during the week of July 6-9, 1992, by D. P. Morgan, L. J. Mansue and L. C. Schideman.

Drainage area.--739 sq mi.

Gage.-- A four path Ferranti O.R.E. 7410 Acoustical velocity meter, Decwriter printer, Campbell Scientific CR-10 datalogger with a temperature thermocouple, Handar SDI-12 shaft encoder operated over a float stilling well in canal, a stage potentiometer operated by a manometer, and a telemetry system within an 8 ft x 8 ft x 8 ft concrete block shelter. AC power is available to run the equipment, heater, air conditioner, telephone modem and security system.

Eight velocity transducers are installed at four locations along the canal walls with two locations on each bank approximately 170 ft apart and 162 ft across from the other bank. The velocity transducers are installed in or attached to 3 or 6 inch plastic pipes which were fabricated to be adjusted from the top of the canal wall. The transducers attached to the 6 inch pipe are secured by being directly inserted into holes in the 6 inch pipe. The transducers attached to the 3 inch pipes are secured by being epoxied into a 3 inch to 2 inch reducer which is then inserted into a 2 inch hole in the 3 inch plastic pipe. This assembly is then secured with lag bolts through each side of the pipe. These pipes are located within chases cut into the limestone canal walls or within natural recessed openings. They are secured to the canal walls by a pair of steel strap mounting brackets located above the water surface to hold the pipes in a fixed position. One set of three transducers (upper, middle, and lower paths) is located along the east (left) bank approximately 130 feet upstream of the gage. The other set of three transducers is located along the west (right) bank near the upstream side of the bridge. The remaining pair of transducers make up the cross-path. The upstream cross-path transducer is located approximately 170 feet upstream of the bridge on the west (right) bank and the downstream transducer is located on the east (left) bank near the upstream side of the bridge. Each pair (path) of transducers are at approximately the same elevation, across the canal from one another at approximately a 45 degree angle to the canal sides, and at different vertical locations within the cross-section. Each "pair" forms a velocity path. One stage transducer is attached to the east (left) canal wall near the gage house and is pointed at the water surface. All transducers are linked to the acoustical velocity meter by individual electrical wires. The wires from the west (right) bank are attached to the canal wall, submerged along the canal bottom, attached to the east (left) wall within the chase, and buried under ground to the gage house.

A PVC stilling well is mounted next to stage transducer on the same mounting bracket that is attached to the east (left) canal wall. A float operated SDI-12 shaft encoder is linked to CR10 datalogger by buried cable.

The orifice for the manometer is attached to the east (left) canal wall located near the stage transducer and is pointed at the canal bottom.

An outside staff gage is bolted to the east (left) canal wall, in the same natural crevice as the uplooker transducer and the manometer orifice.

A security system is installed with a direct telephone line to the Romeoville Police Station. Anyone entering the gage house has 30 SECONDS TO TURN OFF THE SYSTEM by using the key found on the top of the security control box. The security control box is located at the left side of the door as you enter. Upon leaving the gage house to activate the system, shut the front door, turn the system on, remove the key and return to top of the security control box, turn out the overhead light, open the door, exit, and close the door. YOU HAVE 45 SECONDS TO COMPLETE THE ABOVE PROCEDURE.

Elevations of prominent features, in feet above gage datum, are as follows:

Velocity path no. 1 (top) transducers	16.51
Velocity path no. 2 (middle) transducers	12.26
Velocity path no. 3 (cross) transducers	13.16
Velocity path no. 4 (bottom) transducers	8.28
Stage transducer	15.75
Orifice	18.00

AVM transducer path lengths and angles are as follows:

Length of velocity paths 1,2, and 4	236. feet
Length of velocity path 3	235. feet
Angle of velocity paths 1,2, and 4	44.5 degrees
Angle of velocity path 3	44.0 degrees

SPECIAL NOTE: Repair work at this gage sometimes requires a dive. If a dive is required then TWO DIVERS AND A LINETENDER (SPOTTER) MUST BE ON HAND! ALL DIVES will be conducted using the "buddy system" as per safety regulations. BOTH DIVERS WILL BE DRESSED IN DRY SUITS.

Gage datum.--551.89 ft NGVD of 1929, determined from USAE BM 296.1 No. 113. The bench mark is the top of a copper bolt leaded vertically into the top of the bridge seat on the pier at the east end of the swing-bridge over Chicago Sanitary and Ship Canal at Romeoville. The bolt is near the south end of coping and 0.95 ft west of east end. Elevation 595.064 ft NGVD of 1929.

Reference and bench marks.--BM-1.--Copper bolt on top of and near downstream end of left bridge pier. Elevation = 43.17 ft.

Regulation and diversion.--Flow is diverted from Lake Michigan and is regulated by the Lockport Lock and Dam. The amount of diversion (3,200 cfs) is set by the December 1, 1980 amendment to the Supreme Court of the United States Decree of June 12, 1967.

Accuracy.-- The discharge records should be excellent.

Cooperation.-- U.S. Army Corps of Engineers, Chicago District

Observer.--None

Twenty-four verticals should be taken at the following predetermined stations:

6	32	60	88	116	148
10	39	67	95	123	158
18	46	74	102	130	163
25	53	81	109	138	168

note: Stationing is in feet from the right edge of water at the canal wall (station 6ft is located at REW and station 168ft at LEW).

The mean velocity for each section should be determined using the ".2, .6, and .8" velocity method in each vertical to describe the flow more accurately for calibration of the acoustical velocity meter. The equation for the mean section velocity is as follows:

$$v(avg) = [((v(.2) + v(.8)) / 2) + v(.6)] / 2$$

The AVM discharge during the discharge measurement shall be weighted based on data recorded during the discharge measurement. Intermediate watch times (beginning and ending times) at each measurement station shall be recorded on the measurement note sheet. One minute AVM stage, velocity, and discharge readings shall recorded on the Decwriter. These recorded values shall then be used to compute the weighted AVM discharge using the following formula:

Weighted AVM Q = sum[Qmeas x Qavm] / Qmeas(total)

where: Qmeas = the discharge measured in each sub-area (section).

Qavm = the average AVM discharge recorded during the time that the section was measured.

Qmeas(total) = the total discharge measured.

Discharge measurements can also be made using an acoustical doppler meter from one boat pulled across canal attached to tagline as mention above. This will become the preferred way to make measurements because one measurement can be made in 4 minutes, therefore a series of measurements can be made in the same time a single conventional boat measurement can be made.

Floods.-- None, due to regulation.

Point of zero flow.--Can occur at any stage.

Winter flow.--Free of ice formation.

BM-2.--Bronze gaging station tablet in gage house concrete pad near landward side of gage door. Elevation = 35.44 ft.

RP-3.--Head of lag-bolt in power pole located 15 feet upstream of left end of bridge. Elevation = 37.65 ft.

RP-4.--Carragebolt in canal wall near top of staff board. Elevation = 29.34 ft.

Channel and control.--The canal at this location was constructed by using dynamite to cut an opening in the limestone outcrop of near vertical walls 34 ft deep and a top width of 162 ft. The channel bottom is almost horizontal with some rounding at the face of each bank. The control for low and medium flows is the Greater Chicago Metropolitan Sanitary District Dam and the U.S. Army Corps of Engineers Lock at Lockport, 5.2 mi downstream. High flow is controlled by the Lock and Dam and the Greater Chicago Metropolitan Sanitary District Controlling Works, 3.0 mi downstream, which diverts water to the Des Plaines River. The water surface elevation in the canal is maintained at about a 25 ft stage at the gage. When heavy rains are forecasted the water surface is drawn down about 4-5 ft by opening the controlling works to temporarily lower flood waters and to increase the discharge from the Chicago area. During these periods the stage at the gage decreases and the velocity and discharge increase.

Discharge measurements.--Measurements are made from boats using a tagline stretched across the channel at a point halfway between the upstream and downstream transducers. This measurement point is marked on each canal wall with red paint and two bolt anchors. The tagline is attached to "J" bolts which are secured into these anchors. Then the tagline can be pulled up tight using a winch. Measurement time should be minimized by having two boat crews measuring at the same time, starting from opposite sides of the canal. Full 40 second velocity sampling times are required to maintain the high degree of accuracy required for this site. Discharge measurements should also be made during periods of minimal changes in discharge (ie. minimal barge/boat traffic and changes in the gate openings at the dam 3 miles downstream). Possible variations in the flow should be checked by telephoning the Greater Chicago Metropolitan Sanitary District's (GCMSD) Supervising Civil Engineer, Bill Eyre, of the General Division for Maintenance and Operation (312-751-5102).

APPENDIX 4

05536995 CHICAGO SANITARY/SHIP CANAL AT ROMEOVILLE, IL
1989 WATER YEAR

STATION ANALYSIS
URBANA FIELD HEADQUARTERS

EQUIPMENT.--An acoustic velocity meter (AVM), is used to collect stage and velocity record and to compute discharge. Velocity data are collected with 4 pairs of ultrasonic transducers; stage data is collected with a vertically-mounted ultrasonic transducer.

Other equipment housed in a 8' x 8' concrete block shelter includes: a digital water-stage recorder operated by a manometer which is used to check AVM stage readings; A CR-10 datalogger, which is used to record AVM data; a printer, which also records AVM data; a telephone connected to the AVM modem system on which the gage may be called for readings; a Data Collection Platform (DCP); an air conditioner and electric heater. The equipment is powered by AC current and is secured by an eight foot high cyclone and barbed-wire fence and an alarm system which is connected to the Romeoville Police Department. The outside gage is a wire-weight gage which is mounted to the upstream guard rail.

AVM RECORD.--Two different AVM's were in operation during the water year. The old Sarasota AVM was in operation from Oct 1 to Nov 3. A new ORE AVM was installed during the period from Nov 3 to Nov 17 and was officially in operation from Nov 17 to Sept 30. Both AVM's furnished satisfactory record throughout the water year, except as follows: Nov 3 to Nov 17, the new AVM was being installed; Jan. 31 to Feb. 3, the AVM was down due to failure of the power surge protector; June 12 to June 14, the AVM was down for repairs to uplooker transducer; August 22 to August 23, the AVM had shut itself down possibly due to a current surge from a nearby lightning strike(no apparent damage to equipment); and September 26 to September 30, the AVM was down due to the destruction of the submarine cables by barge traffic. Estimated daily discharges for these periods were provided by the Army Corps of Engineers. The estimates were determined from the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) records for the Lockport Dam which were adjusted based on a regression equation developed by the Corps.

Velocity paths 1 and 3 were not working from Oct 1 (previous WY) to Nov 3. The correction factor of 0.988 applied during the 1988 WY was also applied to the daily mean discharges computed using paths 2 and 4 for this year. This correction factor was based on an analysis made during the 1988 WY which investigated the accuracy of computing daily discharge using various combinations of the velocity paths.

The uplooking stage transducer started giving bad data on June 1, failed on June 12, and was replaced on June 14. After the new stage transducer was installed the gage height datum was incorrectly set in the AVM and was not corrected until after Sept. 30. Therefore, manometer stage data collected during the period June 1 to Sept. 30 was used for computing discharge rather than the AVM stage data.

Various path lengths, path angles, and all path elevations stored in the O.R.E. AVM were incorrect during the period Nov. 17 to Sept. 30. Therefore, the AVM recorded discharges and velocities during this period were incorrect. In addition, the discharge equations in

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1990 WATER YEAR

Correction factors for the bad velocity readings was developed using the AVM velocity equation, V=(L*dt)/(2*T^2*cos(theta)). Therefore, Vcorrected= Vold(Lcorrect/Lold), which by substitution becomes Vcorrect=Vold(0.961).

b) The path angles for the bottom, middle, and top paths were incorrectly set at 41 degrees from Oct. 1 to Mar. 21. The correct path angle was 42 degrees + or - 5 minutes. Utilizing the AVM velocity equation resulted in the correction factor, Vcorrect=Vold(1.016). The path angle for the cross path was also set incorrectly at 44.5 degrees during the same period. The correct path angle for this path was 44 degrees + or - 5 minutes. Which, utilizing the AVM velocity equation resulted in the correction factor, Vcorrect= Vold(0.992).

c) All velocity path elevations were incorrectly set in the AVM for the period Oct. 1 to Apr. 5. These errors resulted in incorrect discharge values being computed by the AVM. However, since the AVM computed discharges are not used for the official record these errors only resulted in relatively small "real time" discharge data errors. The correct path elevations were measured on March 19, 1990, and can be found listed in the Station Description dated August 1, 1990. The official discharge equations and a description of the methodology can be found in the Station Quality Assurance Plan dated August 1, 1990.

d) The path velocities were corrected and the discharge was correctly computed using a computer program on the Prime Mini Computer. All correctly computed daily discharge records were reviewed and down loaded into the ADAPS data base.

GAGE-HEIGHT RECORD: The gage-height datum for the uplooking stage transducer that was installed June 14, 1989 was incorrectly set in the AVM and was not corrected until 1400 hours March 21, 1990. The uplooking stage transducer did not provide satisfactory gage-height record during the period Oct. 1 to Mar. 21 due to incorrect datum setting; May 8, transducer assembly slipped down and was at an angle; May 9, assembly dangling by one strap; May 24, removed assembly for repairs and reinstalled on May 25; June 12, found assembly at an angle; and following the end of the water year on Oct. 15, 1990 found assembly gone. The manometer provided satisfactory stage record during the year. Therefore, manometer stage record collected during the period Oct. 1 to Sept. 30 was used to compute discharge in lieu of the AVM uplooking stage record.

DATUM CORRECTIONS.-- Corrections to (wire-weight) gage

	DATE	FOUND	LEFT
Levels	06-03-87	+.003'	+.003'

No datum corrections were warranted during the water year.

VELOCITY CORRECTIONS.--Application of velocity correction factors:

From October 01, 1989 at 0015 hours to March 19, 1990 at 1745 hours:

Vcorrect VEL-U(1) = Vold VEL-U(1) * 1.016 * 0.961
Vcorrect VEL-M(2) = Vold VEL-M(2) * 1.016 * 0.961
Vcorrect VEL-X(3) = Vold VEL-X(3) * 0.992

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1989 WATER YEAR

during the 1989 water year. These measurements range in discharge from 2,072 to 14,900 ft3/s. The daily discharge range experienced during the water year was from 1,790 ft3/s to 12,800 ft3/s. With the exception of measurements no. 43, 44, and 46 all measurements confirmed the AVM discharge within 4.3 percent of the measured discharge. These measurements were believed to have been made with polymer cups and were not used in the analysis.

All measurements were made with the .2, .6, and .8 method to obtain point velocities in the verticals. Mean velocity for each vertical was computed in the following manner:

$$v(avg) = [((v(.2) + v(.8)) / 2) + v(.6)] / 2$$

AVM discharges were discharge measurement weighed to adjust for change in discharge during the measurement.

DISCHARGE.-- Sarasota AVM discharges were used from October 1 to Nov 2. Discharge was computed using the attached equations (note: the equation format and detailed description of the method can be found in the Station Quality Assurance Plan dated 8/1/90) for the period, Nov 17 to Sept. 30. The periods of no records or less than 80 AVM readings per day are Nov. 3-17, Jan. 31 - Feb. 3, June 12-14, Aug. 22-23, and Sept. 26-30. Estimated daily discharges for these periods were determined from the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) records for the Lockport Controlling Works which were adjusted based on a regression equation developed by the Corps of Engineers.

On April 5, 1990, a meeting was held at the AVM site to discuss the 1989 WY discharge records with representatives from the Corps of Engineers (COE), Chicago District, and IDOT Divisiont of Water Resources (DWR). Attendees included David Stedfast (USGS), David Morgan (USGS), Tom Price (COE), Tim Lormand (COE), and Dan Injerd (DWR). The status of the current AVM equipment, proposed improvements, and quality of this years record were discussed. All parties agreed that the O.R.E. equipment was both doing well and was a definite improvement over the Sarasota AVM. The proposed improvements included moving the upstream transducers on the gage side downstream 20 feet to a natural crack in the canal wall and locating the manometer orifice in a stilling well. Both DWR and COE representatives agreed that the 1989 daily discharge records were acceptable and appeared very good after comparison to daily discharges computed by the COE using MWRDGC Lockport records.

REMARKS.--AVM discharge records are good except for periods of no record, which are fair.

Written by David A. Stedfast
Checked by David P. Morgan
Date August 3, 1990

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1990 WATER YEAR

The records for water year 1990 were re-computed in November 1992 by Kevin Oberg and Steve Melching, Illinois District, USGS. The records were re-computed to correct for an error in the average depth for the reach measured by the AVM. See report "Discharge and Regression Analyses for Acoustic Velocity Meter Data for Chicago Sanitary and Ship Canal at Romeoville, Illinois", by C.S. Melching and K.A. Oberg for more details. In addition, Melching and Oberg developed a new set of regression equations for estimating missing record, using data provided by MWRDGC for the Lockport Powerhouse and Controlling Works. These new equations, also described in the above report, were used to estimate days of missing record for the 1990 water year.

Revised by: Kevin Oberg
Date: May 27, 1993

05536995 CHICAGO SANITARY/SHIP CANAL AT ROMEOVILLE, IL
1990 WATER YEAR

STATION ANALYSIS
URBANA FIELD HEADQUARTERS

EQUIPMENT.--A Ferranti O.R.E. Inc. Accusonic Flowmeter Model 7410, hereafter referred to as an acoustic velocity meter (AVM), is used to collect stage and velocity record and to compute discharge. Velocity data are collected with 4 pairs of ultrasonic transducers; stage data is collected with a vertically mounted ultrasonic transducer.

Other equipment housed in a 8' x 8' concrete block shelter includes: a manometer which is used to check AVM stage readings and serves as a back-up system for collecting stage; A CR1O datalogger, which is used to record AVM and manometer data; a printer, which also records AVM data; a telephone connected to the CR10 modem system on which the gage may be called for readings; a Data Collection Platform (DCP); an air conditioner and electric heater. The equipment is powered by AC current and is secured by an eight foot high cyclone and barbed-wire fence and an alarm system which is connected to the Romeoville Police Department.

The outside gage is a wire-weight gage mounted to the upstream guard rail of the Romeoville Road (135th Street) bridge and was used until September 18, 1990, at which time the bridge was condemned and removed from service because of an unsafe structural condition. An outside staff gage was installed on November 2, 1990, and is now the base outside gage.

AVM RECORD.--The AVM furnished satisfactory record throughout the water year, except as follows: Oct. 1 to 6, the AVM was down due to the destruction of the submarine cables by barge traffic; Oct. 10 to 13, transducer assembly knocked out of alignment by a barge; Nov. 15 to 21, bad velocity transducers plus the transducers were dropped from their mounting into the canal; Mar. 16 to 19, transducer assembly knocked out of alignment by a barge; Apr. 29 to May 1, a short in the junction box caused the AVM to shut down and stop taking velocity measurements; May 5 to 7, no gage-height record due to equipment malfunction; May 9 to 30, the AVM was down due to the destruction of the submarine cables by barge traffic; and June 14, AVM transceiver damaged by lightning.

VELOCITY RECORD: Values for the path lengths, path angles, and path elevations were incorrectly stored in the AVM during most of the 1989 water year. These errors continued into the 1990 water year until March 1990. Therefore, the AVM recorded velocites and discharges during this period were incorrect. The equations in the AVM are not the official equations for computing discharge record, however, they do provide useful provisional "real-time" information to the cooperator.

Discussion of the correction factors as applied to the path length, path, angle, and path elevations:

a) The path lengths for the bottom and middle path were incorrectly set at 255.9 ft. and 255.6 ft. respectively during the period Oct. 1 to Mar. 19. The top path length was incorrectly set to 255.9 ft. during the period Oct. 1 to Mar. 19. The correct path length for all three of these paths was 246 ft. as measured on March 19, 1990.

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Correction factors for the bad velocity readings was developed using the AVM velocity equation, V=(L*dt)/(2*T^2*cos(theta)). Therefore, Vcorrected= Vold(Lcorrect/Lold), which by substitution becomes Vcorrect=Vold(0.961).

b) The path angles for the bottom, middle, and top paths were incorrectly set at 41 degrees from Oct. 1 to Mar. 21. The correct path angle was 42 degrees + or - 5 minutes. Utilizing the AVM velocity equation resulted in the correction factor, Vcorrect=Vold(1.016). The path angle for the cross path was also set incorrectly at 44.5 degrees during the same period. The correct path angle for this path was 44 degrees + or - 5 minutes. Which, utilizing the AVM velocity equation resulted in the correction factor, Vcorrect= Vold(0.992).

c) All velocity path elevations were incorrectly set in the AVM for the period Oct. 1 to Apr. 5. These errors resulted in incorrect discharge values being computed by the AVM. However, since the AVM computed discharges are not used for the official record these errors only resulted in relatively small "real time" discharge data errors. The correct path elevations were measured on March 19, 1990, and can be found listed in the Station Description dated August 1, 1990. The official discharge equations and a description of the methodology can be found in the Station Quality Assurance Plan dated August 1, 1990.

d) The path velocities were corrected and the discharge was correctly computed using a computer program on the Prime Mini Computer. All correctly computed daily discharge records were reviewed and down loaded into the ADAPS data base.

GAGE-HEIGHT RECORD: The gage-height datum for the uplooking stage transducer that was installed June 14, 1989 was incorrectly set in the AVM and was not corrected until 1400 hours March 21, 1990. The uplooking stage transducer did not provide satisfactory gage-height record during the period Oct. 1 to Mar. 21 due to incorrect datum setting; May 8, transducer assembly slipped down and was at an angle; May 9, assembly dangling by one strap; May 24, removed assembly for repairs and reinstalled on May 25; June 12, found assembly at an angle; and following the end of the water year on Oct. 15, 1990 found assembly gone. The manometer provided satisfactory stage record during the year. Therefore, manometer stage record collected during the period Oct. 1 to Sept. 30 was used to compute discharge in lieu of the AVM uplooking stage record.

DATUM CORRECTIONS.-- Corrections to (wire-weight) gage

	DATE	FOUND	LEFT
Levels	06-03-87	+.003'	+.003'

No datum corrections were warranted during the water year.

VELOCITY CORRECTIONS.--Application of velocity correction factors:

From October 01, 1989 at 0015 hours to March 19, 1990 at 1745 hours:

Vcorrect VEL-U(1) = Vold VEL-U(1) * 1.016 * 0.961
Vcorrect VEL-M(2) = Vold VEL-M(2) * 1.016 * 0.961
Vcorrect VEL-X(3) = Vold VEL-X(3) * 0.992

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Vcorrect VEL-L(4) = Vold VEL-L(4) * 1.016 * 0.961

From March 19, 1990 at 1800 hours to March 21, 1990 at 1800 hours:

Vcorrect VEL-U(1) = Vold VEL-U(1) * 1.016
Vcorrect VEL-M(2) = Vold VEL-M(2) * 1.016
Vcorrect VEL-X(3) = Vold VEL-X(3) * 0.992
Vcorrect VEL-L(4) = Vold VEL-L(4) * 1.016

From March 21, 1990 at 1815 hours to September 30, 1990: No correction factors warranted.

GAGE-HEIGHT CORRECTIONS.--Manometer gage-heights were corrected to the outside gage due to manometer / potentiometer drift as shown on attached ADAPS printout of gage-height corrections, based on gage inspections during the year.

RATING.--Eleven discharge measurements, Nos. 52-62, are available to verify the AVM discharges during the 1990 water year. These measurements range from 1,870 to 14,400 ft3/s. The daily range experienced during the year was from 1,762 to an estimated 17,870 ft3/s. With the exceptions of measurements Nos. 54 and 55, all measurements confirmed the AVM discharge within 5.2 percent of the measured discharge. An explanation for measurements Nos. 54 and 55 not confirming the AVM discharge has not been determined. Both measurements were made back-to-back on January 11, 1990.

All measurements were made with the .2, .6, and .8 method to obtain point velocities in the verticals. Mean velocity for each vertical was computed in the following manner:

$$v(avg) = [((v(.2) + v(.8)) / 2) + v(.6)] / 2$$

The AVM discharges (computed using the attached official set of discharge equations) during the discharge measurement are weighted to adjust for change in discharge during the measurement. The procedure for weighted is provided in the Quality Assurance Plan (REV. 08/01/90).

DISCHARGE.--Discharge was computed using AVM velocity and manometer gage height records and the attached equations except for periods of no records or when less than 80 AVM readings were available in any given day. The periods of no records or less than 80 AVM readings per day are Oct. 1 to Oct. 6, Oct. 10 to 13, Nov. 15 to Nov. 21, Mar. 16 to 19, Apr. 29 to May 1, May 4 to 30, and June 14. Estimated daily discharges for these periods were provided by the Army Corps of Engineers. The estimates were determined from the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) records for the Lockport Dam which were adjusted based on a regression equation developed by the Corps of Engineers. ?

REMARKS.--AVM discharge records are good except for periods of no record, which are fair.

Written by G.W. Curtis, February 27, 1991
Checked by D.P. Morgan, March 1, 1991

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1990 WATER YEAR

The records for water year 1990 were re-computed in November 1992 by Kevin Oberg and Steve Melching, Illinois District, USGS. The records were re-computed to correct for an error in the average depth for the reach measured by the AVM. See report "Discharge and Regression Analyses for Acoustic Velocity Meter Data for Chicago Sanitary and Ship Canal at Romeoville, Illinois", by C.S. Melching and K.A. Oberg for more details. In addition, Melching and Oberg developed a new set of regression equations for estimating missing record, using data provided by MWRDGC for the Lockport Powerhouse and Controlling Works. These new equations, also described in the above report, were used to estimate days of missing record for the 1990 water year.

Revised by: Kevin Oberg
Date: May 27, 1993

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1991 WATER YEAR

STATION ANALYSIS
ILLINOIS DISTRICT, U.S.G.S.

EQUIPMENT.--A Ferranti O.R.E. Inc. Accusonic Flowmeter Model 7410, hereafter referred to as an acoustic velocity meter (AVM), is used to collect gage-height and velocity record and to compute discharge. Velocity data are collected with 4 pairs of ultrasonic transducers; gage-height data is collected with a vertically mounted ultrasonic transducer.

Other equipment housed in a 8' x 8' concrete block shelter includes: a manometer which was used as the primary gage-height record and to check AVM gage-height readings; A CR10 datalogger, which is used to record AVM and manometer data; a printer, which also records AVM data; a telephone connected to the CR10 modem system on which the gage may be called for readings; a Data Collection Platform (DCP); an air conditioner and electric heater. The equipment is powered by AC current and is secured by an eight foot high cyclone and barbed-wire fence and an alarm system which is connected to the Romeoville Police Department.

The outside gage is a staff gage mounted to the canal wall in a natural niche where the uplooking gage-height assembly for the AVM and manometer orifice is located. The staff gage was installed on November 2, 1990. Prior to September 18, 1990 the outside gage was a wire-weight gage mounted to the upstream guard rail of the Romeoville Road (135th Street) bridge and was used until the bridge was condemned and removed from service because of an unsafe structural condition.

AVM RECORD.--The AVM furnished satisfactory record throughout the water year, except as follows: March 27 AVM was down due to loss of AC power caused by high winds; April 20 to 24 AVM was down due to the measurement section of AVM locking-up; and May 31 to June 3 AVM was down due to the measurement section of AVM locking up. For the period of no CR10 datalogger record and at other times when the CR10 datalogger failed to record AVM record, the Decwriter AVM printouts were used to fill in the gaps.

VELOCITY RECORD: The parameters for path lengths, path angles, and path elevations were correct in the AVM for the entire year. This information is required in order to compute velocity and discharge correctly. The equations in the AVM are not the official equations for computing discharge record, however, they do provide useful provisional "real-time" information to the cooperator.

Due to prior history of barges hitting or scraping the canal wall and either knocking the upstream main three transducer assembly out of alignment or destroying transducers / assembly, the entire assembly was moved downstream approximately 20 feet into a natural niche on November 2, 1990. This changed the path length, path angle of the upper, middle and lower paths. This move also allowed for the lowering of the lower transducer to be in vertical elevation alignment of the downstream lower transducer. The

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1991 WATER YEAR

path length, path angle and path elevation were determined by station levels ran on November 1, 1990.

Path length, path angle and path elevation are as follows:

Path	Length	Angle	Cosag	Elevation
upper	236	44.5	0.713	16.51
middle	236	44.5	0.713	12.26
x-path	235	44.0	0.719	12.78
lower	236	44.5	0.713	8.28

On several occasions during the year barge traffic hit and destroyed the upstream x-path transducer assembly and once destroyed the downstream x-path transducer assembly which caused several replacements of these assemblies. On May 15 and 16, 1991, both the upstream and downstream mounting brackets for the x-path were changed in hope of making the assemblies and transducers more secure from barge traffic. Also at this time the downstream x-path was replaced with a new assembly. This new assembly changed the x-path elevation from 12.78 feet to13.16 feet. Path length and path angle remained the same.

On June 5, 1991 levels were ran into each of the upper mounting brackets of all transducer assemblies to establish reference point elevations. This was done in order to make it easier to maintain transducer elevation in case of transducer / assembly replacement. However, on June 26, 1991 the reference point for the downstream main three assembly was transferred from the mounting bracket to the top of eye bolt on metal cap of permanent pipe on which the bracket is mounted to.

Using "PLOTWAT" within "ADAPS" all working path velocities were compared graphically to one another and any bad velocity values were deleted from the original Prime datalogger files. These files were used to input the velocity record into ADAPS. Once all the bad velocities were deleted from the Prime datalogger files a computer program on the Prime Mini Computer was used to compute an average AVM velocity using the following relationships:

Mean AVM Vel. = (Vel-U + Vel-M + Vel-X + Vel-L)/4, if all four paths are working, or

If all four paths are not working then the mean AVM velocity is computed by first correcting each working path velocity by the appropriate (Mean AVM Vel)/(path velocity) ratio and then taking their arithmetic mean. The correction ratios are listed below:

(Mean AVM Vel)/(Vel-U) = 0.964
(Mean AVM Vel)/(Vel-M) = 0.989
(Mean AVM Vel)/(Vel-X) = 1.000
(Mean AVM Vel)/(Vel-L) = 1.053

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These relationships were determined by David A. Stedfast, who used a Minitab Statistical Analysis program on a Sun Workstation Computer. The results of his analysis can be found in a folder marked "Velocity Rating" in the Romeoville file cabinet.

GAGE-HEIGHT RECORD: The uplooking gage-height transducer did not provide satisfactory gage-height record during the following periods: October 1-18 due to improper (temporarily) mounting and uplooking assembly gone; March 27 due to loss of AC power caused by high winds; April 12-20 due to uplooking malfunction; April 20-24 AVM was down due to the measurement section of AVM locking-up; and May 31 to June 3 AVM was down due to the measurement section of AVM locking-up. There were also other periods of time including the April 12-20 where the uplooking gage-height would for no reason calculate gage-height a foot or more off in either direction for short periods of time and then come back on to the correct gage-height on its own. Because of these random occurrences of improper gage-heights the valid manometer gage-height record collected during the water year was used to compute discharge in lieu of the AVM uplooking gage-height record.

MANOMETER GAGE-HEIGHT RECORD: The manometer furnished satisfactory record throughout the water year, except as follows: December 25 to February 7 manometer malfunction and NON-U.S.G.S. removal of potentiometer sprocket; June 25 and 26 due to drained battery to CR10 datalogger - no data collected. During periods of no manometer gage-height record the AVM uplooking gage-height was used. The AVM uplooking gage-height was inputted into the same DD as the manometer gage-height and is stored without any tag following the value when you do a unit-value retrieval.

DATUM CORRECTIONS.--

	DATE	FOUND	LEFT	Remarks
Levels	11-01-90	-----	-.001'	Established staff gage
Levels	06-05-91	-----	-----	Established RPs for Transducer assemblies

No datum corrections were warranted during the water year.

VELOCITY CORRECTIONS.--

No correction factors were warranted during the water year.

GAGE-HEIGHT CORRECTIONS.--Manometer gage-heights were corrected to the outside gage due to manometer / potentiometer drift as shown on attached ADAPS printout of gage-height corrections, based on gage inspections during the year.

The project chief of water year 1990 ended the year with a +0.10 ft gage-height correction. Looking at the measurement sheets and inspections for water years 1990 and

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1991 there was not enough information to base this correction, so no correction was used to start water year 1991.

RATING.--Seven discharge measurements, Nos. 63-69, are available to verify the AVM discharges during the 1991 water year. These measurements range from 1,918 to 16,941 ft3/s. The daily range experienced during the year was from 2,009 to 17,530 ft3/s. With the exceptions of Measurements Nos. 63, 64, and 68, all measurements confirmed the weighted AVM discharge within 4.61 percent of the measured discharge.

The AVM discharges computed during the discharge measurement are weighted to adjust for change in discharge during the measurement. The procedure for weighted is provided in the Quality Assurance Plan (REV. 11/13/92). The printout results of weighted discharge for each measurement is attached.

An explanation for Measurement No. 63 for being +5.74% difference is because it was abbreviated measurement of only 13 verticals from a single boat using only .2 and .8 method. Also the AVM discharge per section went from -17.9% to +21.4% difference to the discharge measured in 40 minutes.

An explanation for Measurement No. 64 for being +9.62% difference is because it was noted on the measurement that the field people had to change current meter about a third of the way through the measurement because of problems. Comparing the velocities for the sections prior to the meter change are consistently lower than the AVM. The velocities for the sections after the meter change compare favorably with the AVM. Although the measurement took 1 3/4 hours to make, the AVM discharges were relatively steady except during the last two sections where the discharge increased by 43.9% compared to the measured or 31.3% to the total weighted AVM discharge.

An explanation for Measurement No. 68 for being +5.1% difference is because although the AVM discharge per section only changed by 459 cfs during the measurement, this change at the range of discharge measured amounts to a 19.4% difference. This fluctuation in AVM discharge exceeded the 5% difference to the measured for 57% of the measurement and was up and down throughout the measurement. Actual flow condition during the measurement for the purpose of making a discharge measurement were unsteady.

Discharge Measurement No. 67 was made approximately 4.3 miles upstream of gage off of the downstream side of Lemont Road Bridge due to high velocities and low stages. The AVM discharges used to compute a weighted discharge were time adjusted for travel time of the flood wave using the following equation.

$$t = l / (1.3 * v)$$

where t = time of travel of flood wave between QM section and control (gage) in

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seconds

l = length of reach between measuring section and control (gage) in feet
v = mean velocity of QM in feet/sec

All measurements except No. 63 were made with the .2, .6, and .8 method to obtain point velocities in the verticals. Mean velocity for each vertical was computed in the following manner:

$$v(avg) = [((v(.2) + v(.8)) / 2) + v(.6)] / 2$$

DISCHARGE.--Discharge was computed within "ADAPS" using a velocity-velocity rating (No. 2) and a stage-area rating (No. 1) except for periods of no records or when less than 80 AVM readings were available in any given day. The periods of no records or less than 80 AVM readings per day are March 27, April 20-24 and May 31 to June 3. Estimated daily discharges for these periods were determined from the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) records for the Lockport Dam which were adjusted based on a regression equation developed by the Illinois District, U.S.G.S. See report "Discharge and Regression Analyses for Acoustic Velocity Meter Data for Chicago Sanitary and Ship Canal at Romeoville, Illinois", by C.S. Melching and K.A. Oberg.

VELOCITY-VELOCITY RATING.--Mean Channel Vel. = 0.92 X (Mean AVM Vel.)

STAGE-AREA RATING.--Channel Flow Area = (GH X 162) + 251.0

REMARKS.--AVM discharge records are good except for periods of no record, which are fair.

Written by: D.P. Morgan, June 29, 1992
Revised by: D.P. Morgan, May 19, 1993
Checked by: J.J. Duncker, May 27, 1993

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STATION ANALYSIS
ILLINOIS DISTRICT, U.S.G.S.

EQUIPMENT.--A Ferranti O.R.E. Inc. Accusonic Flowmeter Model 7410, hereafter referred to as an acoustic velocity meter (AVM), is used to collect gageheight and velocity record and to compute discharge. Velocity data are collected with 4 pairs of ultrasonic transducers; gage-height data is collected with a vertically mounted ultrasonic transducer.

Other equipment housed in a 8' x 8' concrete block shelter includes: a manometer which was used as the primary gage-height record and to check AVM gage-height readings; A CR10 datalogger, which is used to record AVM and manometer data; a printer, which also records AVM data; a telephone connected to the CR10 modem system on which the gage may be called for readings; a Data Collection Platform (DCP); an air conditioner and electric heater. The equipment is powered by AC current and is secured by an eight foot high cyclone and barbed-wire fence and an alarm system which is connected to the Romeoville Police Department.

The outside gage is a staff gage mounted to the canal wall in a natural niche where the uplooking gage-height assembly for the AVM and manometer orifice is located.

AVM RECORD.--The AVM furnished satisfactory record throughout the water year, except as follows: April 17 to 21 due to a barge hitting uplooking assembly and pulling out submarine cables for west (right) transducers; July 2 to 6 due to the AVM being hit by lightning. For the periods of no CR10 datalogger record and at other times when the CR10 datalogger failed to record AVM record, the Decwriter AVM printouts were used to fill in the gaps.

VELOCITY RECORD: The parameters for path lengths, path angles, and path elevations were correct in the AVM for the entire year. This information is required in order to compute velocity and discharge correctly. The equations in the AVM are not the official equations for computing discharge record, however, they do provide useful provisional "real-time" information to the cooperator.

Path length, path angle and path elevation are as follows:

Path	Length	Angle	Cosag	Elevation
upper	236	44.5	0.713	16.51
middle	236	44.5	0.713	12.26
x-path	235	44.0	0.719	13.16
lower	236	44.5	0.713	8.28

On April 24 a barge hit and destroyed the upstream main three (upper, middle and lower) transducer assembly. The assembly was replaced on April 29. On May 22 upper, middle and lower paths were shut off in order to pull up the downstream main three transducer assembly to replace the lower transducer. Also during the period of August 7 to 25 the upper, middle and lower paths would cut out from sunset to sunrise, but would

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work fine during daylight hours. During these periods of no upper, middle and lower velocities the x-path was working satisfactory to compute an average AVM velocity.

Using "PLOTWAT" within "ADAPS" all working path velocities were compared graphically to one another and any bad velocity values were deleted from the original Prime datalogger files. These files were used to input the velocity record into ADAPS. Once all the bad velocities were deleted from the Prime datalogger files a computer program on the Prime Mini Computer was used to compute an average AVM velocity using the following relationships:

Mean AVM Vel. = (Vel-U + Vel-M + Vel-X + Vel-L)/4 if all four paths are working, or

If all four paths are not working then the mean AVM velocity is computed by first correcting each working path velocity by the appropriate (Mean AVM Vel)/(path velocity) ratio and then taking their arithmetic mean. The correction ratios are listed below:

(Mean AVM Vel)/(Vel-U) = 0.967
(Mean AVM Vel)/(Vel-M) = 0.990
(Mean AVM Vel)/(Vel-X) = 1.003
(Mean AVM Vel)/(Vel-L) = 1.049

These new relationships were determined by C.S. Melching and L.C. Schideman by using SAS programs on Data General Workstation Computer. The results of this analysis can be found in a folder marked "Velocity Rating" in the Romeoville file cabinet.

GAGE-HEIGHT RECORD: The uplooking gage-height transducer did not provide satisfactory gage-height record during the following periods: April 17 to May 14 due to a barge hitting the uplooking assembly and assembly gone; May 21 due to maintenance; June 17 and June 19 to July 8 due to uplooking transducer malfunction. There were also other periods of time when the uplooking gage-height would for no reason calculate gage-height a foot or more off in either direction for short periods of time and then come back on to the correct gage-height on its own. Because of these random occurrences of improper gage-heights the valid manometer gage-height record collected during the water year was used to compute discharge in lieu of the AVM uplooking gage-height record.

MANOMETER GAGE-HEIGHT RECORD: The manometer furnished satisfactory record throughout the water year, except as follows: December 23 to January 13 due to the potentiometer going bad; April 15, July 2 to 6 due to manometer malfunction. During periods of no manometer gage-height record the AVM uplooking gage-height was used. The AVM uplooking gage-height was inputted into the same DD as the manometer gage-height and is stored without any tag following the value when you do a unit-value

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retrieval.

DATUM CORRECTIONS.--

	DATE	FOUND	LEFT	Remarks
Levels	11-01-90	-----	-.001'	Established staff gage
Levels	06-05-91	-----	------	Established RPs for Transducer assemblies

No datum corrections were warranted during the water year.

VELOCITY CORRECTIONS.--No correction factors were warranted during the water year.

GAGE-HEIGHT CORRECTIONS.--Manometer gage-heights were corrected to the outside gage due to manometer / potentiometer drift as shown on attached ADAPS printout of gage-height corrections, based on gage inspections during the year. Whenever possible an average gageheight readings (during QM's) were used to determine correction factors due to the stage elevation fluctuation in the canal.

RATING.--Four conventional discharge measurements, Nos. 70-74D, and one series of Acoustic Doppler Meter measurements (June 26) are available to verify the AVM discharges during the 1992 water year. These measurements range from 2,297 to 3,977 ft3/s. The daily range experienced during the year was from 2,077 to 10,650 ft3/s. With the exceptions of Measurements No. 71 all measurements confirmed the weighted AVM discharge within 4.5 percent of the measured discharge.

The AVM discharges computed during the discharge measurement are weighted to adjust for change in discharge during the measurement. The procedure for weighted is provided in the Quality Assurance Plan (REV. 05/19/93). The printout results of weighted discharge for each measurement is attached.

An explanation for Measurement No. 70 for being +2.78% difference and Measurement No. 71 for being -22.78% difference is as follows: During both measurements the AVM discharges indicate flow conditions were unsteady. During measurement No. 70 the fluctuation in AVM discharge during the last third went from 2656 cfs up to 4291 cfs and back down to 1940 cfs and that during the first two thirds the AVM discharge was approximately 15.7% less than measured. Because of this large change in AVM discharge a check measurement was made. The fluctuation in AVM discharge during measurement No. 71 was less but went from 1686 cfs up to 2454 cfs back down to 1790 cfs and was consistently less than measured. The measured discharge between the two measurements were within 4.2% of each other and verify each other. The last third of measurement No. 70 compensates the first two thirds and because of the unsteady flow condition at these low flow conditions would be hard to measure correctly and any

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change in flow would be significant.

No analytical procedures have been established yet for acoustical doppler meter (ADCP) measurements but provisional analysis shows that the velocities and discharges measured by the ADCP compare favorable with the AVM.

All conventional measurements were made with the .2, .6, and .8 method to obtain point velocities in the verticals. Mean velocity for each vertical was computed in the following manner:

$$v(avg) = [((v(.2) + v(.8)) / 2) + v(.6)] / 2$$

DISCHARGE.--Discharges were computed within "ADAPS" using a velocity-velocity rating (No. 2) and a stage-area rating (No. 1) except for periods of no record or when less than 80 AVM readings were available in any given day. The periods of no record or less than 80 AVM readings per day are April 17 to 21 and July 2 to 6. Estimated daily discharges for these periods were determined from the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) records for the Lockport Dam which were adjusted based on a regression equation developed by the Illinois District, U.S.G.S. See report "Discharge and Regression Analyses for Acoustic Velocity Meter Data for Chicago Sanitary and Ship Canal at Romeoville, Illinois", by C.S. Melching and K.A. Oberg.

VELOCITY-VELOCITY RATING.-- Mean Channel Vel. = 0.92 X (Mean AVM Vel.)

STAGE-AREA RATING.-- Channel Flow Area = (GH X 162) + 251.0

REMARKS.--AVM discharge records are good except for periods of no record, which are fair.

Written by: D.P. Morgan, May 20, 1993
Checked by: J.J. Duncker, May 27, 1993

APPENDIX 5

Stability of the Measuring Section

There is some evidence that from time to time varying amounts of debris are accumulated and transported away from the vicinity of the measuring section. The purpose of this analysis is to find out the extent to which the stability of the mean bottom elevation of the channel is affected by these events.

The data for this analysis was compiled from discharge measurements made at the downstream side of the Romeoville Road bridge see table 1a. The area listed in the table is described by equation 1a

$$A = C * (Gh + X) \qquad (1a)$$

Where:

A is the cross-sectional area in square feet

Gh gage height in feet

X depth correction factor (departure from the zero of the gage at time of measurement)

C is equal to 162 (width of the channel)

Equation 1a can be used to compute X when A is known

$$X = A/162 - Gh \qquad (2a)$$

For example the depth correction factor at the time of the first measurement made on March 22, 1984 was X=4190/162-25.5 = 0.36 feet.

Values of X for the rest of the discharge measurements in the data set were computed and listed in table 1a.

Table 1a. Depth Correction X

Meas. No.	Date	Width	Gage Height	Area	Measured Discharge	AVM Discharge	Observed Velocity	Index X
1	22-Mar-84	163	25.50	4190	6400	6310	1.53	0.36
2	12-Jun-84	164	25.20	4170	3710	3591	0.89	0.54
3	29-Jun-84	164	24.60	4088	3400	2436	0.83	0.63
4	16-Oct-84	164	22.20	3660	7670	8477	2.10	0.39
5	25-Feb-85	164	23.40	3830	5770	6117	1.51	0.24
6	04-Mar-85	164	22.20	3640	17700	17908	4.86	0.27
7	04-Apr-85	164	22.40	3680	17900	17842	4.86	0.32
8	29-Aug-85	164	24.90	4110	3460	2685	0.84	0.47
9	17-Oct-85	164	25.00	4090	2550	1486	0.62	0.25
10	19-Nov-85	164	23.20	3800	6660	6383	1.75	0.26
11	20-Nov-85	163	22.20	3650	8510	8230	2.33	0.33
12	20-Dec-85	164	25.10	4160	2920	2675	0.70	0.58
13	10-Jan-86	164	25.00	4280	1360	944	0.32	1.42
14	04-Apr-86	164	25.10	4210	1880	1392	0.45	0.89
15	01-Jul-86	164	24.30	3970	5100	4827	1.28	0.21
16	14-Jul-86	164	24.70	4150	3050	2678	0.73	0.92
17	07-Aug-86	164	24.70	4090	4720	4134	1.15	0.55
18	22-Sep-86	164	24.70	4150	4400	2541	1.06	0.92
19	25-Sep-86	164	24.80	4080	4460	4389	1.09	0.39
20	03-Oct-86	164	21.80	3660	15800	15725	4.32	0.79
21	12-Dec-86	164	25.00	4170	3430	3275	0.82	0.74
22	26-Jan-87	164	25.00	4190	2850	2903	0.68	0.86
23	16-Mar-87	164	25.10	4180	1950	2180	0.47	0.70
24	07-Apr-87	164	25.00	4170	2430	2383	0.58	0.74
25	15-May-87	164	25.10	4190	3120	3114	0.74	0.76
26	19-Jun-87	164	24.30	4080	7300	6838	1.79	0.89
27	24-Jul-87	164	24.70	4110	3970	3992	0.97	0.67
28	17-Aug-87	164	20.90	3450	14700	14325	4.26	0.40
29	09-Oct-87	164	24.90	4140	2670	2689	0.64	0.66
30	15-Oct-87	164	24.80	4160	2930	2837	0.70	0.88
31	15-Oct-87	164	24.90	4170	2460	2116	0.59	0.84
32	15-Oct-87	164	25.10	4160	2660	2271	0.64	0.58
33	19-Oct-87	164	25.20	4180	2320	1983	0.56	0.60
34	19-Oct-87	164	25.20	4170	2550	1983	0.61	0.54
35	03-Nov-87	164	25.10	4150	2020	1993	0.49	0.52
36	23-Nov-87	164	24.90	4150	2810	2847	0.68	0.72
37	30-Dec-87	164	25.00	4140	2840	3803	0.69	0.56
38	12-Feb-88	164	25.50	4220	2080	2181	0.49	0.55
39	10-Jun-88	164	25.00	4160	4110	4181	0.99	0.68
40	27-Jul-88	164	25.20	4150	3010	2942	0.73	0.42
41	15-Sep-88	164	24.80	4100	5230	5228	1.28	0.51

Table 1a. Depth Correction X (continued)

Meas No.	Date	Width	Gage Height	Area	Measured Discharge	AVM Discharge	Observed Velocity	Index X
42	18-Nov-88	164	25.10	4210	4510	3810	1.07	0.89
43	13-Jan-89	164	25.30	4210	2580	2677	0.61	0.69
44	03-Mar-89	164	25.50	4220	2250	2401	0.53	0.55
45	05-Apr-89	164	25.60	4230	2560	2634	0.61	0.51
46	03-May-89	164	25.40	4140	2070	2233	0.50	0.16
47	01-Jun-89	164	21.20	3530	14400	14323	4.08	0.59
48	01-Jun-89	164	21.10	3550	15100	14209	4.25	0.81
49	18-Jul-89	164	24.70	4140	5480	5330	1.32	0.86
50	04-Aug-89	164	25.10	4140	4040	4090	0.98	0.46
51	12-Sep-89	164	24.70	4200	6010	5932	1.43	1.23
52	21-Nov-89	163	25.60	4170	2690	2804	0.65	0.14
53	21-Nov-89	163	25.60	4190	2890	2705	0.69	0.26
54	11-Jan-90	164	25.20	4200	2070	2319	0.49	0.73
55	11-Jan-90	164	25.10	4140	1990	2241	0.48	0.46
56	06-Mar-90	164	25.60	4260	2270	2046	0.53	0.70
57	06-Mar-90	164	25.50	4250	2700	2929	0.64	0.73
58	24-Apr-90	164	25.70	4220	2730	2746	0.65	0.35
59	11-Jul-90	164	25.60	4160	5450	5467	1.31	0.08
60	11-Jul-90	164	25.40	4180	5310	5362	1.27	0.40
61	20-Jul-90	164	20.70	3400	14400	13942	4.24	0.29
62	22-Aug-90	164	25.30	4150	5250	5082	1.27	0.32

Figure 1a Variation of Depth correction

x with Time - March 84 to Aug 1990

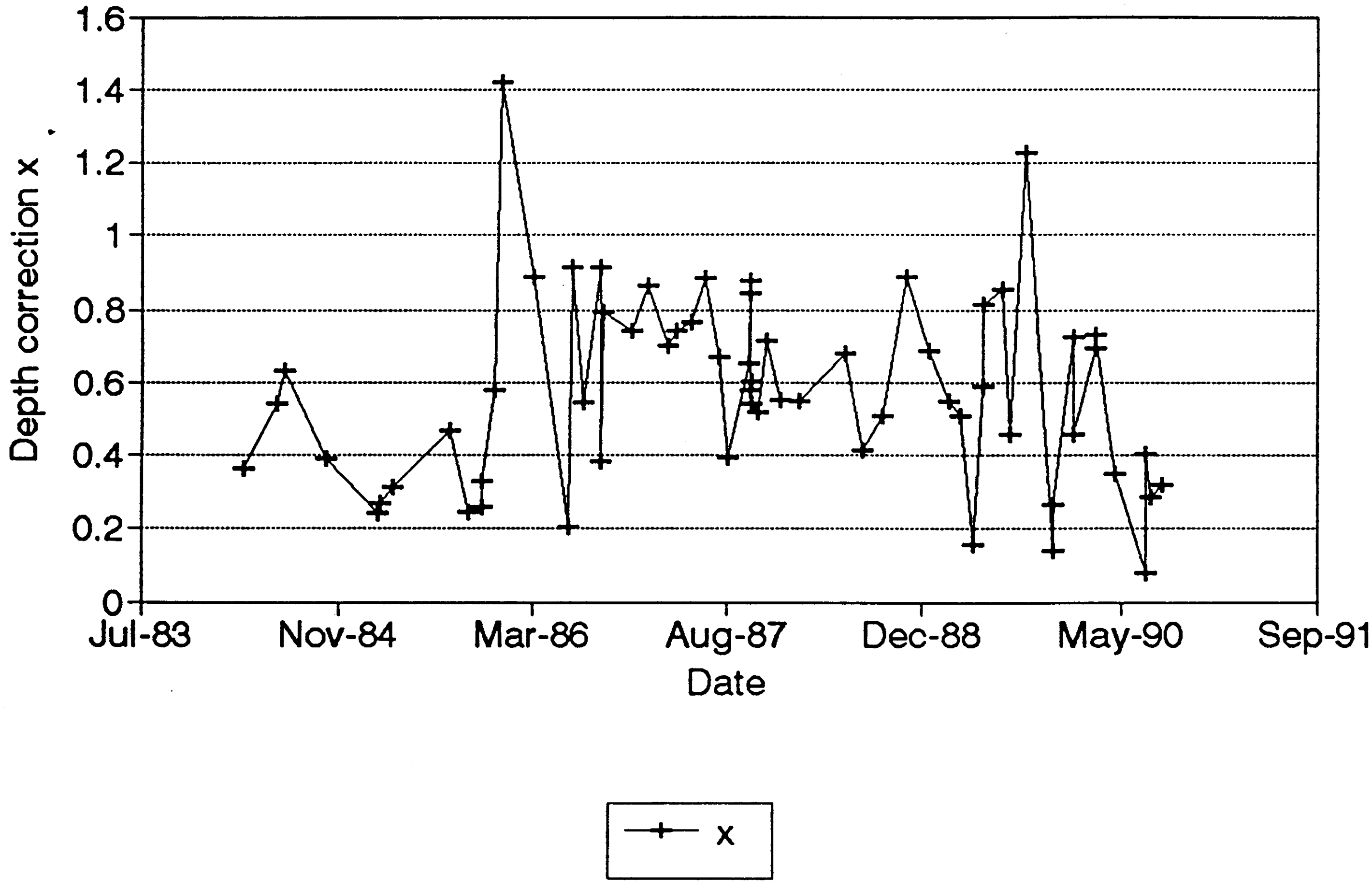

Figure 1a shows a plot of the X values vs. time for the period of record. Figure 1a is a graphic representation of the continuously changing mean bottom of the canal. It shows that during the period of record from March 1984 to August 1990 the mean bottom elevation ranged from about 0.2 to 1.4 feet. The mean for the period of record is about 0.60 feet below the zero of the gage. The results of this analysis indicate that it would be prudent to measure the cross section periodically to determine if a correction or shift to the rating is needed to account for changes in the mean bottom elevation.

APPENDIX 6

Appendix 6 is a USGS review (11/26/93) of a early draft chapter of the Third Technical Committee Report. Chapter 4, "AVM System at Romeoville", of the Committee's final report (August 1994) has been significantly revised, and, therefore, all references to pages, figures, and equations in the old draft chapter are inconsistent with the final report Chapter 4, pp 66-91.

United States Department of the Interior

TAKE PRIDE IN AMERICA

GEOLOGICAL SURVEY
Water Resources Division
102 E. Main St., 4th Floor
Urbana, Illinois 61801

November 26, 1993

Oscar Lara
118 South Clinton
Suite 210
Iowa City, Iowa 52240

Dear Oscar:

I have completed my review of your findings concerning the stage-area rating for the acoustic velocity meter (AVM) on the Chicago Sanitary and Ship Canal at Romeoville, IL. Please accept my apologies for the delay in sending my comments. After discussing the issue in-house, we felt that it would be wise to have it reviewed prior to sending it to you. This is part of the reason for the delay.

Your suggestion of a real-time adjusted rating is excellent for most rivers in the Midwest. However, I do not feel that it is warranted at this location due to the low sediment load, the bedrock channel, the general lack of bed material, and a number of practical reasons. The documents and plots attached provide more details and evidence to support this. I do believe that the cross-sections should be measured at least once per year. If these measurements indicate that it should be done more frequently, then we will do this and apply shifts to the stage-area rating accordingly.

Also enclosed are some of the plots of ADCP data that I promised to send to you. I gave these to the other committee members and the Chicago Corps when we last met. I have also enclosed a diskette with the mean daily stages and velocities for Romeoville for the 1989 and 1990 water years. Please refer to the station analyses to know which stage was used during these two water years. In general the manometer stage was used throughout the whole period, but there is a substantial portion of the 1989 water year when the AVM stage was used.

Thanks for sharing your comments with me. They are valuable and have caused us to give greater consideration to this aspect of the data being collected at the AVM. If you have any questions, please do not hesitate to call. Please let me know if you would like me to come out to Iowa City when you meet with the rest of the review committee.

Sincerely,

Kevin

Kevin A. Oberg
Chief, Network Operations Section

Enclosure

Comments on Technical Committee Findings regarding the Romeoville AVM Stage-area Rating

The following comments are provided after reviewing pages 23-37 of the draft report of the Third Technical Review Committee for Lake Michigan Diversion Accounting. This portion of the report concerns the stage-area rating for the acoustic velocity meter (AVM) on the Chicago Sanitary and Ship Canal (the Canal) at Romeoville, Illinois.

In general, the use of a time-variant stage-area rating technique, as defined by equation 13 on page 27, is a sound practice for most streams in the Midwest. If the physical nature of the canal was not so well-known and the chance of rapid changes in the channel cross-section so small, the time-variant stage-area rating would unquestionably be used at this site. The following subsections discuss (1) the physical characteristics of the Canal, (2) the reasons for the changes in depth correction factors determined from individual discharge measurements, (3) the possibility of a rating bias and the consequences, (4) the cross-section measurements made at Romeoville, and (5) the conclusions that can be made from the above.

Physical characteristics

A substantial portion of the Chicago Sanitary and Ship Canal was cut out of bedrock, including the reach up- and downstream of the AVM. The bedrock cut is more than 40 feet deep near the gage. The cut is rectangular as can be seen from the cross-section plots (figures 1-3). Sediment concentrations in the canal are small compared to nearby rivers and streams. During water years 1987 to 1990, the maximum sediment concentration measured in the canal was 133 milligrams per liter (mg/l), compared to 282 mg/l at Des Plaines River at Riverside, IL, 550 mg/l at Illinois River at Marseilles, and 843 mg/l at Du Page River at Shorewood. Most sediment concentrations measured during this period were less than 50 mg/l. During a recent study of the quality of bed sediments in the Upper Illinois River watershed, bed material samples were obtained from eight sites along the canal. At most of these locations, it was very difficult to get a sample of sufficient size for analysis, and in some cases no sample could be obtained.

Prior to 1989, the AVM transducers had to be serviced using a diver. Several USGS employees, including Jim Duncker, made dives at the AVM. Although visibility is extremely poor, Duncker was able to describe the bottom of the canal based on "feel". The bottom is covered with some loose gravel and pebbles, approximately the size of a quarter or smaller. Duncker believes that the layer of material covering the bedrock is shallow because there is little or no displacement when standing on the bottom. Near the sides, especially at the downstream transducers, there is some material that has accumulated because of slumping of the side walls.

Changing Depth Correction Factors

In the draft report, equation 14 (p. 27) is used to compute a depth correction factor using the known width of the canal (162 feet), the area from a discharge measurement, and the gage height of the measurement. The statement is made that the depth correction factor "defines the bed elevation at the time of the discharge measurement". This statement would be correct, assuming that stage is constant throughout the measurement. Further, it is important to stress that the bed elevation obtained represents only a single location in the reach, the velocity of which is measured by the AVM. Thus, the bed elevation that is computed using equation 14 is not directly comparable to the mean bed elevation used by the USGS in the slope-area rating that is computed for the reach defined by the upstream and downstream AVM transducer assemblies. Therefore, it is not appropriate to compare a stage-area rating based on discharge measurements at a single, non-constant, location in the reach and a stage-area rating computed for the reach using measured cross-sections at the upstream and downstream AVM transducers and a point halfway between the transducers.

There are also errors in the areas computed for each of the discharge measurements that need to be considered. These errors include equipment error (problem with sounding reel, and others) and human error. While neither of these are expected to be large, they will have an effect on the resulting value computed for the depth correction factor. Examination of depth correction factors for discharge measurements made on the same day (table 1) show that the values for the depth correction factor can vary as much as 0.38 feet from one measurement to the next.

Table 1.-- Discharge measurements made on the same day and the difference between depth correction factors computed for each pair of measurements.

Discharge measurement number	Difference in depth-correction factor (feet)
6-7	0.05
31-32	.30
33-34	.06
47-48	.12
52-53	.12
54-55	.27
56-57	.03
59-60	.38
70-71	.10

With this as a background, an alternative explanation for the apparent changes in the depth-correction factor with time is presented. Figure 10 of the draft report illustrates these changes well. Measurements 1-62 were all made from the upstream side of the Romeoville Road bridge. This approximately coincides with the location of the downstream cross-section. Measurement 67 was made from the Lemont Road bridge approximately 4 miles upstream. Measurements 63-66 and 68 were made using a boat, halfway between the downstream transducer assembly and the midpoint between the upstream and downstream transducer assemblies. Measurements 69-72 were all made halfway between the upstream and downstream transducer assemblies. As the measuring point moved further upstream, the mean depth increased.

This is supported by the discharge measurement results as well as the two sets of cross-section measurements made in June, 1991 and October, 1993. Both of these measurements show that the middle cross-section is the deepest of the three measured. This explains why the depth correction factor appears to increase with time. That is, the depth-correction factor changes with measurement location and measurement location changes with time. Figure 4 (which is a plot of the same data shown in Figure 10 of the committee's report) illustrates this. The mean depth correction factor for measurements 1 to 62 is 0.58 (table 2). This is not much different than the mean depth for the downstream cross-section (measured in June, 1991) of 0.41 feet. The mean depth-correction factor for measurements 69 to 72 is 2.10, which compares well to the mean depth for the middle cross-section (measured in June, 1991) of 2.09 feet.

Table 2.-- Mean depth correction factors for the corresponding set of discharge measurements.

Measurement numbers	1-62	63-72	63-68	69-72
Mean depth correction factor (feet)	0.58	2.09	1.41	2.10

Based on the discharge measurement data alone, it is evident that attributing the apparent change in the depth-correction factor over time to scour and fill is inappropriate. Rather most of the changes can be explained when the measurement location is taken into account. Furthermore, it is highly unlikely that significant scour and fill is taking place in the Canal, especially when one considers the physical conditions found in the Canal. Finally, it is also important to emphasize corrections probably should not be made to the AVM record based solely on data for one cross-section. Cross-sectional area from current-meter measurements can be used to indicate whether or not large changes in the area have occurred. However, they are only an indication, and should not be used to develop a stage-area rating for this station.

Fixed Rating Bias

The committee report states that use of a single, fixed rating for the entire period of record introduces a positive bias in the computation of flow areas. The possibility of such a bias is discussed in this section.

The single rating (Area=162*(Stage+1.55)) is used to compute the flow area for all of the AVM discharge records. It is assumed that little or no change in this relation occurs; this, however, is not very likely. Therefore, three questions may be asked. First, how much change is significant? Second, if a significant change is observed, what method should be used to phase in the changed stage-area rating? Finally, can one actually be sure that a positive bias results from use of the current rating, by comparing the rating to current-meter measurements?

It is possible that the use of a fixed rating could introduce a significant bias in the area obtained from the stage-area rating, if significant changes in the channel cross section were taking place over time. Although such changes seem rather doubtful at present, it is prudent to (1) determine whether the channel is changing significantly over time and (2) consider how to correct for any observed changes in the channel cross-section. At present, there is no method for phasing in a change in the stage-area rating over time (time shift). This is something that should undoubtedly be pursued. In order to address (1) above, cross-section measurements should be made at three cross-sections (minimum) once per year. In addition, a method for extracting depth data from acoustic Doppler current profiler (ADCP) data collected at Romeoville should be developed. These data could be used to determine when any large changes in the measuring section have taken place.

Because discharge measurements are made at only one location (cross-section), it is doubtful that results (such as the average depth or depth correction factor) can be extrapolated to the other cross-sections defined by the two main transducer assemblies. The depth of the channel bottom varies significantly from the downstream to the upstream transducer assemblies (tables 3 and 4).

If a positive bias did exist, it will not cause a bias in discharges computed for the entire period, as stated in the committee report. Discharges for the 1991 and 1992 water years were computed using the index-velocity method. In this method, a bias in the stage-area rating will not affect the discharges computed.

Cross-section measurements

Two sets of cross-section measurements have been made in the Canal at Romeoville, one set in June, 1991 and a second in October, 1993. Cross-sections were measured using a boat and sounding weight attached to a tagline stretched across the Canal at the upstream transducer assembly, the downstream transducer assembly, and halfway in between. While soundings were made, the base gage (staff gage) was read at regular intervals. Both sets of measurements were made in the same locations. Results of these cross-section measurements are shown in tables 3 and 4 and figures 1-3.

Based on these measurements, the mean bed elevation has decreased by 0.17 feet. This reflects a change of less than one percent of the depth at normal stage (25.50 feet). It is doubtful that this change is significant and no doubt reflects primarily the error in making such a cross-section measurement. No change in the stage-area rating should be made unless similar results can be obtained from a repeat measurement. The upstream cross-section changed the most, with the mean bottom elevation decreasing by 0.35 feet (tables 3 and 4). However, the October, 1993 measurements show that the shape of the cross-section has changed little in the two years between cross-section measurements (figs. 1 to 3).

Conclusions

Upon consideration of the physical characteristics of the Canal, the changes in measurement location with time, and the lack of a large change in the channel cross-section since 1991, the following conclusions are made.

1. There is little physical evidence to support the assumption that the bed elevation at Romeoville is changing in time because of scour and fill.

2. It is not appropriate to directly compare a stage-area rating developed from discharge measurements taken at one, non-constant location to a stage-area rating based on the mean bed elevation between the upstream and downstream transducer assemblies. The discharge measurements can, however, be used to approximately verify the stage-area rating developed using the measured channel cross-sections.

3. The depth-correction factor computed using equation 14 in the draft committee report verifies the stage-area rating developed using the mean bed elevation between transducer assemblies, when the changes in measurement location are accounted for.

4. The cross-sectional area computed for the discharge measurement often does not account for changes in stage throughout the measurement.

5. Channel cross-sections measured in October, 1993 show that little change in the three cross-sections has occurred. This is significant in that the flow in the Canal was much higher than normal for an extended period in the spring of 1992.

6. Channel cross-section measurements should be made each year in the Canal at Romeoville. This should be incorporated into the QA plan for the gaging station.

7. A method for phasing in significant changes in the stage-area rating should be developed and used as appropriate.

8. Discharges for the 1991 and 1992 water years were computed using the index-velocity method. In this method, a bias in the stage-area rating will not affect the discharges computed.

Figure 1.--Cross-section at upstream transducer assembly, Romeoville, IL

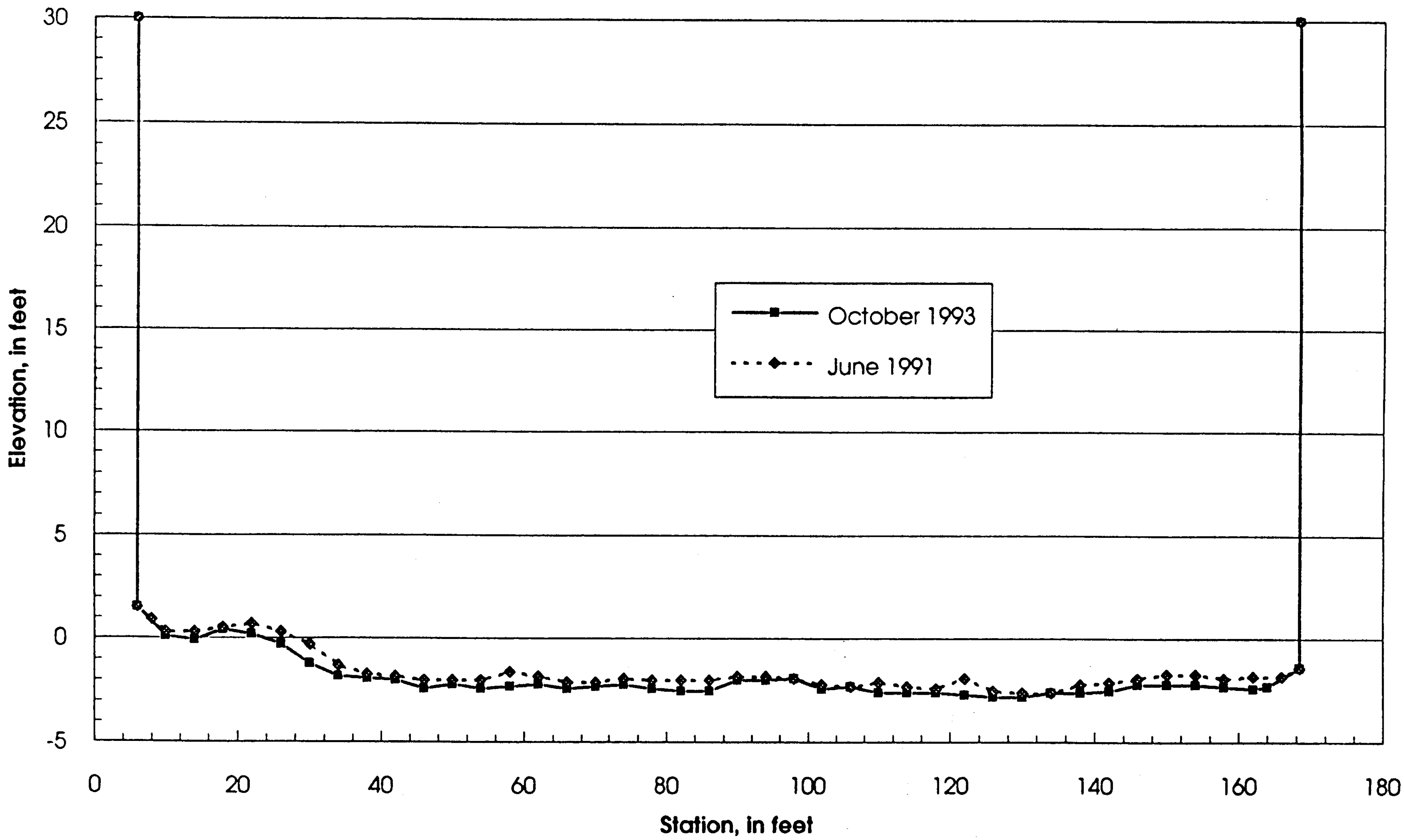

Figure 2.--Cross-section midway between upstream and downstream transducer assemblies, Romeoville, IL

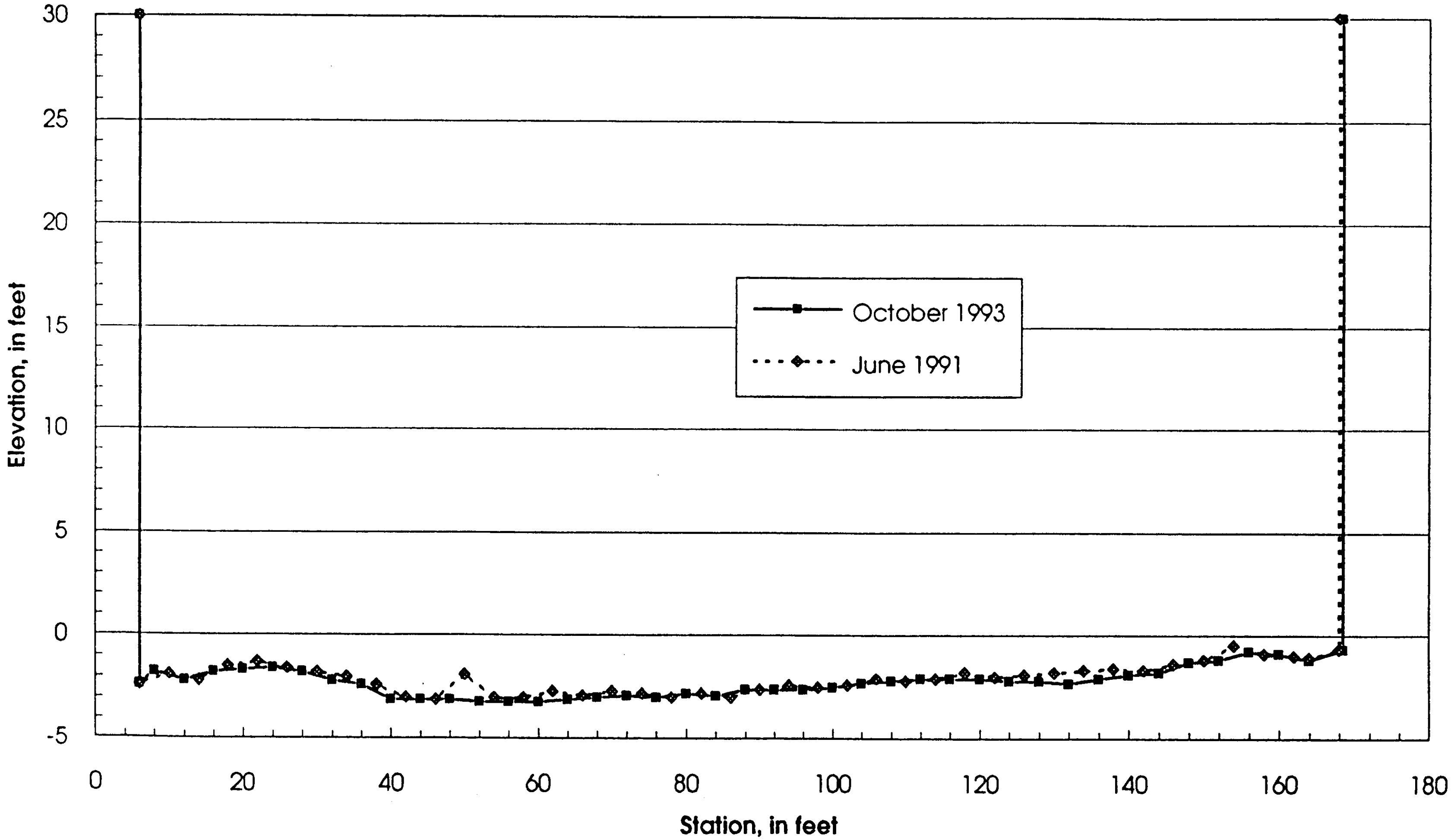

Figure 3.--Cross-section at downstream transducer assembly, Romeoville, IL

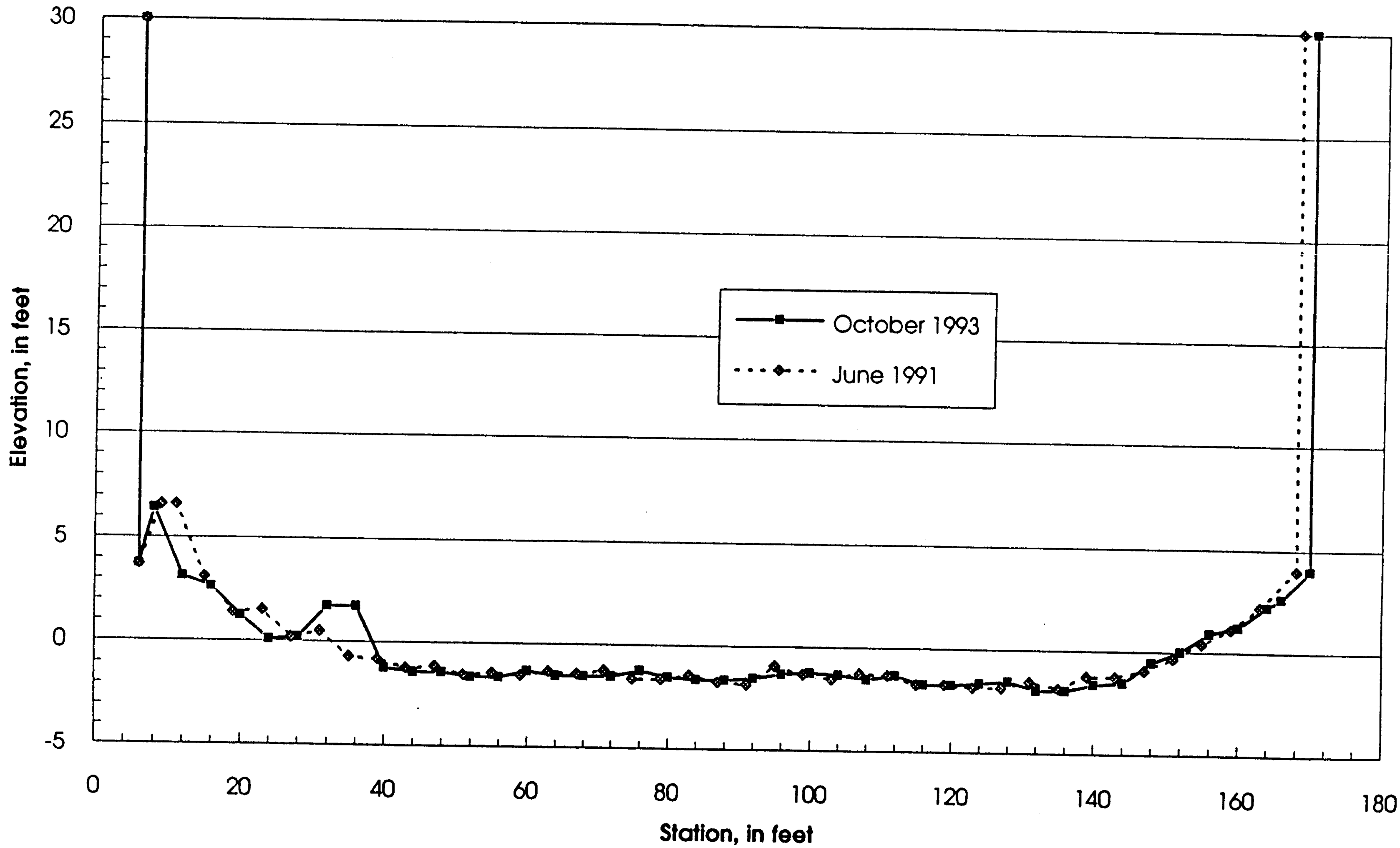

Figure 4.--Depth Correction Factor Computed for Discharge Measurements made at AVM at Romeoville, Illinois.

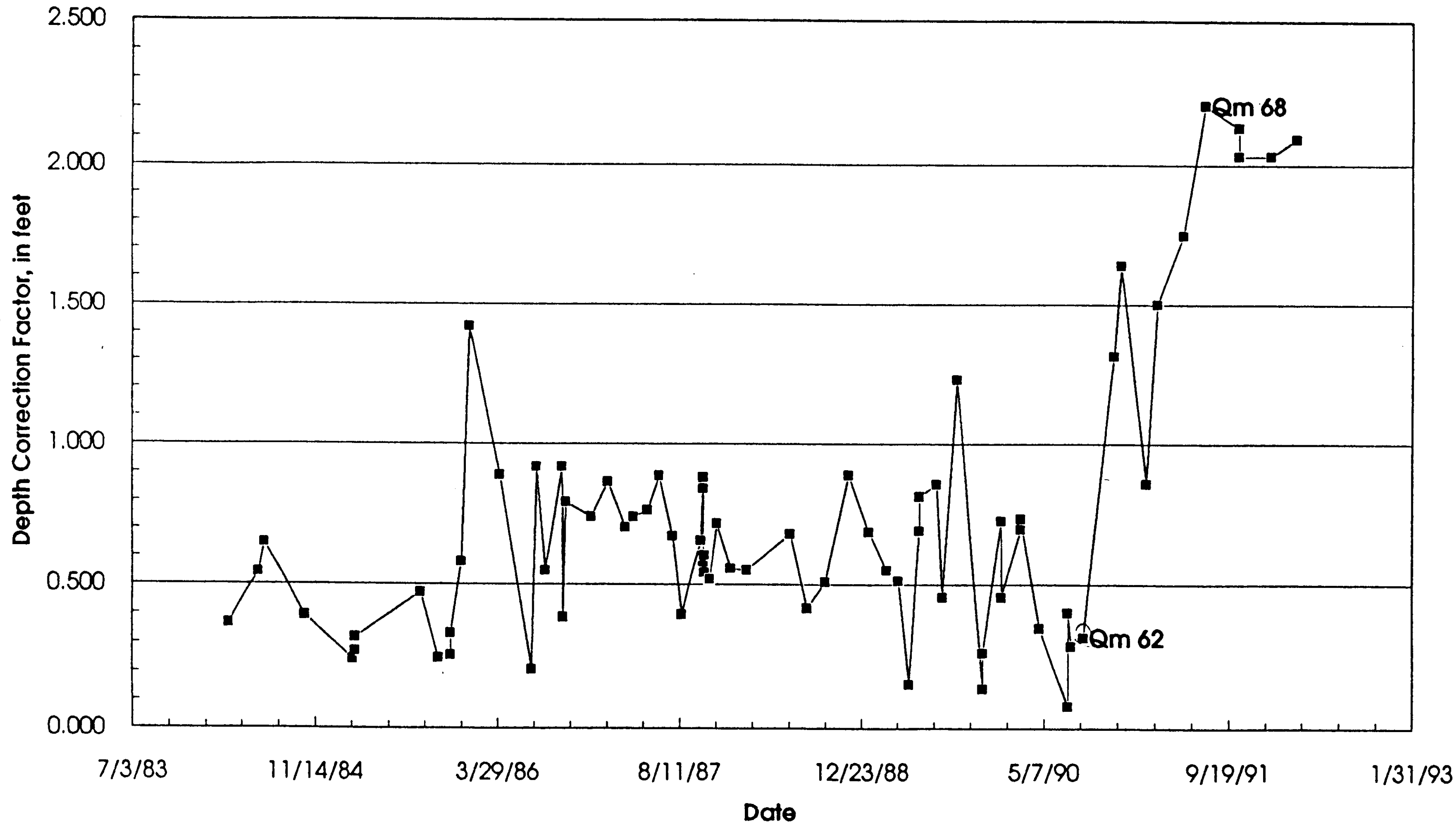

Table 3.–Calculated bottom-elevation data for the Chicago Sanitary and Ship Canal elevations measured at Romeoville, Ill., June 4 and 5, 1991

Upstream				Middle				Downstream			
Station	Elevation	Average Depth	Area	Station	Elevation	Average Depth	Area	Station	Elevation	Average Depth	Area
6	30			6	30			6	30		
6	1.5			6	-2.4			6	3.7		
8	0.9	1.2	2.4	10	-1.9	-2.15	-8.6	9	6.6	5.15	15.45
10	0.3	0.6	1.2	14	-2.2	-2.05	-8.2	11	6.6	6.6	13.2
14	0.3	0.3	1.2	18	-1.5	-1.85	-7.4	15	3.1	4.85	19.4
18	0.5	0.4	1.6	22	-1.3	-1.4	-5.6	19	1.4	2.25	9
22	0.7	0.6	2.4	26	-1.6	-1.45	-5.8	23	1.5	1.45	5.8
26	0.3	0.5	2	30	-1.8	-1.7	-6.8	27	0.2	0.85	3.4
30	-0.3	0	0	34	-2	-1.9	-7.6	31	0.5	0.35	1.4
34	-1.3	-0.8	-3.2	38	-2.4	-2.2	-8.8	35	-0.7	-0.1	-0.4
38	-1.7	-1.5	-6	42	-3	-2.7	-10.8	39	-0.8	-0.75	-3
42	-1.8	-1.75	-7	46	-3.1	-3.05	-12.2	43	-1.2	-1	-4
46	-2	-1.9	-7.6	50	-1.9	-2.5	-10	47	-1.1	-1.15	-4.6
50	-2	-2	-8	54	-3	-2.45	-9.8	51	-1.5	-1.3	-5.2
54	-2	-2	-8	58	-3	-3	-12	55	-1.4	-1.45	-5.8
58	-1.6	-1.8	-7.2	62	-2.7	-2.85	-11.4	59	-1.5	-1.45	-5.8
62	-1.8	-1.7	-6.8	66	-2.9	-2.8	-11.2	63	-1.3	-1.4	-5.6
66	-2.1	-1.95	-7.8	70	-2.7	-2.8	-11.2	67	-1.4	-1.35	-5.4
70	-2.1	-2.1	-8.4	74	-2.8	-2.75	-11	71	-1.2	-1.3	-5.2
74	-1.9	-2	-8	78	-3	-2.9	-11.6	75	-1.6	-1.4	-5.6
78	-2	-1.95	-7.8	82	-2.8	-2.9	-11.6	79	-1.6	-1.6	-6.4
82	-2	-2	-8	86	-3	-2.9	-11.6	83	-1.4	-1.5	-6
86	-2	-2	-8	90	-2.6	-2.8	-11.2	87	-1.7	-1.55	-6.2
90	-1.8	-1.9	-7.6	94	-2.4	-2.5	-10	91	-1.8	-1.75	-7
94	-1.8	-1.8	-7.2	98	-2.5	-2.45	-9.8	95	-0.9	-1.35	-5.4
98	-1.9	-1.85	-7.4	102	-2.4	-2.45	-9.8	99	-1.3	-1.1	-4.4
102	-2.2	-2.05	-8.2	106	-2.1	-2.25	-9	103	-1.5	-1.4	-5.6
106	-2.3	-2.25	-9	110	-2.2	-2.15	-8.6	107	-1.2	-1.35	-5.4
110	-2.1	-2.2	-8.8	114	-2.1	-2.15	-8.6	111	-1.3	-1.25	-5
114	-2.3	-2.2	-8.8	118	-1.8	-1.95	-7.8	115	-1.7	-1.5	-6
118	-2.4	-2.35	-9.4	122	-2	-1.9	-7.6	119	-1.7	-1.7	-6.8
122	-1.9	-2.15	-8.6	126	-1.9	-1.95	-7.8	123	-1.8	-1.75	-7
126	-2.5	-2.2	-8.8	130	-1.8	-1.85	-7.4	127	-1.8	-1.8	-7.2
130	-2.6	-2.55	-10.2	134	-1.7	-1.75	-7	131	-1.5	-1.65	-6.6
134	-2.6	-2.6	-10.4	138	-1.6	-1.65	-6.6	135	-1.8	-1.65	-6.6
138	-2.2	-2.4	-9.6	142	-1.7	-1.65	-6.6	139	-1.2	-1.5	-6
142	-2.1	-2.15	-8.6	146	-1.4	-1.55	-6.2	143	-1.2	-1.2	-4.8
146	-1.9	-2	-8	150	-1.2	-1.3	-5.2	147	-0.9	-1.05	-4.2
150	-1.7	-1.8	-7.2	154	-0.5	-0.85	-3.4	151	-0.3	-0.6	-2.4
154	-1.7	-1.7	-6.8	158	-0.9	-0.7	-2.8	155	0.4	0.05	0.2
158	-1.9	-1.8	-7.2	162	-1	-0.95	-3.8	159	1.1	0.75	3
162	-1.8	-1.85	-7.4	164	-1.1	-1.05	-2.1	163	2.2	1.65	6.6
166	-1.8	-1.8	-7.2	168	-0.7	-0.9	-3.6	168	4	3.1	15.5
168.5	-1.4	-1.6	-4	168	30			168	30		
168.5	30										
Mean Depth		Total		Mean Depth		Total		Mean Depth		Total	
-1.609		-261.4		-2.087		-338.1		-0.411		-66.65	

Average Depth for the three cross-sections -1.549

Table 4.–Calculated bottom-elevation data for the Chicago Sanitary and Ship Canal elevations measured at Romeoville, Ill., October, 12, 1993

Upstream				Middle				Downstream			
Station	Elevation	Average Depth	Area	Station	Elevation	Average Depth	Area	Station	Elevation	Average Depth	Area
6	30			6	30			6	30		
6	1.5			6	-2.4			6	3.7		
10	0.1	0.8	3.2	8	-1.8	-2.1	-4.2	8	6.4	5.05	10.1
14	-0.1	0	0	12	-2.2	-2	-8	12	3.1	4.75	19
18	0.4	0.15	0.6	16	-1.8	-2	-8	16	2.6	2.85	11.4
22	0.2	0.3	1.2	20	-1.7	-1.75	-7	20	1.2	1.9	7.6
26	-0.3	-0.05	-0.2	24	-1.6	-1.65	-6.6	24	0.1	0.65	2.6
30	-1.2	-0.75	-3	28	-1.8	-1.7	-6.8	28	0.2	0.15	0.6
34	-1.8	-1.5	-6	32	-2.2	-2	-8	32	1.7	0.95	3.8
38	-1.9	-1.85	-7.4	36	-2.4	-2.3	-9.2	36	1.7	1.7	6.8
42	-2	-1.95	-7.8	40	-3.1	-2.75	-11	40	-1.2	0.25	1
46	-2.4	-2.2	-8.8	44	-3.1	-3.1	-12.4	44	-1.4	-1.3	-5.2
50	-2.2	-2.3	-9.2	48	-3.1	-3.1	-12.4	48	-1.4	-1.4	-5.6
54	-2.4	-2.3	-9.2	52	-3.2	-3.15	-12.6	52	-1.6	-1.5	-6
58	-2.3	-2.35	-9.4	56	-3.2	-3.2	-12.8	56	-1.6	-1.6	-6.4
62	-2.2	-2.25	-9	60	-3.2	-3.2	-12.8	60	-1.3	-1.45	-5.8
66	-2.4	-2.3	-9.2	64	-3.1	-3.15	-12.6	64	-1.5	-1.4	-5.6
70	-2.3	-2.35	-9.4	68	-3	-3.05	-12.2	68	-1.5	-1.5	-6
74	-2.2	-2.25	-9	72	-2.9	-2.95	-11.8	72	-1.5	-1.5	-6
78	-2.4	-2.3	-9.2	76	-3	-2.95	-11.8	76	-1.2	-1.35	-5.4
82	-2.5	-2.45	-9.8	80	-2.8	-2.9	-11.6	80	-1.5	-1.35	-5.4
86	-2.5	-2.5	-10	84	-2.9	-2.85	-11.4	84	-1.6	-1.55	-6.2
90	-2	-2.25	-9	88	-2.6	-2.75	-11	88	-1.6	-1.6	-6.4
94	-2	-2	-8	92	-2.6	-2.6	-10.4	92	-1.5	-1.55	-6.2
98	-1.9	-1.95	-7.8	96	-2.6	-2.6	-10.4	96	-1.3	-1.4	-5.6
102	-2.4	-2.15	-8.6	100	-2.5	-2.55	-10.2	100	-1.2	-1.25	-5
106	-2.3	-2.35	-9.4	104	-2.3	-2.4	-9.6	104	-1.3	-1.25	-5
110	-2.6	-2.45	-9.8	108	-2.2	-2.25	-9	108	-1.5	-1.4	-5.6
114	-2.6	-2.6	-10.4	112	-2.1	-2.15	-8.6	112	-1.3	-1.4	-5.6
118	-2.6	-2.6	-10.4	116	-2.1	-2.1	-8.4	116	-1.7	-1.5	-6
122	-2.7	-2.65	-10.6	120	-2.1	-2.1	-8.4	120	-1.7	-1.7	-6.8
126	-2.8	-2.75	-11	124	-2.2	-2.15	-8.6	124	-1.6	-1.65	-6.6
130	-2.8	-2.8	-11.2	128	-2.2	-2.2	-8.8	128	-1.5	-1.55	-6.2
134	-2.6	-2.7	-10.8	132	-2.3	-2.25	-9	132	-1.9	-1.7	-6.8
138	-2.6	-2.6	-10.4	136	-2.1	-2.2	-8.8	136	-1.9	-1.9	-7.6
142	-2.5	-2.55	-10.2	140	-1.9	-2	-8	140	-1.6	-1.75	-7
146	-2.2	-2.35	-9.4	144	-1.8	-1.85	-7.4	144	-1.5	-1.55	-6.2
150	-2.2	-2.2	-8.8	148	-1.3	-1.55	-6.2	148	-0.5	-1	-4
154	-2.2	-2.2	-8.8	152	-1.2	-1.25	-5	152	0	-0.25	-1
158	-2.3	-2.25	-9	156	-0.8	-1	-4	156	0.9	0.45	1.8
162	-2.4	-2.35	-9.4	160	-0.9	-0.85	-3.4	160	1.2	1.05	4.2
164	-2.3	-2.35	-4.7	164	-1.2	-1.05	-4.2	164	2.2	1.7	6.8
168.5	-1.4	-1.85	-8.325	168.5	-0.7	-0.95	-4.275	166	2.6	2.4	4.8
168.5	30			168.5	30			170	4	3.3	13.2
								170	30		
Mean Depth		Total		Mean Depth		Total		Mean Depth		Total	
-1.955		-317.6		-2.258		-366.9		-0.422		-67.5	

Average Depth for the three cross-sections -1.723

APPENDIX 7

ROMEOVILLE AVM QUALITY ASSURANCE PLAN

Quality Assurance Plan for the Acoustic Velocity Meters in the Chicago Sanitary and Ship Canal at Romeoville, Illinois.

PURPOSE AND SCOPE

The purpose of this quality assurance plan is to provide procedures for the standardization and documentation of streamflow record for the Acoustic Velocity Meter (AVM) on the Chicago Sanitary and Ship Canal at Romeoville, Illinois, also referred to as Romeoville. Procedures will be presented for the collection, analysis, computation, and review of AVM records for Romeoville.

This plan is to be used as a guide to aid personnel responsible for AVM site inspections, discharge measurements, data collection and analysis of records at the AVM at Romeoville. The plan describes procedures to be followed and steps to be taken to insure the quality of the record for this site.

DOCUMENTATION

A log book will be maintained in the gage house to document all activities related to the operation and maintenance of the AVM. All problems, changes to equipment or procedures, observations, and conversations with colleagues and representatives from other agencies and manufacturers which relate to the operation of the AVM will be noted.

GAGE INSPECTIONS

During visits to the AVM, the following tasks should be performed and recorded in the log book.

1. All stage-gage readings shall be read and recorded - (wire-weight, manometer, float and AVM depth gage) and readings shall be read before, after, and at 2 minute intervals during each discharge measurement.

2. On a quarterly basis, 15-second AVM velocity and stage readings shall be recorded on the Decwriter for a period of five minutes. The results of this test including the number of successful readings for each path shall be recorded in the log book. This test will insure that consistent and reasonable velocities and stage readings are being recorded by the AVM.

3. All parameters (data stored in the AVM memory and related to path lengths, transducers, elevations, channel widths), shall be read and checked against a master list, which is kept in the gagehouse on a quarterly basis. The results of this check shall be recorded in the logbook. Under NO circumstances should these parameters be changed. These parameters relate to the specific physical characteristics of the site.

4. The 15-minute data, which is recorded on the Decwriter, should be scanned to insure readings are reasonable and path velocities are not anomalous.

DISCHARGE MEASUREMENTS

1. The project chief shall be in complete charge of all aspects of the discharge measurements. The main responsibility of the project chief during the measurement shall be to read and record the outside gage, manometer, float and the AVM gage heights every two minutes. There will be a pre-measurement meeting so that all personnel involved will know what to do and when to do it.

2. Discharge measurements will be made at the rate of 6 per year and should cover the range in discharge experienced at the site during the year.

3. Discharge measurements should be made during periods of minimal changes in discharge (i.e. minimal barge/boat traffic and changes in the gate openings at the dam 3 miles downstream). Possible variations in the flow should be checked by telephoning the Metropolitain Water Reclamation District of Greater Chicago (MWRDGC) Supervising Civil Engineer, Bill Eyre, of the General Division for Operation and Maintenance (312-751-5102).

4. Measurement time shall be minimized by having two boat crews measuring at the same time, starting from opposite ends of the section. Using a digitizer, full 40 second velocity reading times shall be used. Also, each boat crew shall have a working headset and appropriate current meter rating table as a backup to digitizer failure. The minimum sounding weight shall be 50 lbs and a 75 lbs sounding weight shall be in the boat in case it is needed. In case of high flow, measurements shall be made from the Lemont Road bridge (next bridge upstream) and shall use 100 lbs sounding weights.

5. Twenty-four verticals at predesignated stationing, with readings at .2, .6 and .8 will be made for each measurement. Starting and ending times shall be recorded on the measurement sheet for each vertical. Each vertical shall be complete and uninterrupted. In case of equipment failure or boat traffic that vertical will be restarted. The boat tagline shall be secured the same way each time (6 ft station at REW) so that the twenty-four verticals will be taken at the same locations each time discharge measurements are made. The twenty-four verticals will be taken at the following predetermined stations:

6	32	60	88	116	148
10	39	67	95	123	158
18	46	74	102	130	163
25	53	81	109	138	168

note: Stationing is in feet from the right edge of water at the canal wall (station 6 ft is located at REW and station 168 ft at LEW).

The equation for the mean velocity for each section is as follows:

$$v(avg) = [((v(.2) + v(.8)) / 2) + v(.6)] / 2$$

6. Appropriate information on the measurement face sheet for each crew shall be filled out (Susp., method coef., Hor. angle coef., Susp. coef., meter no., type of meter, meter ___ ft. above bottom of weight., spin test info, measurement rating, cross section info, flow, comp. by ______, and any additional remarks).

7. The AVM discharge during the discharge measurement shall be weighted based on data recorded during the discharge measurement. Intermediate watch times (ending time) at each measurement station shall be recorded on the measurement note sheet. One minute AVM stage, velocity, and discharge readings shall be recorded on the Decwriter. These recorded values shall then be used to compute the weighted AVM discharge using the following formula:

   Weighted AVM Q = sum[Qmeas x Qavm]/Qmeas(total)

   Where: Qmeas = the discharge measured in each sub-area(section).
   Qavm = the average AVM discharge recorded during the time that the section was measured.
   Qmeas(total) = the total discharge measured.

8. ALL measurements shall be checked against the AVM weighted discharge and if there is a discrepancy of more than five percent a complete check measurement will be made.

9. Discharge measurements can also be made using an acoustical doppler meter from one boat pulled across canal attached to tagline as mention above. This will become the preferred way to make measurements because one measurement can be made in 4 minutes, therefore a series of measurements can be made in the same time a single conventional boat measurement can be made. The tagline may not be used if the project chief deems it to be unsafe or if accurate measurements may be made without the aid of the tagline. The tagline will only be absolutely necessary during measurements of very low flows.

No field personnel shall leave the measuring stie until the project chief verifies that a check measurement is not required.

ROUTINE MAINTENANCE

1. Routine station levels shall be run every two years.
2. Levels shall be run to the transducers every two years or if changes to the transducer locations are made. Level notes shall include all relevant information including tape downs from the reference mark on the transducer mounting bracket to any reference mark on the PVC pipe and/or to each transducer. If any relevant measurements were not made at the time of the level run then the location where this information can be found shall be referenced in the level notes.
3. Transducer path lengths and angles shall be measured and remeasured if physical changes to the transducer locations are made.
4. Voltage on memory circuit boards (Ram and R. T. clock) shall be checked annually.
5. The AVM shall be serviced by the manufacturer annually as part of a service contract.
6. Telemetry (telephone) shall be operated and maintained to facilitate reception of daily real-time data and to minimize AVM problems.
7. The Sutron DCP will be operated and maintained by the Rock Island District (RID) Corps of Engineers. Any identified problems with the DCP or DCP data will be relayed to RID (Bill McCutcheon).

DATA ANALYSIS

1. The AVM data being recorded by the CR10 shall be entered on the computer and checked for anomalies.
2. Velocity and depth unit values shall be graphically plotted to identify possible anomalous data.
3. Discharge measurements shall be furnished to the cooperator (CHI - COE) on a monthly basis.
4. Official discharge records shall be computed using a velocity-velocity rating and a stage-area rating in ADAPS. The stage-area and velocity-velocity ratings are given by the following equations:

   Channel Flow Area = (GH X 162) + 251.0

   Mean Channel Vel. = 0.92 X (Mean AVM Vel.)

   where:

   GH = gage height, in feet
   Mean AVM Vel. = the mean AVM velocity if all four paths are working or
   = (Vel-U + Vel-M + Vel-X + Vel-L)/4

   note: If all four paths are not working then the mean AVM velocity is computed by first correcting each working path velocity by the appropriate (Mean AVM Vel)/(path velocity) ratio and then taking their arithmetic mean. The correction ratios are listed below:

   (Mean AVM Vel)/(Vel-U) = 0.967
   (Mean AVM Vel)/(Vel-M) = 0.990
   (Mean AVM Vel)/(Vel-X) = 1.003
   (Mean AVM Vel)/(Vel-L) = 1.049

5. On at least an annual basis, the relation between measured discharge and the AVM weighted discharge shall be examined to ensure that there is no consistent bias.
6. An extensive and detailed station analysis shall be written every water year.

MISSING AVM RECORD

Missing record shall be estimated by using regression equations based on MWRDGC-reported flows at Lockport. The regression equations used to estimate missing record are documented in the report "Discharge and Regression Analyses for Acoustic Velocity Meter Data for Chicago Sanitary and Ship Canal at Romeoville, Illinois", by C.S. Melching and K.A. Oberg.

RECORD REVIEW

ROMEOVILLE AVM QUALITY ASSURANCE PLAN

1. The AVM discharge records shall be reviewed annually by an independent district reviewer.

2. A comparison shall be made annually between the AVM computed daily discharges and those estimated using the regression with Lockport records.

3. Because this discharge record is being computed to meet specific legal requirements, the agencies involved shall meet annually to review and agree upon the data. A technical committee composed of representatives from USGS, CHI-COE, and IDOT-DWR shall review and document this record annually.

Written by: D.A. Stedfast, August 15, 1991
Checked by: D.P. Morgan, August 15, 1991
Revised by: D.P. Morgan, May 19, 1993

APPENDIX 8

Lake Michigan Diversion Accounting Third Technical Committee
Workshop Number 1 Tentative Agenda

US Army Corps of Engineers, Chicago District
Suite 600, 111 North Canal Street
Chicago IL

Monday, 22 February 1993

1 to 4 pm NCC and Committee meeting in Engineering Conference Room

- Introductions to District Engineer, Chief of Engineering Division, and others
- Review of Scope of Work
- Goals
- Discussion

Tuesday, 23 February 1993

Field trip to AVM, WSW treatment plant, McCook Quarry, Mainstream Pump Station, and other sites

Wednesday, 24 February 1993

Presentations by other interested parties in Main Conference Room

- 8:30 am Welcome by DE, Introductions
- 9:00 am Overview of Diversion Accounting
- 9:30 am Illinois State Water Survey
- 10:00 am Break
- 10:15 am Metropolitan Water Reclamation District of Greater Chicago
- 11:30 am Illinois Department of Transportation
- noon Lunch Break
- 1:00 pm United States Geologic Survey
- 3:00 pm Discussions

Thursday, 25 February 1993

Morning field trip to Des Plaines pump station, O'Hare TARP, and Chicago Lock

Afternoon presentation on diversion accounting procedures in Engineering Conference Room

- 1:00 pm Data sources and problems
- 1:45 pm Modeling procedures
- 3:30 pm Discussions

Friday, 26 February 1993

Meeting of Committee and NCC for review and summary with scheduling of topics for Workshop Number 2 in Engineering Conference Room

Lake Michigan Diversion Accounting
Third Technical Committee
Second Workshop
Tentative Schedule

Monday, 3 May 1993

1:00 pm — Discussion of Agenda
Engineering Division Conference Room

1:30 — Lakefront Leakage Measurements, Kevin Oberg USGS
Engineering Division Conference Room

4:00 pm — Adjourn for day

Tuesday, 4 May 1993

9:00 am — Leave Chicago District offices for Chicago Lock

9:15 am — Arrive Chicago Lock

Demonstration of Acoustic Doppler Current Profiler (ADCP) flow meter and dye study at Chicago Lock

Leave Chicago Lock for Chicago District offices when Committee satisfied.

Adjourn for day

Wednesday, 5 May 1993

8:00 am — Discussion of future lakefront leakage measurements (if not covered on Tuesday)
Planning Division Conference Room

10:00 am — Status of Second Technical Committee recommendations
Planning Division Conference Room

11:30 am — Lunch

12:30 pm — Review of Diversion Accounting Process
Engineering Division Conference Room

4:00 pm — Adjourn for day

Thursday, 6 May 1993

8:00 am — Review of Diversion Accounting Process
Planning Division Conference Room

11:30 am — Lunch

12:30 pm — Review of Diversion Accounting Process
Engineering Division Conference Room

3:30 pm — Scheduling of Third Workshop
Engineering Division Conference Room

4:00 pm — Adjourn until next workshop

Lake Michigan Diversion Accounting
Third Technical Committee
Schedule for Third Workshop

Monday, 19 July 1993

1:00 PM	Discussion of week's events.
1:30 PM	Discuss events since last meeting.
2:00 PM	Discuss technical issues raised by the committee.
3:30 PM	Adjourn.

Tuesday, 20 July 1993

8:30 AM	Trip to Wilmette. Visit a new precipitation gage site.
11:30 AM	Lunch on the road.
12:30 PM	Trip to O'Brien Lock.
3:30 PM	Adjourn.

Wednesday, 21 July 1993

8:00 AM	Discuss technical issues (as listed by Committee).
11:30 AM	Lunch
12:30 PM	Continue technical discussion, if needed. Discuss issues (QA and Master Plan).
3:30 PM	Adjourn.

Thursday, 22 July 1993

8:00 AM	USGS discussion of Chicago Lock flow measurements. Discussion of Des Plaines flow measurements. Discussion of AVM index velocity & rating.
11:45 AM	Lunch
12:30 PM	Summary and wrap-up.
1:00 PM	Technical Committee (members only) meeting

Schedule for Meeting Rooms

Monday, 19 July 1993		
	Engineering Conf. Room	10:30 am to 4:30 pm
Tuesday, 20 July 1993		
	Engineering Conf. Room	7:30 am to 9 am
	Rental van.	8 am to 5 pm
Wednesday, 21 July 1993		
	Main Conf. Room	7:30 am to 12:30 pm
	Engineering Conf. Room	12:30 pm to 4:30 pm
Thursday, 22 July 1993		
	Main Conf. Room	7:30 am to 11:30
	Engineering Conf. Room	Noon to 4:30 pm