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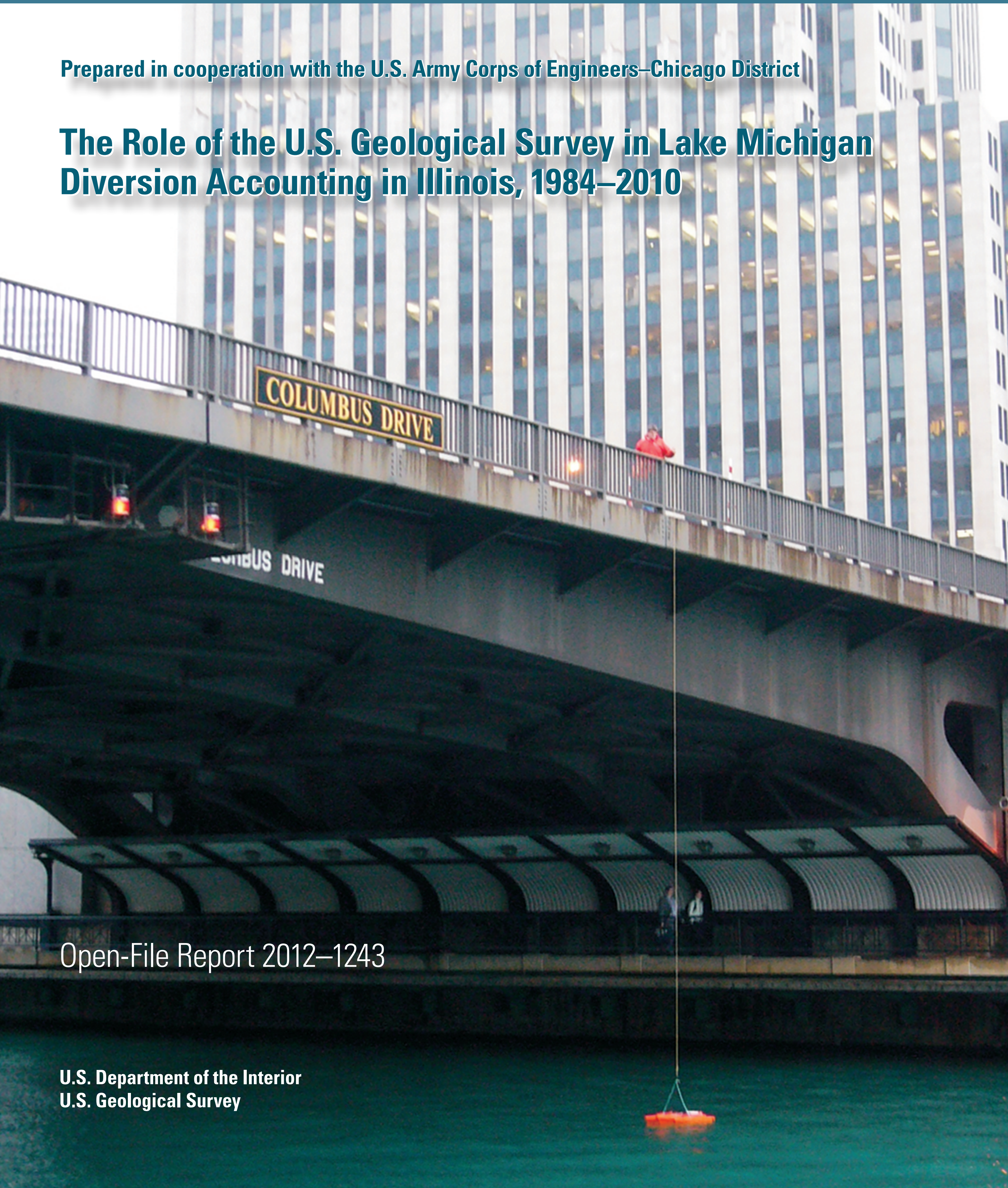
The Role of the U.S. Geological Survey in Lake Michigan Diversion Accounting in Illinois, 1984–2010



Open-File Report 2012–1243

U.S. Department of the Interior
U.S. Geological Survey

Cover photo. U.S. Geological Survey personnel making an acoustic Doppler current profiler discharge measurement on the Chicago River at Columbus Drive at Chicago, Illinois.

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By Kevin K. Johnson, James J. Duncker, and P. Ryan Jackson

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Conversion Factors and Vertical Datum

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter (cm)
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
meter (m)	1.094	yard (yd)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the Chicago City Datum (CCD), the National Geodetic Vertical Datum of 1929 (NGVD 29), and the North American Vertical Datum of 1988 (NAVD 88).

Water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.

Abbreviatons

ADCP	acoustic Doppler current profiler
ADVM	acoustic Doppler velocity meter
AVM	acoustic velocity meter
BM	Bench Mark
CAWS	Chicago Area Waterway System
CCD	Chicago City Datum
CD	Chicago District
CW	controlling works
CRCD	Chicago River at Columbus Drive
CRCW	Chicago River Controlling Works
CROLD	Calumet River below O'Brien Lock and Dam
CSSC	Chicago Sanitary and Ship Canal
DCP	data–collection platform
GPS	global positioning system
HADCP	Horizontal Acoustic Doppler Current Profiler
Hz	Hertz
IL WSC	Illinois Water Science Center
I and M	Illinois and Michigan
LMDA	Lake Michigan Diversion Accounting
LMO-6	Lake Michigan Outflow report 6
MOU	Memorandum of Understanding
MWRDGC	Metropolitan Water Reclamation District of Greater Chicago
NAVD	North American Vertical Datum
NGVD	National Geodetic Vertical Datum
NGS	National Geodetic Survey
NSC	North Shore Channel
OSW	Office of Surface Water
QA	quality assurance
RTK	real–time kinematic
SG	sluice gate
TIN	triangulated irregular network
TLL	turbine, lockage, and leakage
U of I	University of Illinois
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WSC	Water Science Center
WCW	Wilmette Controlling Works

Acknowledgments

The authors would like to thank the many agencies and personnel who have contributed to flow monitoring at the Chicago Sanitary and Ship Canal and to the overall understanding of the Chicago Area Waterway System. These agencies and personnel include, but are not limited to, the U.S. Army Corps of Engineers–Chicago District, the U.S. Army Corps of Engineers–Rock Island District, the Metropolitan Water Reclamation District of Greater Chicago, the State of Illinois–Department of Natural Resources, and the members of the Lake Michigan Diversion Accounting Technical Review Committee.

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Abstract

The State of Illinois' annual withdrawl from Lake Michigan is limited by a U.S. Supreme Court decree. The U.S. Geological Survey (USGS) is responsible for monitoring flows in the Chicago area waterway system (CAWS) as part of the Lake Michigan Diversion Accounting (LMDA) overseen by the U.S. Army Corps of Engineers, Chicago District. Every five years, the USGS streamgage practices in the CAWS are reviewed by a committee of practicing engineers and academics to ensure that the best engineering practices are implemented in accordance with the U.S. Supreme Court decree and as part of LMDA. This report provides a perspective on the role of the USGS in LMDA from 1984 to 2010 including the responses to the review committees. Six technical review committees have been convened by the U.S. Corps of Engineers to evaluate the key components of LMDA especially the USGS streamgages within the CAWS. Any changes in streamgaging practices at CAWS gaging stations require detailed analysis to ensure the change will not adversely affect the ability of the USGS to accurately monitor flows.

Introduction

Since the completion of the Illinois and Michigan (I and M) Canal in 1848, water has been diverted from the Lake Michigan Basin into the Illinois River Basin through man-made waterways. The I and M Canal was built primarily as a connecting waterway for the transportation of commodities and people between the Great Lakes and the Mississippi River. Rapid population growth of the city of Chicago in the late 1800's spurred the construction of a larger canal system connecting the two basins that would serve both transportation and sewage-disposal functions. Completion of the Chicago Sanitary and Ship Canal (CSSC) in 1900 and subsequent expansion of the canal system to include the North Shore Channel (NSC) (1910) and the Calumet-Sag Channel (1922) gave the Chicago area a waterway that served its transportation and wastewater needs (fig. 1).

The diversion of Lake Michigan water into the Illinois River Basin has been challenged in legal settings since its inception (Naujoks, 1946). A series of legal rulings have established the amount of Lake Michigan water that the State of Illinois is allowed to divert each year (Naujoks, 1946). The annual amount of diversion varied with the different legal rulings, which led up to the 1967 U.S. Supreme Court Decree (modified in 1980), that limits the diversion to a mean annual flow of 3,200 cubic feet per second (ft^3/s).

Purpose and Scope

The information in this report is based upon data from archived records from the U.S. Geological Survey (USGS)–Illinois Water Science Center (IL WSC) and the U.S. Army Corps of Engineers (USACE)–Chicago District (CD). Flow data from five USGS streamflow-gaging stations located on the Chicago Area Waterway System (CAWS) were used to define the complex hydraulic setting of the waterway.

This report describes flow monitoring in the CSSC and other parts of the CAWS for the purpose of Lake Michigan Diversion Accounting (LMDA). The report includes (1) a history of the USGS involvement in LMDA flow monitoring following the 1980 U.S. Supreme Court Decree, (2) descriptions of USGS acoustic velocity streamflow-gaging stations, and (3) a summary of data collected.

Background

Legal Setting for Diversion Accounting in the Chicago Sanitary and Ship Canal

In 1930, a U.S. Supreme Court Decree mandated that Lake Michigan diversion flows be computed based upon discharge measurements at the control structures at Lockport, Illinois. Sluice gate and turbine settings at the Lockport Powerhouse and Lockport Controlling Works, and the number of lockages per day at the Lockport Lock were used to compute an overall mean daily flow and mean annual flow. A 1967 U.S. Supreme Court Decree (appendix 1) set the allowable

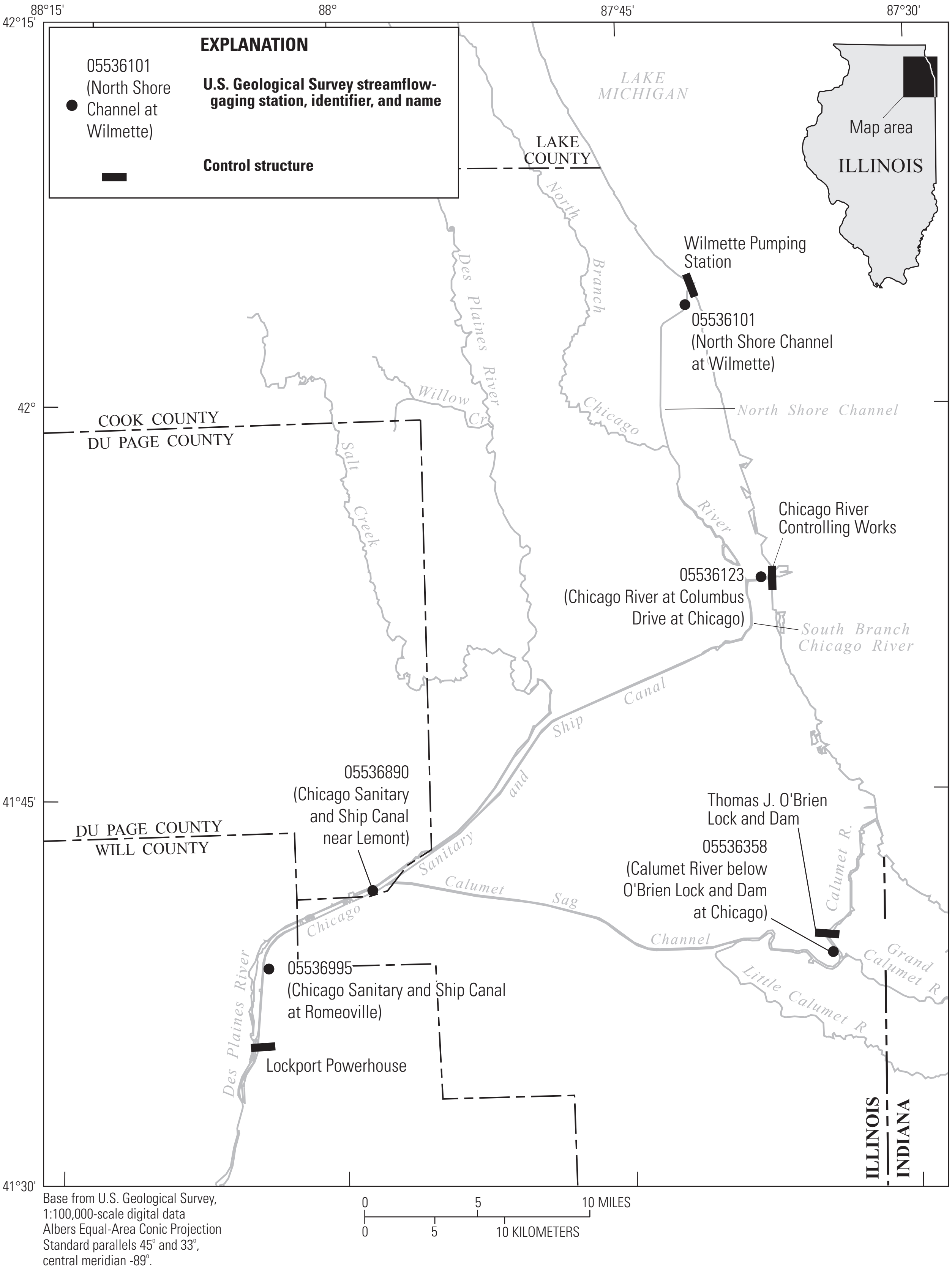


Figure 1. Location of study area in and around Chicago, Illinois.

mean annual flow to 3,200 ft^3/s. The diversion-flow computations were made by Metropolitan Sanitary District (pre-cursor to the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC)) engineers. The 1967 decree also transferred the flow-computation responsibility to the Illinois Department of Transportation–Office of Water Resources. A 1980 U.S. Supreme Court Decree (appendix 2) re-confirmed the State of Illinois diversion to a mean annual flow of 3,200 ft^3/s and added additional limits on the cumulative deviation of annual flows above or below the 3,200 ft^3/s limit (see appendix 2). The 1980 decree assigned the USACE with the task of diversion accounting. The decree directed the USACE to establish the diversion-accounting procedures, work with the USGS to measure flows within the waterway, and convene a technical review committee every 5 years to review diversion accounting. A technical review of the LMDA program by a panel of independent experts ensures "that current best-engineering practices and scientific knowledge" are being used in diversion accounting. Each technical review committee is appointed to conduct a comprehensive review of current diversion-accounting procedures. The procedures include but are not limited to the following: (1) current accounting results, (2) diversion-related measurements and measurement techniques at USGS streamgages, control structures, precipitation gages, and other pertinent structures, (3) hydrologic and hydraulic modeling, (4) procedures used to calculate and verify flows that are not directly measured, and (5) the status of recommendations from previous review committees.

Instrumentation

Acoustic Velocity Meter

The acoustic velocity meter (AVM) is useful in measuring velocity and computing discharge at sites where a stage-discharge relation can result in more than one possible discharge for a given gage height because of variable backwater conditions or drawdown conditions. The index-velocity method also is useful for sites where slopes are too flat to permit measurements accurate enough for slope computations (Levesque and Oberg, 2012). Other advantages of AVMs include the continuous record of observed water velocity, the nonmechanical operation of the instrument, and the ability to measure very low velocities (slower than traditional mechanical meters can detect) and flow reversals. These attributes make the AVM an ideal instrument for measuring velocity in the CSSC because of the need for continuous-velocity record, slopes are very flat, and velocity is very slow and even reversed at times.

An AVM measures the difference in travel time of a sound wave transmitted in reciprocal diagonal directions across the stream, and thus, measures the velocity as the travel time is proportional to the velocity of flowing water. The sound wave propagation is along a known path length and at a known angle diagonal to flow (Laenen, 1985; Stedtnitz Maritime Technology Limited, 1993). The speed of sound changes with temperature, salinity, and depth. Temperature and salinity are compensated for within the central processing unit of the AVM. Salinity for the CSSC is assumed to be freshwater, and the depth of the transducers becomes an insignificant constant because the measured depths in the canal are less than 10 m. A more detailed discussion of conditions on the CSSC with respect to the speed of sound and the affect of road salt on temperature, salinity, and depth is found in Jackson and others (2012). The transducers are connected to the AVM by cables, with one set of cables running underwater across the channel. The theory of the AVM is that the traveltime for a sound wave in the upstream direction (t_{US}) will be slower than the traveltime in the downstream direction (t_{DS}), and the difference in traveltime is proportional to the water velocity. The time of travel for the acoustic signal can be accurately measured by the AVM, and the path length (L) and angle between transducers (θ, theta) are known as stable constants. Therefore, the mean velocity of the water along the AVM path, V_p, and the mean velocity in the streamwise direction, V_S, can be computed using equations 1a and 1b, respectively. This is known as the time-of-travel method for determining velocity.

$$V_p = \frac{L}{2}\left(\frac{1}{t_{DS}} - \frac{1}{t_{US}}\right) \quad (1a)$$

$$V_S = \frac{V_p}{\cos\theta} \quad (1b)$$

Acoustic Doppler Current Profiler (ADCP)

Throughout the 1980's and into the 1990's, the field of hydroacoustics continued to improve with the development of the first acoustic Doppler current profiler (ADCP) intended for river discharge measurements (Gordon, 1996). The development of the ADCP began with oceanographic applications and then progressed into freshwater riverine settings. The USGS recognized the advantages of the ADCP over the conventional Price AA current meter for discharge measurements, especially in low-velocity and unsteady-flow conditions typical of the CSSC. While a lot of work had been done previously on the accuracy of conventional Price AA current meter measurements (Rantz and others, 1982; Sauer and Meyer, 1992), very little information existed in 1992 about the accuracy of the ADCP. ADCPs were first used for discharge measurements in the CSSC at Romeoville, Ill., on June 26, 1992. A manned boat with a downward-looking ADCP traversed the channel cross section at Romeoville and measured velocity profiles below the boat at a rate of about 0.5 hertz (Hz) (fig. 2). A discharge measurement could be made with an ADCP in as little as 12 minutes as compared to the 60 minutes required for multiple bridge cranes using the Price AA current meter. The ADCP represented a substantial change in discharge-measurement technology and a significant improvement over conventional Price AA current meter measurements in low velocity and unsteady flow conditions, typical of the CSSC.

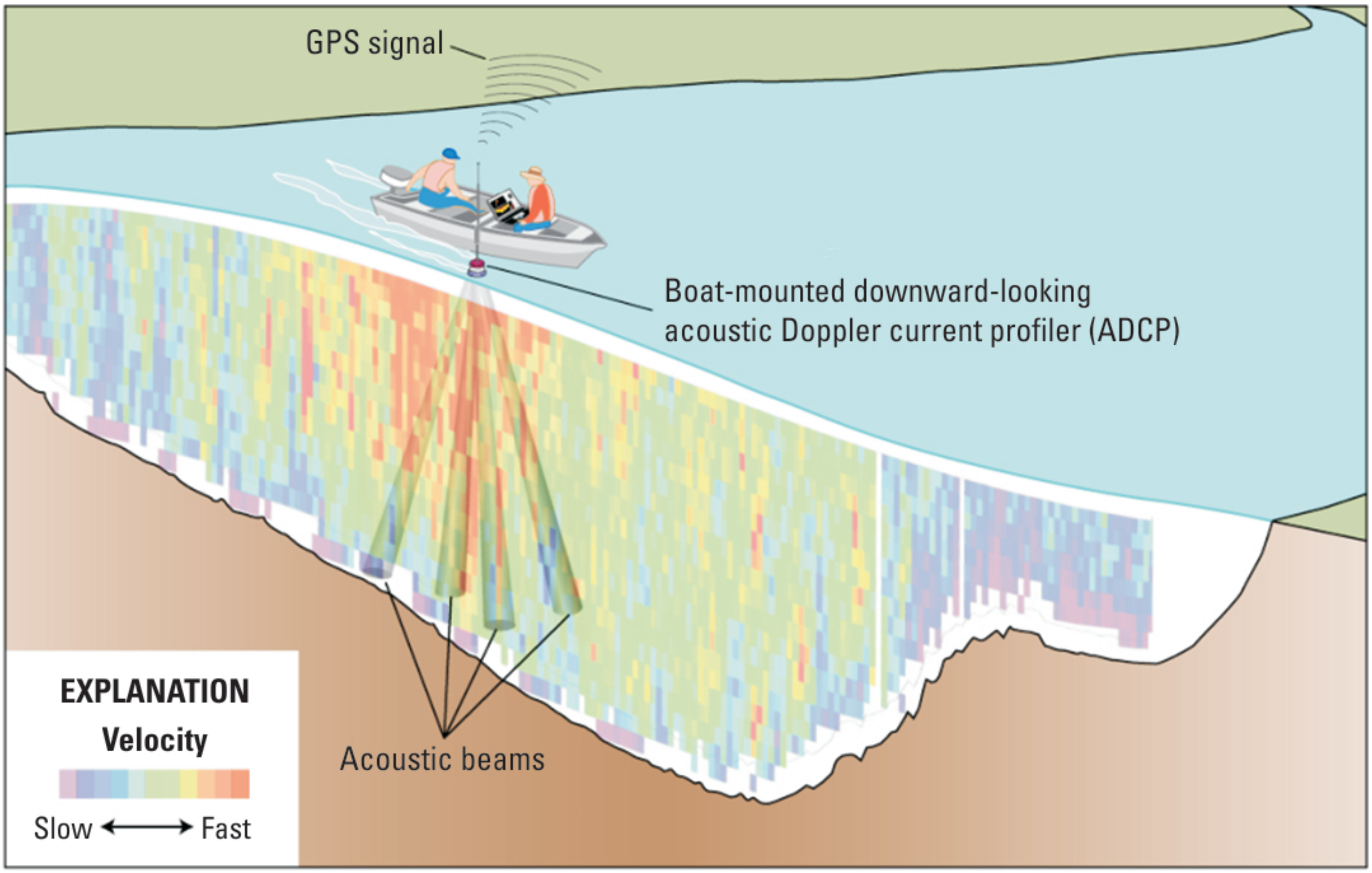


Figure 2. Drawing showing a moving-boat discharge measurement with a boat-mounted acoustic Doppler current profiler (ADCP) and differential global positioning system (GPS) and the resulting velocity-magnitude profile data.

Index-Velocity Ratings

An index-velocity rating relates the measured AVM or acoustic Doppler velocity meter (ADVM) instrument velocity, known as the index velocity (V_i), to the mean channel velocity (V_m) as determined from discharge measurements (Rantz and others, 1982; Morlock and others, 2002). The index-velocity rating is used to predict mean channel velocity from indexed velocity. The relation between V_i and V_m varies with discharge; therefore, multiple measurements of discharge over a range of flow conditions is required to develop an index-velocity rating. The predicted mean channel velocities computed with the index-velocity rating are multiplied by the cross-sectional area from the stage-area rating to obtain discharge.

Stage-Area Rating

A stage-area rating is developed from a detailed channel cross-section survey, including both the main river channel and overbank flood plain (if applicable). The cross-section survey can be done using a combination of techniques such as an engineer’s level and rod, sounding weights, echo sounders, or an ADCP. The purpose of the survey is to define the relation between cross-sectional area and water-surface elevation or stage at the cross section of interest. Elevations of the cross section generally are referenced to the gage datum in terms of stage, and distances are referenced in the same units for the cross section. Once the standard cross section is established, the area for each stage value can be calculated. These values can be used alone as the stage-area rating or an equation can be obtained from a regression analysis. A linear or quadratic equation generally fits the cross-sectional area versus stage relation. Area will vary with stage and it is advisable to re-survey the same cross section on a regular basis to track changes in the channel geometry that may affect the rating relation.

Index Velocity-Mean Velocity Rating

The velocity-velocity (mean channel velocity-index velocity) rating is developed through a series of discharge measurements made throughout a range of flow conditions. The overall accuracy of the rating is a function of the quality of the stage, index velocity, and ADCP discharge-measurement data. Standardized field protocols along with synchronization of instrument clocks and time stamps among the AVM, data logger, and ADCP helps to reduce the uncertainty in the data. ADCP transect data and AVM velocity readings can be used as a single rating point or grouped together and averaged as a point representing multiple transects. The option chosen depends upon the unsteadiness and variability in the flow rate during the discharge measurement. The rating is developed by plotting the measured cross-channel velocity from the AVM (AVM index velocity) on the x-axis and the mean channel velocity from the discharge measurement on the y-axis. A linear regression of the data points provides a velocity-velocity rating equation. In an error analysis of computed discharges for streamflow-gaging stations on the CAWS, Duncker and others (2006) concluded that the velocity-velocity ratings should not be forced through the zero X-Y intercept and the rating should fit the data through the full range of velocities. Forcing the velocity-velocity rating through the zero X-Y intercept also incorrectly reduces the uncertainty associated with the computed discharge.

A History of Lake Michigan Diversion Accounting

The remainder of this report presents the history of LMDA with a focus on the USGS streamgages on the CAWS and their role in diversion accounting. Each of these gages is discussed in detail. and the stage-area and velocity-velocity ratings for each gage are presented.

Lake Michigan Diversion Accounting: Pre-1984

Prior to 1984, accounting for diversion of Lake Michigan water through the CSSC was accomplished by estimating flows based upon a combination of ratings for the turbines and sluice gates, lockages, and leakage estimates at the MWRDGC–Lockport Powerhouse, MWRDGC–Lockport Controlling Works, and the USACE–Lockport Lock.

Recommendations of the First Technical Review Committee (1981)

The USACE was directed by a 1980 U.S. Supreme Court Decree to regularly—approximately every 5 years—convene a technical review of the LMDA program by a panel of independent experts. The First Technical Review Committee for the LMDA comprised three members: Dr. William H. Espey, Harry H. Barnes, Jr., and Dr. Svein Vigander. In 1981, the committee concluded that the overall accounting process lacked credibility and that “every flow measurement was deficient with respect to quality assurance” (Espey and others, 1981). Prior to the committee’s review, significant efforts were made by the USACE–Detroit District to directly measure the flow in the canal for comparison to the estimated diversion flows; however, unsteady flow conditions led to inconclusive results. A key recommendation from the First Technical Review Committee was to evaluate an AVM system for the measurement of velocity and computation of discharge in the CSSC near Lockport, Ill.

Lake Michigan Diversion Accounting: 1984–89

The recommendation from the First Technical Review Committee (Espey and others, 1981) to evaluate an AVM system for the measurement of velocity for the computation of discharge ushered in new and developing technology that fully embraced the 1980 U.S. Supreme Court Decree to use best-engineering practices to measure discharge on the CSSC.

Establishment of a USGS Streamgage for Diversion Accounting

In late 1984, the Illinois Department of Transportation–Office of Water Resources cooperated with the USGS to establish a streamflow-gaging station at Romeoville, Ill. (USGS station number 05536995). The State of Illinois was acting on the recommendations of the First Technical Review Committee (1981) for LMDA that was convened by the USACE. The committee’s recommendation was based on a 1979 evaluation of an AVM in the CSSC at Willow Springs Road by the Metropolitan Sanitary District and subsequent improvements in AVM technology. Establishment of the USGS streamflow-gaging station at Romeoville marked a distinct advancement in the technology used to compute flows in the CSSC and the first time continuous monitoring of the Lake Michigan diversion was accomplished by computation of discharge using direct measurements of stage and velocity in the canal.

The USGS streamflow-gaging station at Romeoville consisted of a four-path AVM, manufactured by Sarasota Corporation (a United Kingdom company); a vertical acoustic beam; and an independent pressure transducer for stage readings. The AVM system was mounted to the canal walls on both banks and cross-channel cables were laid along the canal bed. The four velocity paths were configured in an X-pattern with three of the velocity paths (upper, middle, and lower) in one of the diagonals of the X-configuration and a fourth velocity path (cross path) in the other diagonal of the X-configuration (fig. 3). Additional equipment for data logging and instrument operation was housed in a shelter on the left bank, adjacent to the 135th Street swing bridge (fig. 4).

Problems and shortcomings associated with the operation and maintenance of the AVM streamflow-gaging station on the CSSC at Romeoville were discovered soon after installation. Tow boat operators on the CSSC routinely scraped the canal walls with their barges as they navigated through this reach of the canal. When the canal was drawn down for a storm, the original elevation mounting of the top path of transducers would be out of water. During normal canal operations, the top path also could be corrupted by a fully loaded barge passing by in the canal. After several incidents in which the transducers and mounting pipes were torn off of the walls by barges, commercial divers were contracted to return to the site and notch the walls allowing the instrumentation to be recessed into the notches and protected from the barges. The cross-channel cables also suffered damage from harsh conditions in

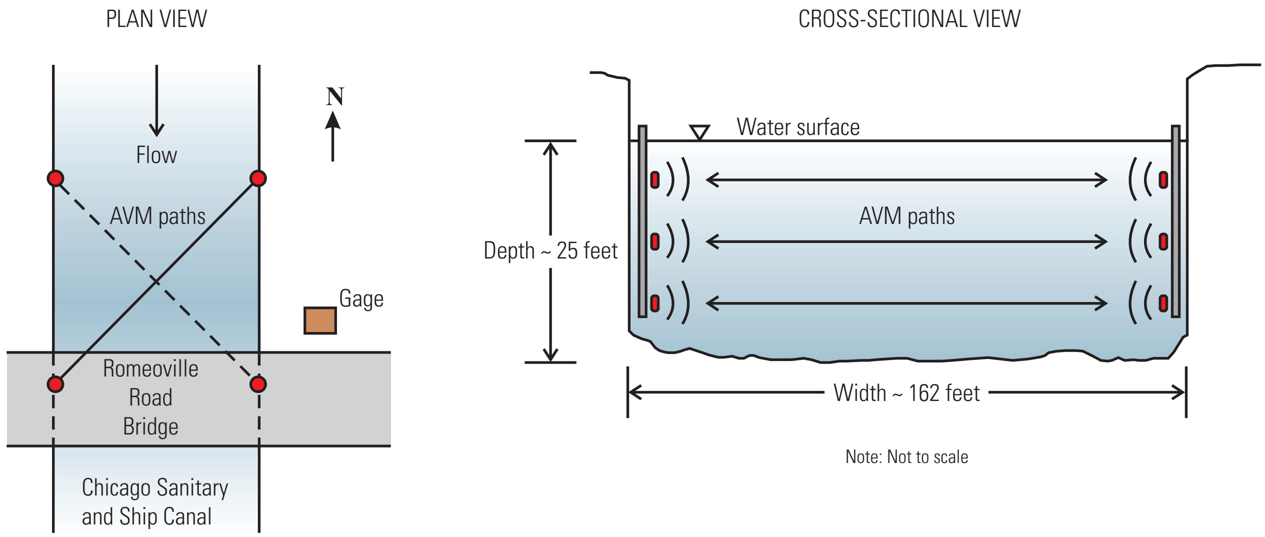


Figure 3. Plan and cross-sectional views of the acoustic velocity meter (AVM) streamflow-gaging station on the Chicago Sanitary and Ship Canal at Romeoville, Illinois.

Figure 4. Historic photograph (1988) showing the 135th Street swing bridge near the U.S. Geological Survey acoustic velocity meter streamflow-gaging station on the Chicago Sanitary and Ship Canal at Romeoville, Illinois. The streamflow-gaging station was located on the upstream side of the swing bridge just to the right of this photograph. (Photograph by Martin Stupich, Historic American Engineering Record.)

the canal. Increased velocity in the canal owing to large storms created enough strain on the cables to cause breakage or cause them to be exposed to barge traffic and ultimately severed. Ultimately, weighting the cables to the bed and protecting the cables along the canal walls resulted in extended periods of operation of the AVM without disruption. Maintaining the integrity of underwater cross-channel cables and transducers is a large part of the regular operation and maintenance of an AVM streamflow-gaging station. By September 1986, disruptions at the AVM streamflow-gaging station at Romeoville were minimized through improved installations of transducers and cables; however, the reliability of the Sarasota AVM had not improved. Repairs to the Sarasota were costly and generally involved bringing a company engineer to the site from the United Kingdom. Components of the AVM system were not easily repaired or serviceable by USGS technicians. On November 17, 1988, the four-path Sarasota AVM was replaced with a four-path ORE AVM because of numerous maintenance problems.

Recommendations of the Second Technical Review Committee (1986)

The Second Technical Review Committee convened in 1986 and included Dr. William H. Espey, Harry H. Barnes, Jr., and David E. Westdall. The committee focused on the improvements in the hydrologic modeling, which is part of the overall LMDA program, and the new AVM streamflow-gaging station (Espey and others, 1987). By 1986, the LMDA program had been turned over from the State of Illinois to the USACE–CD). Beginning on October 1, 1987, the USACE–CD was authorized by Congress to carry out measurements and make necessary computations required by the 1980 U.S. Supreme Court Decree (see appendix 3). The operation of the AVM had become more reliable and the Second Technical Review Committee focused on AVM operation and evaluated the regression developed by the USGS between the AVM flow data and flow data from the MSD–Lockport Powerhouse and Controlling Works and Lockport Lock that was used to estimate missing days of discharge record. The committee recommended that any regression be evaluated based upon flow-controlling characteristics (turbines only; turbines and sluice gates combined; and turbines, sluice gates, and controlling works combined) and that written guidelines be developed to improve the quality of the AVM record. Melching and Oberg (1993) documented the relation between Romeoville and MSD–Lockport Powerhouse and Controlling Works and Lockport Lock as well as established guidelines for future multivariate regression analysis among sites on the CSSC.

Based upon these recommendations and the recommendations of the First Technical Review Committee, the USGS developed a site-specific quality-assurance (QA) plan for the collection of data at the AVM streamflow-gaging station at Romeoville. The purpose of the QA plan was "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." The QA plan was used as a guide to aid personnel responsible for AVM site inspections, discharge measurements, and data collection and analysis of records at the AVM streamflow-gaging station at Romeoville. Subsequent technical review committees have reinforced the adherence to the QA plan. The QA plan and protocols first developed for the streamflow-gaging station at Romeoville have since served as a template for operations and procedures at other USGS AVM streamflow-gaging stations.

An Upgrade at Romeoville

By 1987, flows computed by the USGS for the CSSC using the AVM streamflow-gaging station at Romeoville had achieved credibility; however, the upkeep and maintenance of the AVM instrumentation and problems with underwater cables continued. A great deal of emphasis was placed on minimizing the amount of missing AVM record. Throughout the 1980's, there was continued development and advancement in AVM technology; in 1988, the USGS chose to upgrade the AVM instrumentation at the streamflow-gaging station at Romeoville. In November 1988, USGS technicians installed a new four-path AVM system manufactured by ORE Corporation. When the ORE AVM was installed, the downstream transducers were located 20 feet (ft) downstream of the original location to better protect the transducers from barge traffic. The AVM parameters for path lengths and angle were adjusted to the new values. In 1990, the upstream transducers were relocated approximately another 20 ft downstream to a natural crevice in the canal wall to better protect the transducers from barge traffic. Again, the AVM parameters for path length and angle were adjusted to the new values. These changes retained the original X-configuration of the Sarasota AVM, but resulted in new AVM path length and angle.

Lake Michigan Diversion Accounting: 1990–95

In 1990, the 135th Street swing bridge was closed to traffic, and construction began on a new high-arch bridge over the CSSC. The bridge construction did not directly affect the adjacent USGS streamflow-gaging station; however, it did change the streamflow-gaging station operations with regard to outside water-level readings and discharge measurements. The wire-weight reference gage on the swing bridge became inaccessible; thus, the auxiliary staff gage located in a notch along the left bank (beneath the bridge) became the reference gage for gage heights. Discharge measurements during the bridge construction period were made from a boat using a tagline located at the midpoint of the AVM velocity paths. When the new high-arch bridge was completed in 1998, discharge measurements returned to the downstream side of the high-arch bridge using a tethered-boat ADCP.

Concern over the continuity of flow records between the Sarasota AVM system and the new ORE AVM system led to a USGS study that compared the discharges computed from the two AVM systems (Melching and Oberg, 1993). The comparison utilized two different statistical approaches for estimating discharge at the streamflow-gaging station at Romeoville on the basis of MWRDGC discharge estimates at Lockport. The results of this comparison indicated that natural variation in the flows recorded by the Sarasota AVM and the ORE AVM was far greater than any differences that could be attributed to the performance of the AVM instruments.

Lakefront Leakage

In 1993, the USACE diversion accounting annual report revealed that the State of Illinois had exceeded the 3,200 ft^3/s limit for water years 1986–89 by an average of 598 ft^3/s for the 4 years. Analysis of the annual diversion water budget indicated that the imbalances were in part a result of leakage through the three lakefront control structures (U.S. Army Corps of Engineers, 1993, p. 18). USGS discharge measurements made during April–July 1993 quantified the leakage at the three lakefront control structures as 133 ft^3/s at the Chicago River Controlling Works (CRCW), 21 ft^3/s at the O'Brien Lock and Dam, and approximately 15 ft^3/s at the Wilmette Pumping Station (Oberg and Schmidt, 1994). With this quantity of leakage applied to the annual flows, the exceedance of the annual water budget for this time period ranged from 19 to 53 percent for through leakage. Leakage through the control structures is the result of design flaws, poor integrity of the seals on the control structures, and a head difference across the structure. Lake Michigan water level is normally higher than the CAWS water level on the opposite side of the control structure, thus favoring flow from the lake to the CAWS. Large gates at each end of the lock structures contain rubber seals to minimize leakage when the gates are closed. In 1993, the USACE determined that the gate seals at the Chicago Lock were leaking, and the triangle gates would not fully close. The USACE made emergency repairs to the Chicago Lock gates in May 1993. Inspections of the Thomas J. O'Brien Lock and Dam and the Wilmette Pumping Station revealed leakage, but not as much as the leakage at the Chicago Lock. In addition to leakage through the lock gates, leakage also was observed along much of the inner harbor walls of the CRCW. These leakage measurements and visual observations helped to quantify the water-budget imbalances. Additional repair efforts were made on the Chicago Lock gates in September 1993 in an effort to further reduce leakage through the structure.

Repair to the lock gates at the CRCW addressed only part of the overall leakage problem. Leakage also occurred along most of the length of the inner harbor breakwater walls adjacent to the Chicago Lock. The responsibility for this part of the structure belonged to the State of Illinois. In 1998, the State began construction on a new wall inside the inner harbor. The new wall cut off the south turning basin in the inner harbor and shortened the length of the harbor wall that was exposed to leakage. The new wall also included a set of sluice gates to replace the CRCW south sluice gates and a pumping station to pump river water back into the lake. The new wall (see fig. 5) was completed during 2000 and resulted in much reduced leakage through the Chicago River Park District (DuSable Harbor).

Figure 5. The Chicago River Controlling Works, Chicago Lock, and DuSable Harbor, Chicago, Illinois.

Recommendations of the Third Technical Review Committee (1993)

In 1993, the Third Technical Review Committee comprised Dr. William H. Espey, Mr. O.G. Lara, and Dr. R.L. Barkau. They concluded that overall, the accuracy of the USACE diversion accounting had improved from both the hydrologic-modeling and discharge-measurement components and that the USACE was in accordance with the 1980 decree to be utilizing the "current best-engineering practices and scientific knowledge" to compute the State of Illinois' diversion. The increased overall accuracy of diversion accounting also indicated that through water year 1990, the State of Illinois was exceeding the cumulative deviation allowed by the 1980 decree (Espey and others, 1994).

Lake Michigan Diversion Accounting: 1996–2004

Streamflow-Gaging Station at Romeoville for Accounting

The ORE AVM furnished satisfactory record for much of water years 1996–2004. The USGS upgraded the stage sensor from the original mercury manometer to a pressure transducer as part of a USGS-wide policy to remove mercury from streamflow-gaging stations.

Lakefront Streamflow-Gaging Stations for Accounting

Since the inception of the technical review process and the convening of technical review committees for LMDA, the concept of a lakefront-accounting system was suggested (Espey and others, 1981). A lakefront-accounting system would move the primary diversion-monitoring location from the streamflow-gaging station at Romeoville to new streamflow-gaging stations established in close proximity to the lakefront-diversion structures: Chicago Lock and CRCW, O'Brien Lock and Dam, and the Wilmette Controlling Works (WCW). A Memorandum of Understanding (MOU) from the July 1996 Great Lakes Mediation prescribed a 3-year transition from the Romeoville-accounting system to the lakefront-accounting system. Comparison of the two accounting systems during the transition period was to be used to determine the accuracy and feasibility of lakefront accounting. In response to the MOU, in 1996, the USACE funded the USGS to establish three additional AVM streamflow-gaging stations in close proximity to the lakefront-diversion structures.

During summer 1996, USGS personnel and personnel from the AVM manufacturer visited potential monitoring locations. The three locations selected for monitoring were the Chicago River at Columbus Drive (CRCD) west of CRCW, the Calumet River below O'Brien Lock and Dam (CROLD) south of CROLD, and the NSC at Wilmette south of WCW(fig. 6). Each of these sites represented challenges for accurately monitoring the flow. Hydraulic settings for each of the three locations were unique and complex, yet visual assessments made during the previous site visits did not reveal the full complexity of the flows at these locations. Seasonal variations in the flow and the close proximity to flow-control structures added to the complexity of each site. The complexity of the hydraulic settings at the lakefront accounting streamflow-gaging stations was not realized until after AVM velocity data were collected and computed for an extended period and numerous ADCP discharge measurements were made under varying flow conditions. As the USGS developed the index-velocity ratings for each site, it became apparent that the locations were less than ideal for accurate computation of flow. Nevertheless, significant efforts were made to compute accurate discharge measurements at each station.

Figure 6. Map of study area showing the locations of the three lakefront accounting acoustic velocity meter streamflow-gaging stations in Illinois.

Recommendations of the Fourth Technical Review Committee (1998)

In 1988, the Fourth Technical Review Committee comprised Dr. William H. Espey, Dr. Arthur R. Schmidt, and Dr. R.L. Barkau. They conducted a thorough review of the Romeoville accounting and lakefront accounting AVM streamflow records and recognized the complexity of the hydraulic conditions at each location. The Committee evaluated the use of ADCPs for discharge measurement at the streamflow-gaging station at Romeoville and identified potential sources of random and systematic errors in the use of ADCPs and the index-velocity method of computing discharge. The Fourth Technical Review Committee's recommendations regarding the sources of ADCP error were incorporated into the QA plan for the Romeoville and lakefront streamflow-gaging stations. The Committee's report recognized the uncertainty and "noise" in the index-velocity ratings at the lakefront accounting streamflow-gaging stations and offered suggestions regarding improvements in instrumentation and measurement procedures. The Committee strongly emphasized that the draft QA plan be updated and finalized (Espey and others, 2001).

Uncertainty Analysis of Mean Annual Discharge Computations

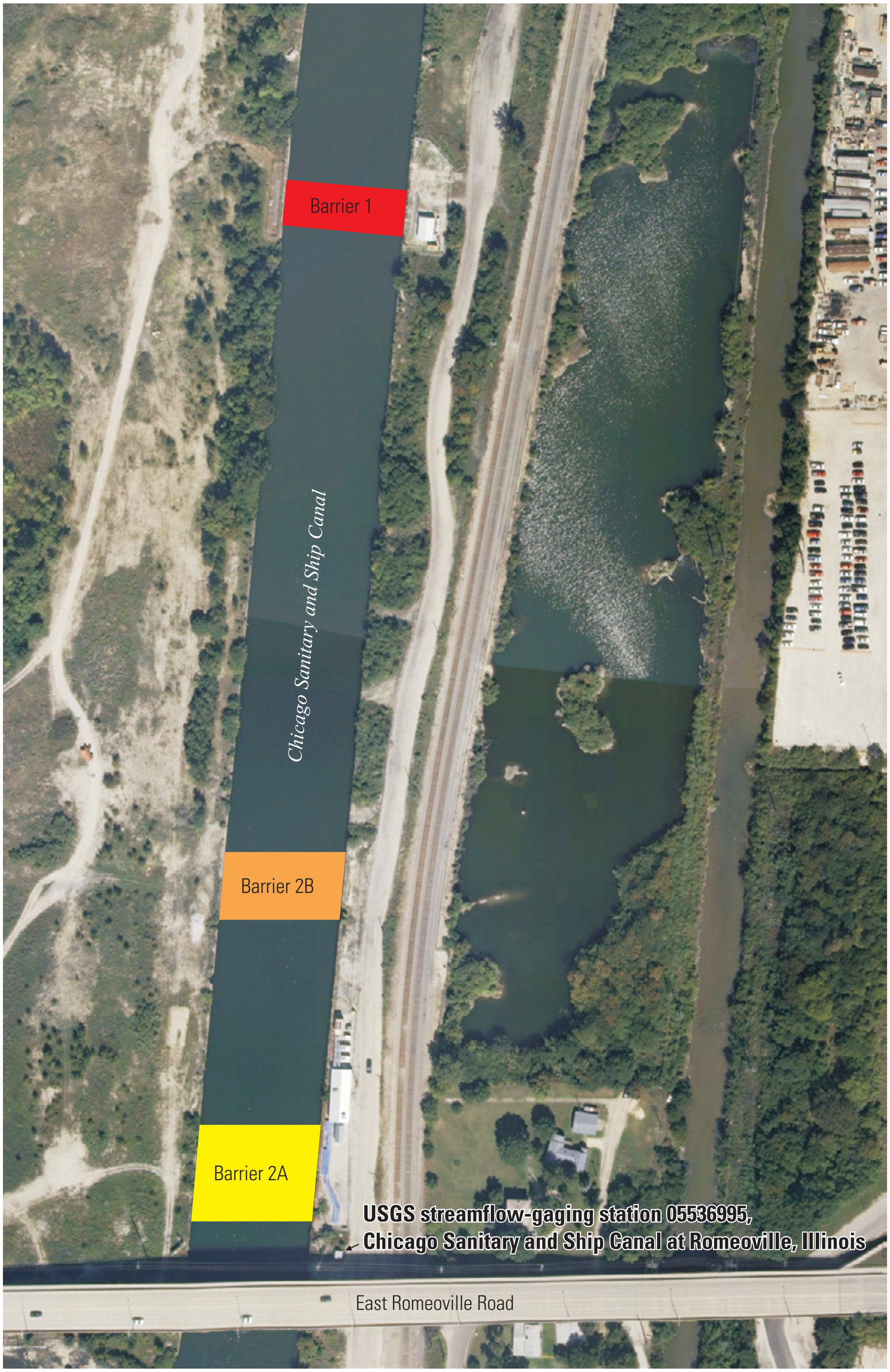
As the USGS collected AVM data at the lakefront-accounting streamgages and the index-velocity ratings were being developed, it became apparent that the uncertainty of the discharge computations may not be the same for all sites. In 2000, the USACE funded the USGS to evaluate the uncertainty in the discharge data for each of the lakefront AVM streamflow-gaging stations. A statistical analysis was utilized to determine uncertainty in the mean annual flows. In order to determine the uncertainty in the mean annual discharge, it was necessary to account for each error-source component of the discharge computation at each of the lakefront streamflow-gaging stations. After adding the streamflow-gaging station at Romeoville to the analysis, Duncker and others (2006) concluded that for the LMDA, the lakefront-accounting method (using flow data computed at the Columbus Drive, O'Brien Lock and Dam, and Wilmette AVM streamgages) and the Romeoville accounting method (using just the AVM streamgage at Romeoville) had approximately equivalent uncertainty in mean annual diversion, but the uncertainty of flow computations near the lakefront controlling works is much larger than that at Romeoville. This result indicated to the USACE, the State of Illinois, and other Great Lakes States that the two accounting methods were both acceptable for LMDA. However, wording in the 1980 U.S. Supreme Court Decree and the 1986 MOU made the Romeoville accounting method more favorable to the State of Illinois owing to differences in the lakefront and Romeoville accounting methodology for accumulating balance of flows over/under the mean annual limit of 3,200 ft^3/s. The Romeoville accounting method also resulted in a significant cost saving with respect to the operation and maintenance of one streamflow-gaging station instead of the three lakefront streamflow-gaging stations.

Invasive Species and the Fish Barrier at Romeoville

In April 2002, the USACE installed an electric dispersal barrier (barrier 1) in the CSSC at a location approximately 1,500 ft upstream of the USGS streamflow-gaging station at Romeoville (fig. 7). The electric barrier was installed in an attempt to halt the migration of an invasive species of fish (the Round Goby) from entering the Mississippi River Watershed by way of the CSSC. The electric barrier consisted of a set of 13 underwater cables that, when in operation, induced an electric field throughout the water column and deterred fish from passing.

Research in laboratory settings by the USGS–Great Lakes Science Center and the University of Michigan (Savino and Kostich, 2000) showed that the Round Goby would not cross through the electrical field, and if it tried, the electric current was sufficient to kill the fish. Unfortunately, by the time the electric dispersal barrier was completed in 2002, the Round Goby had already established itself in the Illinois River downstream of the electric dispersal barrier. The USACE also recognized that other invasive species from either the Lake Michigan Basin or the Mississippi River Basin could gain access through the CSSC. In 2002, the Asian carp (collectively the black, bighead, and silver carps) were already well established in the Mississippi and lower Illinois River Basins, were spreading upstream into the Illinois River (Kolar and others, 2007), and posed a threat to the ecology of Lake Michigan and the other Great Lakes.

In January 2003, the USACE held a meeting at the Lockport Lock and Dam at which time the USGS was informed about plans for the construction of a second electric dispersal barrier (barrier 2B) in the CSSC approximately 800 ft downstream of barrier 1. A third barrier (barrier 2A) was to be located 1,200 ft downstream of barrier 1 and 300 ft upstream of the streamflow-gaging station. Barriers 2A and 2B are the permanent barriers that can emit a voltage up to 5 volts. Barriers 2A and 2B are designed to operate as a pair; one can preserve the barrier function while the other is shutdown for maintenance. Research on the canal in the vicinity of the first electric dispersal barrier using common carp equipped with radio transmitters showed that one of the tagged fish had passed through the barrier. It was believed that this fish likely passed through the electric field at the same time as a barge moved through the barrier. On other occasions, operation and maintenance issues forced the USACE to temporarily shutdown the electric dispersal barrier. This demonstrated the need for a second electric dispersal barrier that would maintain an electric field while one barrier was disabled for maintenance or other issues. Barrier 2B also consisted of a grid of electrodes extending across the channel that would induce an electric field throughout the wetted cross section.



Imagery from ESRI World Imagery, Aerials Express, 2009

Figure 7. Enhanced photograph showing the U.S. Army Corps of Engineers electric fish barrier near the U.S. Geological Survey streamflow-gaging station at Romeoville, Illinois.

The USGS was informed that the proposed location for barrier 2B would bring the electric field closer to the measuring section of the AVM streamflow-gaging station at Romeoville. At that time, it was not known if the electrical field generated by the second barrier would have an effect on the AVM instrumentation. A series of ADCP discharge measurements were made with the barrier 1 electrical field in place. Analysis of the ADCP measurements showed a strong effect on the internal compass of the ADCP. Based upon the barrier's electrical field effect on the ADCP discharge measurements, a decision was made to relocate the streamflow-gaging station at Romeoville away from the electric dispersal barriers.

Lake Michigan Diversion Accounting: 2004–12

Relocating the streamflow-gaging station at Romeoville was not a trivial task. The streamflow-gaging station at Romeoville had well-established field-operation and discharge-measurement protocols that were specific to the site and conditions; it also had a set of established and documented regression equations for estimating missing discharge record by using reported discharge values from the Lockport Lock, powerhouse, and controlling works. The streamflow-gaging station also had a site-specific QA plan and an error analysis published report to provide overall confidence in the reported flows. The index-velocity rating had over 440 discharge measurements, which equates to more than 440 pairs of mean velocity and index velocity. A stable channel cut into bedrock with almost ideal channel geometry for flow monitoring made for a discharge-monitoring location with very low uncertainty in the discharge measurements. USGS staff were determined that if the streamflow-gaging station had to be relocated, the only suitable site would have comparable or possibly improved monitoring conditions.

Relocation of the Streamflow-Gaging Station at Romeoville to Lemont, Illinois

The end of the lakefront-accounting trial and the need to relocate the streamflow-gaging station at Romeoville to a new location presented a lot of change to the overall network of streamflow-gaging stations on the CAWS. The location for the replacement of the streamflow-gaging station at Romeoville was selected in June 2003, in cooperation with the USACE–CD, USGS hydrologists, and the Fifth Technical Review Committee (Dr. William H. Espey, Dr. Charles S. Melching, and Mr. Dean M. Mades). The site of the new streamflow-gaging station was located approximately 5.9 mi upstream of the streamflow-gaging station at Romeoville on the right bank (approximately 1.5 mi upstream of Lemont Road), at mi 12.0 of the CSSC (Illinois Waterway Mile 302.0). Permission was obtained from MWRDGC, DuPage County Forest Preserve, and Argonne National Laboratory to locate the streamgage at the desired location. Construction began in January 2004 with clearing the site and excavating a section down to bedrock in order to blast and notch both bedrock banks of the channel to provide a protected area to mount the streamflow-gaging equipment (fig. 8). The construction, power connection, and instrumentation of the site were completed on December 7, 2004, and the streamflow-gaging station on the CSSC near Lemont, Ill., officially began recording data.

In 2003, initial discussions about the relocation of the streamgage identified a need for overlapping concurrent data between the streamflow-gaging station on the CSSC at Romeoville and the new streamflow-gaging station on the CSSC at Lemont. Plans were developed to use identical velocity-measurement technology (3-path Accusonic AVMs at each site) for the comparison; however, on December 1, 2004, the cross-channel cables for the operation of the AVM and the orifice line for the pressure sensor at the streamflow-gaging station at Romeoville were severed by a barge. In consultation with personnel at the USGS–IL WSC, USGS–Office of Surface Water (OSW), and USACE–CD, the decision was made to forgo the expense of new AVM cables and the cost of commercial divers to secure the cables because the streamgage would soon be discontinued. A new orifice line was installed in the notch near the staff plates to facilitate gage height measurements with the pressure transducer, and a SonTek Argonaut® side looking acoustic Doppler velocity meter (SL ADVM) was installed at the streamflow-gaging station at Romeoville at the same elevation as the AVM middle-path transducers. Several discharge measurements were made at different discharge regimes to create a new index-velocity rating for the ADVM at Romeoville, as well as begin the rating creation process at the new streamflow-gaging station at Lemont. A new rating had to be developed at Romeoville because the different technologies measured different portions of the cross section. The AVM measured velocity, along a diagonal, across the entire channel. The ADVM only measured a portion of the channel; approximately 15 ft within each edge was not measured because of the flow disturbances created from wall friction and to avoid the effects of side-lobe interference. During the deployment of the ADVM at Romeoville, construction of the electric dispersal barrier 2A began just upstream of the gage structure. Figure 9 shows the initial construction of barrier 2A and the close proximity to the gage house at Romeoville. In May 2006, the ADVM deployment and all other gage equipment was removed from the streamflow-gaging station at Romeoville because of construction activities at the barrier.

Rating-Curve Development, by Station

This section includes discussion of the rating-curve development (stage-area and index velocity-mean velocity) at each of the five historic USGS LMDA streamgages on the CAWS. This discussion includes details about the index-velocity instrumentation used at each streamgage, the discharge measurements used to develop the ratings, and the evolution of the ratings at each streamgage. In addition, mean annual flows are presented for each streamgage for the years in which it was in operation.

A

Figure 8. Photographs showing construction of the acoustic velocity meter streamflow-gaging station on the Chicago Sanitary and Ship Canal at Lemont, Illinois. *A*, distant view, *B*, close up view.

B

Figure 9. Photograph showing proximity of electric dispersal barrier 2A construction activities to the streamflow-gaging station on the Chicago Sanitary and Ship Canal at Romeoville, Illinois.

Chicago Sanitary and Ship Canal at Romeoville, Illinois (05536995)

Streamgage History

The original USGS streamflow-gaging station at Romeoville was installed in 1984 and consisted of a four-path AVM (manufactured by Sarasota Corporation), vertical acoustic beam, and a bubbler/pressure transducer for stage readings. A concrete-block gage house was built on the left bank on the upstream side of the 135th Street swing bridge to house the instrumentation. Cross-channel transducer cables were laid on the bed of the canal and connected the transducers at fixed elevations on both canal walls. The vertical acoustic beam consisted of an upward-looking transducer mounted inside a vertical pipe to act as a stilling well and record the water-surface elevation. Velocity and stage readings were recorded to an electronic data logger and transmitted to the USGS–IL WSC, Urbana, Ill., by telephone telemetry. A paper printer also was connected to the AVM to produce a paper copy backup of the AVM data. In 1988, the Sarasota AVM was replaced by an ORE AVM owing to operation and maintenance issues. In 2004, the ORE AVM was replaced by a SonTek Argonaut SL ADVM because of severed cross-channel cables. The SonTek Argonaut SL ADVM was originally installed on May 11, 2001, and was used as a backup index-velocity instrument from May 12, 2001, to July 14, 2003; it was removed because it did not produce AVM equivalent discharge record. The ADVM was again deployed on December 10, 2004, following the break of the AVM cross-channel cables and was used through May 10, 2006, with a new velocity-velocity rating.

Stage-Area Rating

While the flow is highly unsteady in the CSSC, the geometry of the bedrock channel near Romeoville is stable. During the entire period of operation, one stage-area equation was used. The CSSC does not carry much sediment and is excavated into bedrock; therefore, there has been little change to the channel geometry over time. Stage-area rating number 1.0 for the CSSC at Romeoville, Ill., is

$$A_{CSSCR} = 162 * G_{CSSCR} + 251 \quad (2)$$

where

A_{CSSCR} is the rated area for the CSSC at Romeoville and

G_{CSSCR} is the gage height measured by the USGS streamgage in the CSSC at Romeoville.

Depth soundings, from a B-reel and weight, across the full width of the channel were used to construct the stage-area rating. Water level recorded by the vertical transducer beam and bubbler were then input to the stage-area rating (equation 2) to compute a cross-sectional area for every stage reading.

Index-Velocity Rating

Discharge for the streamflow-gaging station at Romeoville was computed using a direct-measurement approach prior to October 1990 and with the index-velocity method starting in October 1990. The direct-measurement approach using the AVM effectively sectioned the cross section into bins surrounding each velocity path, and the mean velocity for that path was multiplied by the cross-sectional area nearest that path to get a discharge for that bin. The area of the bottom path remained constant, even with changing stage, and the area of the top path was dynamic and dependent on the gage height for the height of the bin. Summing the discharges for each of the path bins resulted in the total discharge. This method was applied until the index-velocity method was recommended by the USGS–OSW and there were sufficient data compiled to build an index-velocity rating. The initial discharge measurements for the index-velocity rating were made from the 135th Street swing bridge using Price AA current meters. The complex hydraulic setting and extremely unsteady flow in the CSSC required simultaneous deployment of multiple (as many as 8) current meter set-ups to measure the discharge at equally spaced intervals across the full width of the channel and at multiple points in the vertical (up to 10). In spite of this manpower-intensive effort at measuring discharge, the rapidly changing flows in the canal often would result in uncertainty in the index-velocity rating and final discharge-measurement computation.

Seventy-four Price AA current-meter discharge measurements were used for developing the index-velocity ratings at the streamflow-gaging station at Romeoville from 1984 to 1992. Unsteady flow, especially at the lower range of flows, made for large uncertainty in the index-velocity rating. At the upper range of flows, the index-velocity rating shows less scatter as higher flows that result from storm runoff are usually sustained for longer periods of time. There also is less barge traffic because navigation is restricted above 7,500 ft^3/s. This results in fewer lockages at the Lockport Lock and more sustained and consistent operations at the Lockport Powerhouse, which lead to less unsteadiness in the flow at Romeoville. Discharge measurement number 75 on December 16, 1992, was the first broadband ADCP discharge measurement made in the CSSC at Romeoville, and the reported discharge was the average of 10 transects. In 1994, a decision was made to treat individual transects as individual discharge measurements because of the unsteadiness of flow. This practice continued until the gage was discontinued in 2006.

Five index-velocity ratings were implemented at Romeoville through the period of record. The first two 'ratings' consisted of sets of discharge equations, which were used to transform individual AVM path velocities to total discharge by including the stage-area rating in the equations. The equations changed when the Sarasota AVM was replaced by the ORE AVM in 1988. The third, fourth, and fifth ratings were standard velocity-velocity ratings. The primary reasons for the changes in the ratings are the addition of new data (filling in gaps where previously there were no measurements) and changes in discharge-measurement technology, both of which provide an improved dataset of the flow in the CSSC at Romeoville and an improved rating curve. Rating 0.0 was developed for the Sarasota AVM; ratings 1.0, 2.0, and 3.0 were developed for the ORE AVM; and rating 4.0 was developed for the SonTek Argonaut SL ADVM. Velocity rating number 2.0 was effective during October 1990–September 1992 (table 1). This rating was developed using mostly Price AA current-meter discharge measurements to compare the mean measurement velocity to the AVM velocity (fig. 10). Measurement numbers 42–71 were used to develop index-velocity rating number 2.0.

$$V_{I\text{-}CSSCR\text{-}AVM} = 0.92 \times V_{CSSCR\text{-}AVM} + 0 \quad (3)$$

where

$V_{I\text{-}CSSCR\text{-}AVM}$ is the mean channel velocity for the CSSC at Romeoville and

$V_{CSSCR\text{-}AVM}$ is the index velocity recorded by the AVM.

Velocity rating 2.0 was re-evaluated after a sufficient number of ADCP discharge measurements were made. Velocity rating 3.0 was developed using measurements 52–139, spanning the period November 21, 1989–July 21, 1997, and encompassed both Price AA current meter and ADCP measurements for the rating development. Several of the discharge measurements consisted of multiple ADCP transects, sequential in time, that were grouped together as a single discharge measurement; others were individual transects to comprise an independent discharge measurement. USGS OSW Technical Memo 2000.03 provides the recommended procedures for determining whether to use an individual transect or to

Table 1. Index-velocity ratings for the Chicago Sanitary and Ship Canal at Romeoville, Illinois.

[Vmean = Slope*Vindex + Intercept, where Vmean is the mean channel velocity and Vindex is the index velocity for a specific instrument; N/A, fields indicate that a set of discharge equations were used in place of a velocity-velocity rating; AVM, acoustic velocity meter; ADVM, acoustic Doppler velocity meter]

Rating number	Period of application	Slope	Intercept	Instrument
0.0	Apr. 1985 to Nov. 1988	N/A	N/A	Sarasota AVM
1.0	Nov. 1988 to Sept. 1990	N/A	N/A	ORE AVM
2.0	Oct. 1990 to Sept. 1992	0.92	0	ORE AVM
3.0	Oct. 1992 to Dec. 2004	.90	0	ORE AVM
4.0	Dec. 2004 to May 2006	.881	.084	SonTek Argonaut SL ADVM

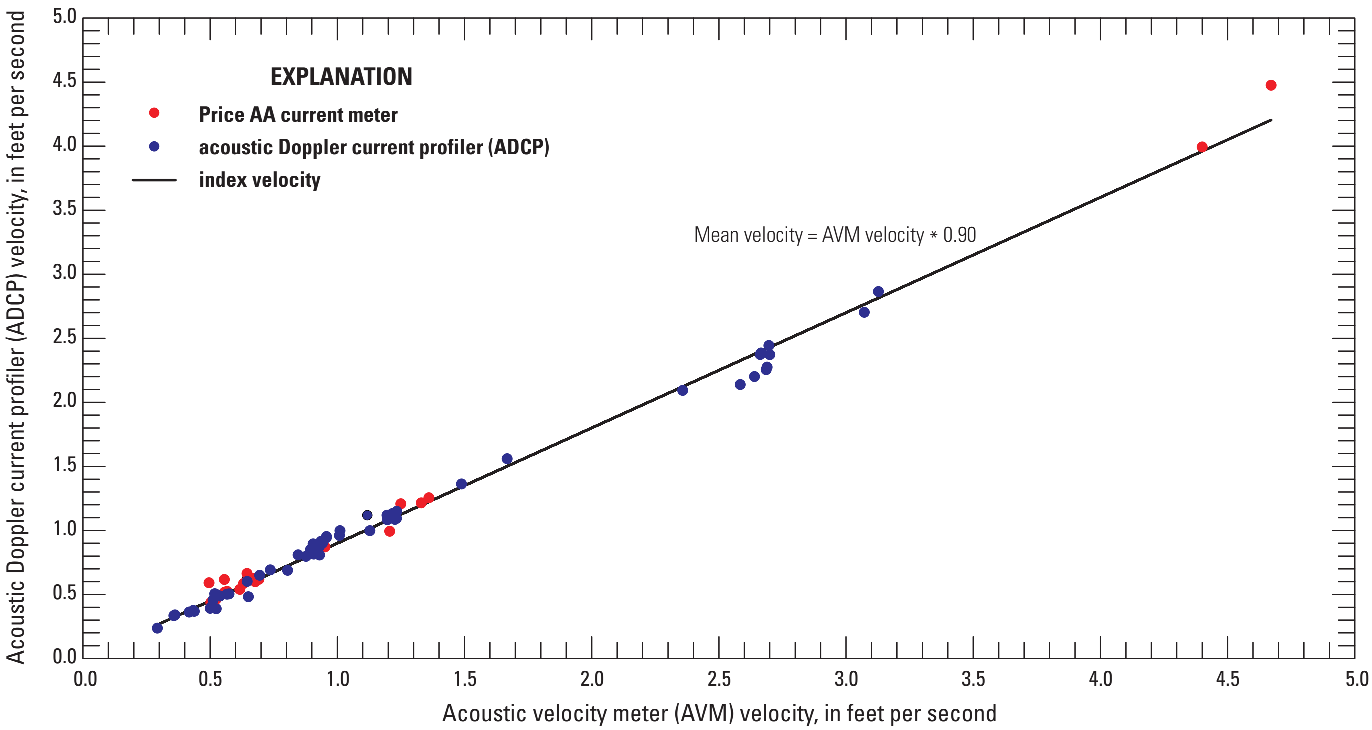


Figure 10. Index-velocity rating for the U.S. Geological Survey acoustic velocity meter streamflow-gaging station on the Chicago Sanitary and Ship Canal at Romeoville, Illinois.

group transects. Index-velocity rating 3.0 was used to compute discharge at the streamflow-gaging station at Romeoville for October 1, 1992–December 3, 2004 (table 1). Measurement numbers 52–416 validated this rating. Rating number 3.0 equation is provided in equation 4.

$$V_{I\text{-}CSSCR\text{-}AVM\text{-}3.0} = 0.90 \times V_{CSSCR\text{-}AVM} + 0 \quad (4)$$

where

$V_{I\text{-}CSSCR\text{-}AVM\text{-}3.0}$ is the index velocity for rating 3.0, and

$V_{CSSCR\text{-}AVM}$ is the mean channel velocity recorded by the AVM.

Velocity rating 3.0 remained in effect until December 2004 when the AVM cross-channel cables were severed by a barge, and the decision was made not to repair them because of the relocation of the streamflow-gaging station to Lemont.

Velocity-velocity rating 4.0 was created for the SonTek Argonaut SL ADVM, which was deployed after the AVM cross-channel cables had been severed in December 2004. The ADVM rating was developed using discharge measurement numbers 417–440 (January 2005–April 2006). This period of record was used for a comparison of discharge between CSSC at Romeoville and CSSC near Lemont. Velocity rating number 4.0 was not reliable for computing discharge. The discharge comparison between Lemont and Romeoville did not agree, nor did the computed discharge agree with MWRDGC's reported daily flows at Lockport. Some of the reasons why the comparison did not work include

- sample bin size was 33 ft near the center of the channel;
- sample location not measuring the entire width of the channel, thus neglecting the frictional effects of the channel walls;
- sample duration too short or too long for the unsteady flow conditions;
- elevation of the meter in the water column; and
- not enough discharge measurements to adequately define a velocity-rating relation.

More detail and discussion on the comparison between Romeoville and Lemont and MWRDGC's LMO6 data from Lockport, including an error analysis of the records, may be discussed and documented in a possible future report. The Argonaut and all other gage equipment was removed May 10, 2006, because of construction activities at the electric dispersal barrier.

Chicago River at Columbus Drive at Chicago, Illinois (05536123)

Streamgage History

In 1993, the USGS was asked by the USACE to use the ADCP and dye-dilution discharge-measurement techniques to quantify the amount of lake water that was leaking through the three control structures, CRCW, O'Brien Lock and Dam, and the Wilmette Controlling Works (Oberg and Schmidt, 1994). The ADCP discharge measurements at that time indicated 133 ft^3/s of leakage at the Chicago Lock, 21 ft^3/s of leakage at the O'Brien Lock and Dam, and less than 15 ft^3/s at the Wilmette Controlling Works (after pump bays were sealed). Dye-dilution discharge measurements at the Chicago Lock confirmed the ADCP measured leakage within 8 percent.

In response to the call for lakefront accounting, the USGS established a four-path AVM streamflow-gaging station on the CRCD on December 2, 1996. The CRCD channel is approximately 200 ft wide and 15–25 ft deep with vertical walls made of sheet piling and concrete. The AVM configuration consisted of a Vshaped set of two paths with two AVM transducers in the vertical on each path (fig. 11 plan view). This configuration results in an upstream set of two velocity paths and a downstream set of two velocity paths. The design was selected using the rationale that two velocity readings in the vertical water column would provide enough information to accurately compute the total discharge. This configuration allowed computation of the discharge using the upstream set of paths, the downstream set of paths, or an average of both the upstream and downstream set of paths.

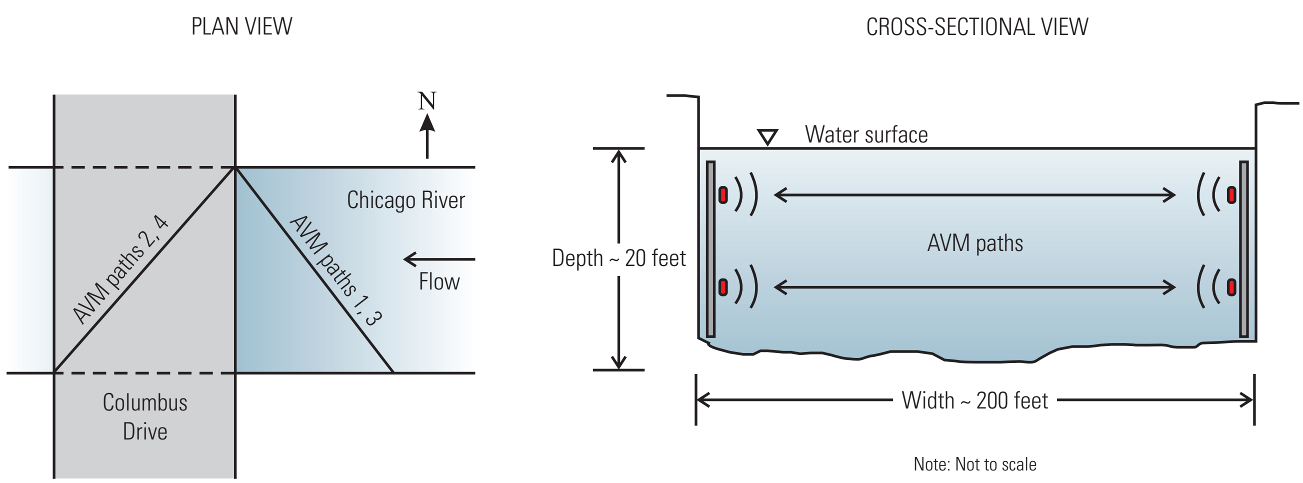


Figure 11. Plan and cross-sectional views of the acoustic velocity meter (AVM) streamflow-gaging station on the Chicago River at Columbus Drive at Chicago, Illinois.

Analyses of the AVM velocity data indicated there was little correlation between the velocities measured in the upstream paths and the velocities measured in the downstream paths, indicating a very unsteady non-uniform flow. Overall, the velocity measurements indicated very low flow.

During large runoff events, the MWRDGC occasionally opens the sluice gates at CRCW, in addition to the gates at Chicago Lock, in order to lower water levels on the Chicago River and prevent flooding in some reaches of the waterway. This is referred to as a backflow. When backflow occurs, Chicago River water containing storm-water runoff and both treated-wastewater effluent and untreated sewage from combined sewer overflows is released into Lake Michigan.

The sluice gates at the CRCW typically are open from approximately mid to late May through October for discretionary diversion. The sluice gates can be opened any time of the year for short periods of navigation makeup and during dry-weather divert from 300 to 1,200 ft^3/s of direct diversion. Direct diversion occurs at all three lakefront control structures and consists of lockage, leakage, discressionary flow, and navigation-makeup flow. While this seems like a significant flow, distributed through a cross-sectional area of approximately 4,500 square feet (ft^2), the resulting water velocities are extremely small (0.07 to 0.30 foot per second (ft/s)). Perturbations from lockages, downstream control structures, and variable inflows and outflows make for unsteady flow in the Columbus Drive reach. It was not uncommon to observe oscillation in flows in the ± 0.10 ft/s range. Flow monitoring at Columbus Drive worked well when Lake Michigan water levels were high and there was significant leakage but has proven to be more difficult with lower lake levels and reduced leakage, yet monitoring at this site currently (2012) continues.

Leakage from lakefront control structures is ultimately recorded by USGS gages (lakefront streamflow-gaging stations and streamflow-gaging stations at Romeoville/Lemont) and counted against the diversion allotment for the State of Illinois. Leakage through the lock structure varies with the head difference across the structure; therefore, it is dependent on the difference between Lake Michigan water level and the CAWS water level.

During winter months (November 1–April 30), the sluice gates at the CRCW are typically closed. In January 1998, USGS scientists making ADCP discharge measurements at Columbus Drive observed that flow was stratified and bi-directional, and the cause for the stratified, bi-directional flows was not known. Figure 12 is a velocity-contour plot showing the bi-directional flow with the near surface flow moving east toward Lake Michigan and the flow at a depth greater than 8 ft moving west, away from the lake. Throughout the period 1998–2005, the USGS continued to make measurements of discharge and water quality in an effort to understand the cause of these bi-directional flows. Subsequent data analysis showed that the bi-directional flows were caused by density currents formed by contrasting density between the relatively warm, road-salt laden, and dense water from the North Branch of the Chicago River (consisting primarily of treated-wastewater effluent) plunging beneath a colder, fresher, and less dense Lake Michigan water leaking through the Chicago River Control Structure. The density and velocity variations in the water associated with the stratified flows often would interfere with the acoustic signal from the AVM at the CRCD streamflow-gaging station. USGS ADCP discharge measurements showed that the density currents could persist for days before dissipating. The density currents can take the form of overflows or underflows depending on density differences between the branches. After USGS personnel shared information on these persistent bi-directional flows with researchers from the University of Illinois (U of I), the researchers constructed both numerical-simulation models and physical models of the main stem of the Chicago River to study the density currents (Bombardelli and García, 2001a, 2001b; García and others, 2005; Manriquez and others, 2005). The USGS collected detailed bathymetric data for the main stem of the Chicago River to support the model development. In 2005, staff from the USGS, U of I, and USACE collected additional detailed water-quality profiles at several bridge cross sections along the main stem and North Branch of the Chicago River to document the density currents. The researchers concluded that the density currents were the result of the relatively warm water from the North Branch of the Chicago River comprising wastewater effluent and surface runoff (containing road salt) plunging beneath the less-dense Lake Michigan water leaking through the Chicago Lock, CRCW, and adjacent breakwater walls (García and others, 2005, 2006, 2007; Jackson and others, 2008). The density-current phenomena have direct effects on water-quality conditions found along the main stem of the Chicago River during the winter months. During the discretionary flow period (May–October), the opening of the sluice gates at the CRCW provides enough flow into the main stem of the Chicago River that the density currents from the North Branch of the Chicago River rarely establish the stratified, bi-directional flow that occurs at times during the non-discretionary flow period (November–April). Subsequent research and analysis of ADCP data has shown that contrasting water densities and stratification are found throughout the CAWS and indicate a more widespread occurrence of density currents (both underflows and overflows) within the waterway (García and others, 2007).

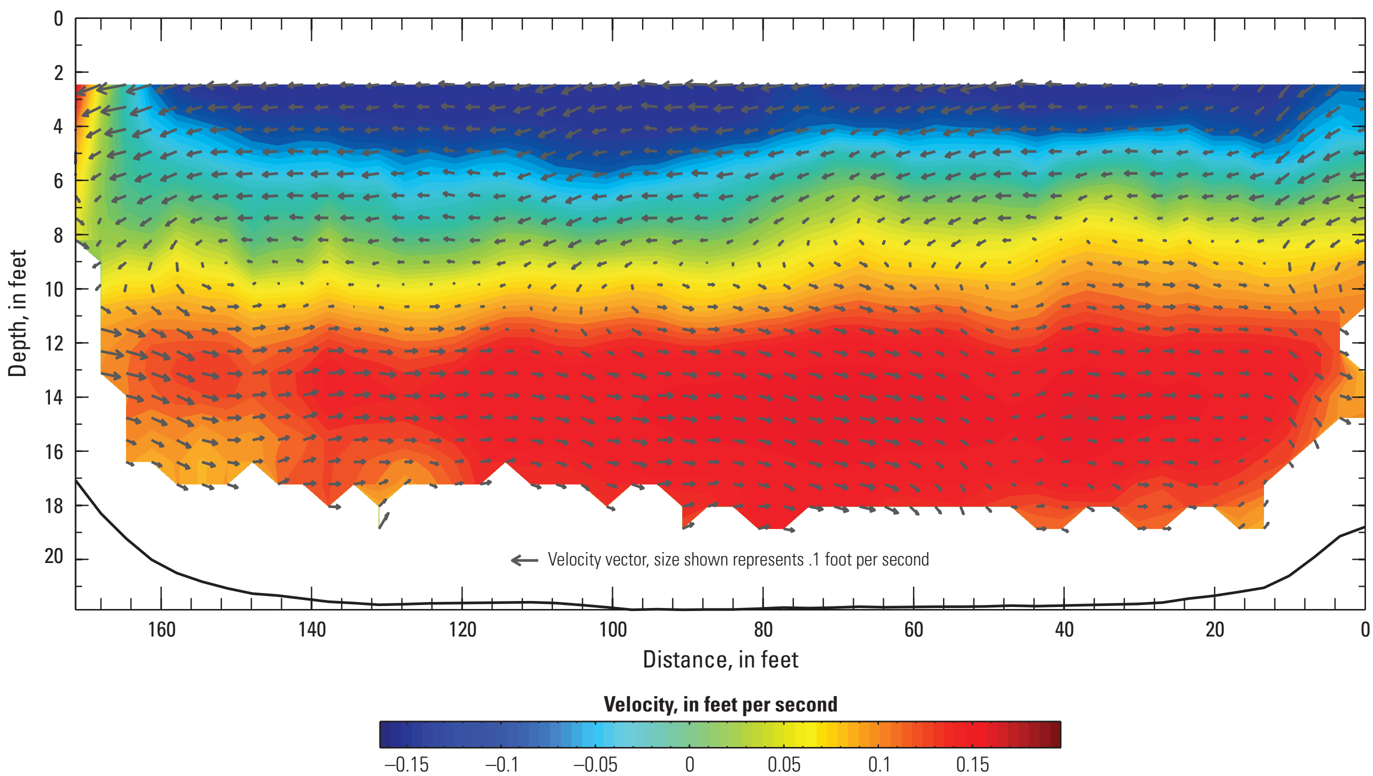


Figure 12. Velocity-contour plot showing bi-directional flow on the Chicago River at Columbus Drive, December 1, 1998. Top flow (blue and purple contour) is moving east, bottom flow (red and yellow contour) is moving west, and the middle (green contour) is the shear layer with near zero velocity (velocity scale magnitude is +/- 0.20 foot per second). The arrows represent secondary velocity within the bi-directional layers.

Stage-Area Rating

The stream reach defined by AVM transducer assemblies was surveyed in 1996 using a single-beam echo sounder and a total station level survey. High buildings surrounding the streamgage eliminated the possibility of using a global positioning system (GPS) because of multipath reflections of the GPS signal off the buildings; instead, a total station was used for the survey positioning. The Chicago River channel at Columbus Drive is rectangular, with a few irregularities on the streambed. Regression analysis of the survey data at the CRCD at Chicago, Ill., yielded the following stage-area rating:

$$A_{CRCD} = (208.33 \times G_{CRCD}) + 5061 \qquad (5)$$

where

A_{CRCD} is the rated area for the Chicago River at Columbus Drive and

G_{CRCD} is the gage height recorded at the gage.

The gage height is referenced to Chicago City Datum (CCD), which corresponds to 579.48 ft NGVD 29. Datum of the gage is 0.00 ft CCD.

Index-Velocity Ratings

Each AVM path at the Columbus Drive streamgage was treated independently, and all the AVM path configurations were evaluated to determine the most accurate index-velocity rating for computation of discharge. Four different velocity-velocity ratings were developed from ADCP and AVM data. Three of the four ratings used the average of two velocity paths, and the fourth rating was for a single AVM path. Paths 2 and 4 were located downstream of paths 1 and 3, as shown in figure 11. The velocity rating initially developed for paths 2 and 4 was a linear equation with zero intercept and was active during October 1996–September 1998 (table 2.).

In October 1998, this rating was re-evaluated and modified using additional discharge measurements. Velocity-rating number 2 was activated in October 1998 and remained in effect until the AVMs failed and were removed in July 2007. Both rating numbers 1 and 2 were considered the primary ratings for the gage and were used when data were valid on their respective paths. Two additional ratings were developed to provide backup ratings in case paths 2 and 4 failed.

Table 2. Index-velocity ratings for the Chicago River at Columbus Drive at Chicago, Illinois.

[V_{mean} = Slope*V_{index} + Intercept, where V_{mean} is the mean channel velocity and V_{index} is the index velocity for a specific instrument]

Rating number	Period of application	Slope	Intercept	Paths used to compute V_{index} (mean)	Comments
1.0	Oct. 1996 to Sept. 1998	0.785	0.0	2,4	Primary
2.0	Oct. 1998 to July 2007	.718	.01	2,4	Primary
3.0	Oct. 1996 to July 2007	.895	.01	1,3	Backup #1
4.0	Oct. 1996 to July 2007	.895	.01	3	Backup #2

The AVM paths 1 and 3 were evaluated similar to previously described paths, essentially resulting in one velocity equation for two velocity-velocity ratings. Ratings 3 and 4 were effective from October 1996 through the end of operation of the AVMs in July 2007. While both ratings have the same equation, rating number 3 uses the mean of the path velocities for paths 1 and 3 to define the index velocity, while rating number 4 uses only the path 3 velocity for the index velocity. Rating 4 was made for path 3 only, because path 1 experienced a significant number of failures and was unreliable for measuring continuous velocity. The same equation was used with ratings 3 and 4 because path 3, the more reliable record, had an appreciable effect on the combined path rating number 3. Multiple ratings at this site provided redundancy in computation of discharge and error checking.

The computed discharge record was compared with the theoretical flow values reported by MWRDGC for the CRCW and the number of lockages reported at Chicago Lock. A regression equation for estimating missing data for periods when the equipment malfunctioned at the streamgage was developed using MWRDGC reported flows as the dependent variable or input. Mean annual flows for the CRCD at Chicago, Ill., calculated by the index-velocity method, are shown in table 3.

The streamflow-gaging station on the CRCD at Chicago, Ill., was operated as part of lakefront accounting during October 1, 1996–September 30, 2006 (fig. 13). The mean annual flows ranged from 119 to 463 ft^3/s during 10 water years of operation (table 3 lists the mean annual flows for water years 1997–2006).

Table 3. Mean annual flows for the Chicago River at Columbus Drive at Chicago Illinois, water years 1997–2006.

[ft^3/s, cubic foot per second]

Water year[1]	Mean annual flow, in ft^3/s
1997	463
1998	359
1999	203
2000	153
2001	119
2002	144
2003	139
2004	125
2005	123
2006	155

[1]Water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.

Figure 13. U.S. Geological Survey personnel making an acoustic Doppler current profiler discharge measurement on the Chicago River at Columbus Drive at Chicago, Illinois.

Calumet River below O'Brien Lock and Dam at Chicago, Illinois (05536358)

Streamgage History

On October 1, 1996, the USGS established a two-path AVM streamflow-gaging station on the CROLD at Chicago, Ill. (fig. 14). The CROLD is approximately 400 ft wide and 15 ft deep along the lock guide wall and in the navigation channel, but sloping along the left bank (fig. 14). There is a vertical wall along the right bank (lock guide wall). The AVM configuration consisted of a V-shaped set (fig. 14) of two paths with one AVM transducer in the vertical on each path. This set-up resulted in an upstream (closest to the lock and dam) velocity path and a downstream velocity path. The design was selected with the AVM manufacturer to provide enough information to accurately compute the total discharge and have redundancy in the index-velocity measurement. The left bank transducers are mounted on a steel piling cluster located approximately 100 ft from the left bank. This pile cluster was needed to mount the AVM transducers in deeper water to allow for changes in stage and minimize disturbance from river traffic. This AVM configuration enabled the discharge to be computed using the upstream path. the downstream path, or an average of the upstream and downstream paths.

Stage-Area Rating

The stage-area rating was developed by collecting bathymetric data through a detailed survey using a fathometer and a differential GPS. The areal extent of the survey was defined by the two AVM paths. The right bank consists of vertical steel sheet piling and the left bank contains gradually sloping cobble-to-mud bed material. The survey data were used to create a triangulated irregular network (TIN) of contiguous non-overlapping triangles representing the riverbed. From the TIN, one representative cross section was extracted to represent the average cross-sectional area covered by the two velocity paths, and this was used to derive an equation representing the stage-area rating. The stage-area rating for the CROLD is given by

$$A_{CROLD} = 400.46 \times G_{CROLD} + 5548.1 \qquad (6)$$

where

A_{CROLD} is the rated area for CROLD and

G_{CROLD} is the gage height at CROLD recorded in CCD elevation.

The gage height is represented in CCD, which corresponds to 579.48 ft NGVD 29. Datum of the gage is 0.00 ft CCD.

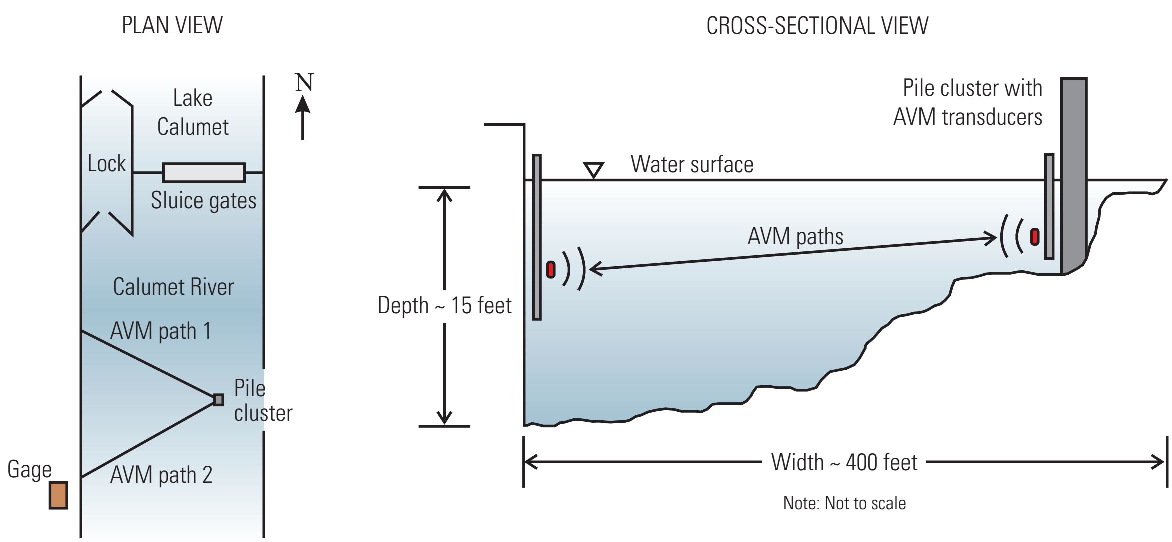


Figure 14. Plan and cross-sectional views of the acoustic velocity meter (AVM) streamflow-gaging station on the Calumet River below O'Brien Lock and Dam at Chicago, Illinois.

Index-Velocity Rating

Analysis of the AVM velocity data indicated there was little correlation among velocities measured in the upstream paths and velocities measured in the downstream paths, indicating non-uniform flow at the site. Overall, the velocity data revealed a very complex, low-flow setting that was affected by the outflows from the lock and dam, wind, a low-slope channel, discharge from the Grand Calumet River, and discharge of wastewater effluent from the MWRDGC's Calumet Water Reclamation Plant downstream. To investigate the correlation between the two AVM paths, data from each path were treated independently and used to define an index-velocity and a rating curve. The two rating curves developed for AVM paths 1 and 2 are shown in equations 7 and 8, respectively.

$$V_{M\text{-}CROLD} = 0.553 \times V_{AVM\ Path\ 1} + 0.0074 \quad (7)$$

$$V_{M\text{-}CROLD} = 0.1265 \times V_{AVM\ Path\ 2} + 0.0268 \quad (8)$$

where

$V_{M\text{-}CROLD}$ is the mean channel velocity in the CROLD at Chicago, Ill.;

$V_{AVM\ Path\ 1}$ is the index velocity for path 1 of the AVM; and

$V_{AVM\ Path\ 2}$ is the index velocity for path 2 of the AVM.

Equations 7 and 8 are substantially different in slope and intercept yet they produce similar discharge results when combined with the stage-area rating. Independent path-rating configurations provided a backup for computing discharge if one of the two velocity paths failed and it became necessary to compute discharge with just a single path.

Discharge measurements used to develop the velocity ratings were made between the sheet piling on the right bank and the pile clustered near the left bank. An illustration of the typical discharge-measurement setup is shown in figure 15. A tethered boat with the ADCP was secured between two ropes and pulled back and forth through the cross section with a person on the left H-pile and on the right bank. The area behind the H-pile was too shallow for the ADCP to measure and was accounted for in the edge estimate. The complex-flow patterns mentioned previously in this section are evident from ADCP discharge measurements and are represented by the velocity-vector map of depth-averaged velocity vectors shown in figure 16. The velocity distribution shown in figure 16 is one of many complex-flow distributions observed at this site. Such complex flows made it difficult to gage discharge at this location.

The streamflow-gaging station on the CROLD at Chicago, Ill., was operated as part of lakefront accounting during October 1, 1996–September 30, 2003. During the 7 water years of operation, the mean annual flows ranged from 88.8 to 191 ft^3/s (table 4 lists the mean annual flows for water years 1997–2003). The station was discontinued on September 30, 2003.

Figure 15. U.S. Geological Survey personnel making an acoustic Doppler current profiler discharge measurement on the Calumet River below O'Brien Lock and Dam at Chicago, Illinois.

Table 4. Mean annual flows for the Calumet River below O'Brien Lock and Dam at Chicago, Illinois, water years 1997–2003.

[cubic foot per second, ft^3/s]

Water year[1]	Mean annual flow, in ft^3/s
1997	191
1998	191
1999	169
2000	140
2001	117
2002	88.8
2003	95.4

[1]Water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.

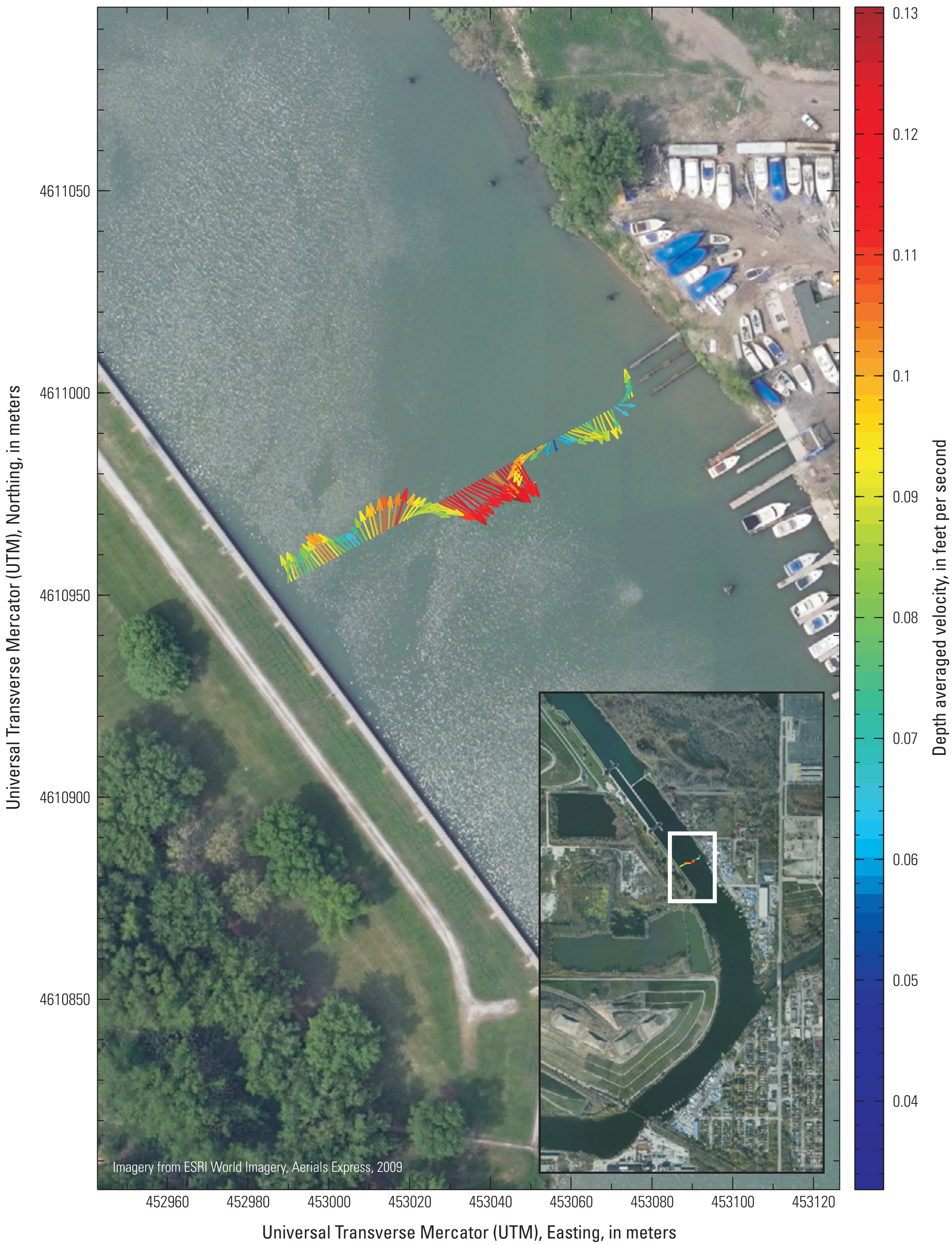


Figure 16. Map view of velocity contours with cross-sectional, depth-averaged velocity vectors plotted to illustrate the complex flow patterns that develop in the vicinity of the streamgage below O'Brien Lock and Dam, Chicago, Illinois.

North Shore Channel at Wilmette, Illinois (05536101)

Streamgage History

On September 7, 1999, the USGS established a two-path AVM streamflow-gaging station on the NSC at Wilmette, Ill. The NSC at Wilmette is approximately 90 ft wide and 9 ft deep in the center of the channel, and the bed slopes downward from both banks. The AVM configuration consisted of a V-shaped set (fig. 17) of two paths with one AVM transducer in the vertical on each path. This configuration resulted in an upstream velocity path and a downstream velocity path. The design was selected so that a single velocity path at this location would provide enough information to accurately compute the total discharge. The AVM transducers were mounted on steel posts driven into the channel bottom. The AVM transducer posts were located approximately 10 ft streamward from each bank.

Analyses of the AVM velocity data indicated that unless the MWRDGC–Wilmette Pumping Station is open and diverting water into the NSC, there is very little flow in the channel at this location. Effluent from the MWRDGC's North Side Water Reclamation Plant backs up water into the upper reaches of the NSC. Water velocities in the channel typically are very low (± 0.2 ft/s). The AVM was used for velocity measurements from September 1999 through the end of water year 2001. On September 13, 2001, a SonTek Argonaut SL ADVM was installed at the same location and elevation as the AVM path and was used as the primary velocity-measurement device during October 1, 2001–September 30, 2003, when the gage was discontinued. The ADVM was able to measure velocity across a nearly equivalent cross section as the AVM at NSC at Wilmette and produced a cleaner velocity record than produced by the AVM. Measuring more of the cross-sectional velocity is a key factor in the computation of discharge and comparison of the two technologies. The AVM and ADVM were operated simultaneously for a few months to ensure continuity of discharge data.

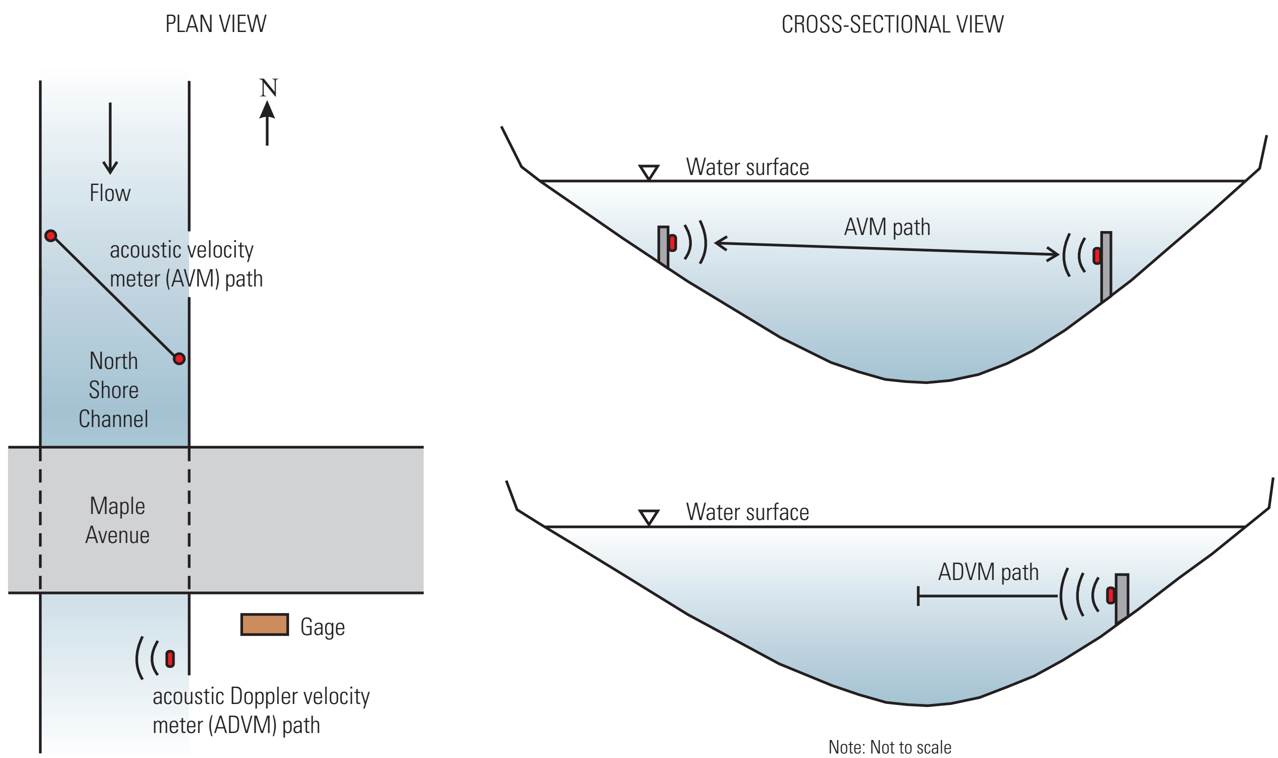


Figure 17. Plan and cross-sectional views of the acoustic velocity meter (AVM) and acoustic Doppler velocity meter (ADVM) streamflow-gaging stations on the North Shore Channel at Wilmette, Illinois.

Stage-Area Rating

The stage-area rating for the NSC at Wilmette, Ill., was developed using a cross-sectional survey from the Maple Avenue Bridge in Wilmette approximately 100 ft downstream of the velocity meter. The survey was done using traditional survey methods and a sounding weight from the bridge deck. A GPS survey with fathometer was not possible in the gage reach because of multipath interference from dense tree cover and the bridge structure. The channel at this location consists of sloping banks with an approximate maximum depth of 9 ft and an average width of approximately 67 ft.

Regression analysis of the channel survey data was used to develop the stage-area equation. The stage-area rating is obtained by

$$A_{NSC} = 91.228 \times G_{NSC} + 639.92 \quad (9)$$

where

A_{NSC} is the rated area for NSC at Wilmette, and
G_{NSC} is the gage height at NSC at Wilmette in CCD.

This rating was used throughout the entire period of record. The gage height was recorded in CCD, and the gage datum is 0.00 ft CCD, at 579.48 ft NGDV 29.

Velocity-Velocity Ratings

The streamflow-gaging station on NSC at Wilmette, Ill., was initially instrumented and operated using the Stednitz Marine Technologies AFFRA AVM. Two hundred and thirty-three discharge-measurement transects were used to develop the velocity-velocity relation for this site, with flows ranging from −12.8 to 179 ft^3/s. The gage elevation of the AVM path and the SonTek Argonaut SL ADVM were at −8.0 ft CCD. A regression analysis of the AVM index velocity and the mean channel velocity for the 233 discharge measurements yielded the index-velocity rating for the NSC at Wilmette, Ill., as

$$V_{M\text{-}NSC} = 0.632 \times V_{NSC\text{-}AVM \text{ or } (ADVM)} + 0.015 \quad (10)$$

where

$V_{M\text{-}NSC}$ is the mean channel velocity for NSC at Wilmette, and
$V_{NSC\text{-}AVM \text{ or } (ADVM)}$ is the index velocity measured by the AVM or ADVM.

This equation was developed using AVM and ADCP data and the AVM index velocity is defined as equation 10.

When the AVM was replaced by the ADVM in September 2001, the ADVM index velocity plotted on the original velocity rating and was statistically indistinguishable from the AVM rating. Therefore, equation 10 was used for calculating the index velocity for the entire period of record, October 1, 1999–September 30, 2003. Table 5 lists the mean annual flows for the streamflow-gaging station on the NSC at Wilmette, Ill., for the period of lakefront accounting. Water years 1997–8 were estimated based on a regression relation between the Wilmette Pumping Station and the streamgage data collected during water years 1999 and 2000.

Table 5. Mean annual flows for the North Shore Channel at Wilmette, Illinois, water years 1997–2003.

[ft^3/s , cubic foot per second; e, estimated from regression]

Water year[1]	Mean annual flow, in ft^3/s
1997	e47.7
1998	e50.0
1999	38.0
2000	21.8
2001	22.1
2002	37.4
2003	51.3

[1]Water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.

Chicago Sanitary and Ship Canal near Lemont, Illinois (05536890)

Streamgage History

In 2003, the decision was made to discontinue lakefront accounting as a method for LMDA. The installation of the electric dispersal barrier at Romeoville forced the relocation of the streamflow-gaging station at Romeoville to a site near Lemont, Ill. Therefore, the two methods for calculating annual discharge for LMDA were being terminated, and a new site would have to be selected, equipment installed, and ratings developed and calibrated. Lemont was selected as the site of the present LMDA streamflow-gaging station based on input from all involved agencies. The site of the new streamflow-gaging station was located approximately 5.9 mi upstream of the streamflow-gaging station at Romeoville on the right bank (Illinois Waterway Mile 302.0). With the necessary permission, notches were constructed into the canal at this location to house the AVM and other instrumentation. The construction, power connection, and instrumentation of the site was completed on December 7, 2004, and the streamflow-gaging station on the CSSC near Lemont, Ill., officially began recording data.

The installation of the streamflow-gaging station at Lemont preceded the removal of the streamflow-gaging station at Romeoville by approximately 17 months in order to collect simultaneous data at both locations to evaluate continuity of discharge records. The effort to ensure continuity of data collected on the CSSC as part of LDMA at the streamflow-gaging stations at Romeoville and Lemont was evident. However, 1 week prior to recording data at the Lemont streamflow-gaging station, the AVM cross-channel cables at Romeoville were severed by a barge. The decision was made by the USGS and the USACE–CD to install a new ADVM at Romeoville rather than replace the AVM for this discontinuing gage. In addition, efforts were made through other means such as simultaneous measurement of discharge; regression analysis of Romeoville data, Lemont data, and MWRDGC Lockport LMO-6 data; and numerical modeling to validate the continuity of record between sites.

At the time of this publication (2012), the streamgage on the CSSC near Lemont, Ill., is comprised of a three-path Accusonic ORE 7510 GS AVM as the primary index-velocity meter, a Teledyne RDI Channel Master Horizontal ADCP with upward-looking stage sensor as the backup index-velocity meter and backup stage sensor (located at the AVM path 2 elevation), and a Para Scientific pressure sensor (PS-2) as the primary stage sensor. In addition, temporary deployments including an upward-looking ADCP and temperature and conductivity strings are located at the streamgage for detailed studies of flow at the site (Jackson and others, 2012).

Gage Datum

On April 17, 2006, real-time kinematic (RTK) GPS levels were run from National Geodetic Survey (NGS) bench mark ME1728 (BM-1 at the streamgage CSSC near Lemont) to BM-2 at the streamgage CSSC at Romeoville. The streamgage CSSC at Romeoville was originally established on the North American Vertical Datum of 1988 (NAVD 88). When the swing bridge was removed from Romeoville, the original first-order bench mark (from which the gage datum was established) was destroyed. Therefore, it is not possible to recover the correct NAVD 29 elevation for the establishing bench mark. The purpose of the RTK GPS levels was to establish a gage datum referenced to NAVD 88 at the new site at Lemont and to confirm NAVD 88 datum at Romeoville. Since the streamflow-gaging station near Lemont was replacing the streamflow-gaging station at Romeoville, it was desired that both streamgages have the same gage datum and that Romeoville should have an updated elevation. Any revision of the previously published NGVD 29 datum would have to be based on a re-conversion from the new RTK GPS NAVD 88 value, because the establishing bench mark was destroyed. The 1988 conversion program predicts a change of $551.89 - 551.60 = -0.29$ ft from 1929 to 1988.

This compares reasonably well with the change of $551.89 - 551.76 = -0.13$ ft that was found, and it is unlikely that a re-conversion would be more reliable. It is assumed that RTK GPS levels actually run from known NAVD 88 elevations are more accurate than the conversion program. No revisions were made to the previously published NGVD 29 value. Although the streamflow-gaging station CSSC at Romeoville is discontinued, it is recommended that any future work use the gage datum of 551.76 ft NAVD 88.

Stage-Area Rating

Prior to gage construction beginning on the streamflow-gaging station on the CSSC near Lemont Ill., a bathymetric survey was completed using a fathometer and differential GPS. This survey was useful in characterizing the canal through the gage section as well as providing for the initial development of a stage-area rating. After construction was completed and the desired measurement cross section was selected, a series of ADCP discharge measurements were made on a tagline approximately 15 ft upstream of the right bank notch. This section was chosen for the area rating and discharge measurement section because the walls in this reach are vertical, and the bottom is nearly flat. Downstream of the cross section, the right bank has collapsed and there is a rubble pile of set block and fill protruding into the channel as shown in figure 18. The depths from the ADCP transects were also verified with a traditional Columbus sounding weight and A-reel. The ADCP and sounding data were entered into a USGS software program (Area-Comp), and a regression analysis yielded a stage-area rating as follows:

$$A_{CSSCL} = 139.83 \times G_{CSSCL} + 670.39 \quad (11)$$

where

A_{CSSCL} is the rated area for the CSSC near Lemont, and

G_{CSSCL} is the gage height at CSSC near Lemont.

Velocity-Velocity Rating

The primary index-velocity measurements for computation of discharge are obtained from the Accusonic ORE 3-path AVM system. The three paths are located at elevations of 18.4 ft, 13.2 ft, and 7.8 ft in the same cross section (see appendix 4–Station Descriptions, *#05536890 Chicago Sanitary and Ship Canal near Lemont, IL*, for the actual path elevations). Velocity for each path is measured for 100 seconds of each 2-minute interval, and the 2-minute values for each path are logged to a data logger. These 2-minute values then are averaged by the data logger program over 10-minute intervals and transmitted by the satellite transmitter. Both the 2- and 10-minute averaged values are stored in the USGS ADAPS database as separate time-series data with different transport codes. The 10-minute data are coded for data-collection platform (DCP) transmission through satellite radio, and the 2-minute data are coded as an electronic data log. The 2-minute data are used mainly for the development of velocity-velocity ratings because of the short duration of an ADCP transect. The 10-minute velocity data are processed using a script file that averages the three velocity-path values to compute the average cross-sectional velocity. The script is provided in appendix 6, and the explanation of how the AVM path coefficients were derived is described in appendix 5–Quality-Assurance Plans, *#05536890 Chicago Sanitary and Ship Canal near Lemont, IL*. Once the three paths are averaged, the AVM index velocities are used with the ADCP discharge measurement data to develop the velocity-velocity rating. A total of 440 discharge measurements were used to construct the velocity-velocity ratings for the streamflow-gaging station CSSC at Romeoville. The velocity-velocity rating for CSSC near Lemont was developed from 43 discharge measurements, consisting of 4 to 16 transects for each discharge measurement, covering the range of flows expected at the site. The index-velocity rating for the CSSC near Lemont, Ill., is

$$V_{I\text{-}CSSCL} = 0.8933 \times V_{AVM} - 0.0202 \quad (12)$$

where

$V_{I\text{-}CSSCL}$ is the index velocity for CSSC near Lemont, and

V_{AVM} is the AVM mean velocity from the average of the three AVM paths.

The computed discharge is a result of multiplying the values from A_{CSSCL} and $V_{I\text{-}CSSCL}$ for either the 1- or 10-minute values.

While the AVM is the primary index-velocity meter used at CSSC near Lemont, a backup system for index-velocity measurement also is available. The backup system is a Teledyne RD Instruments Channel Master horizontal acoustic Doppler current profiler (HADCP). The ADVM is located

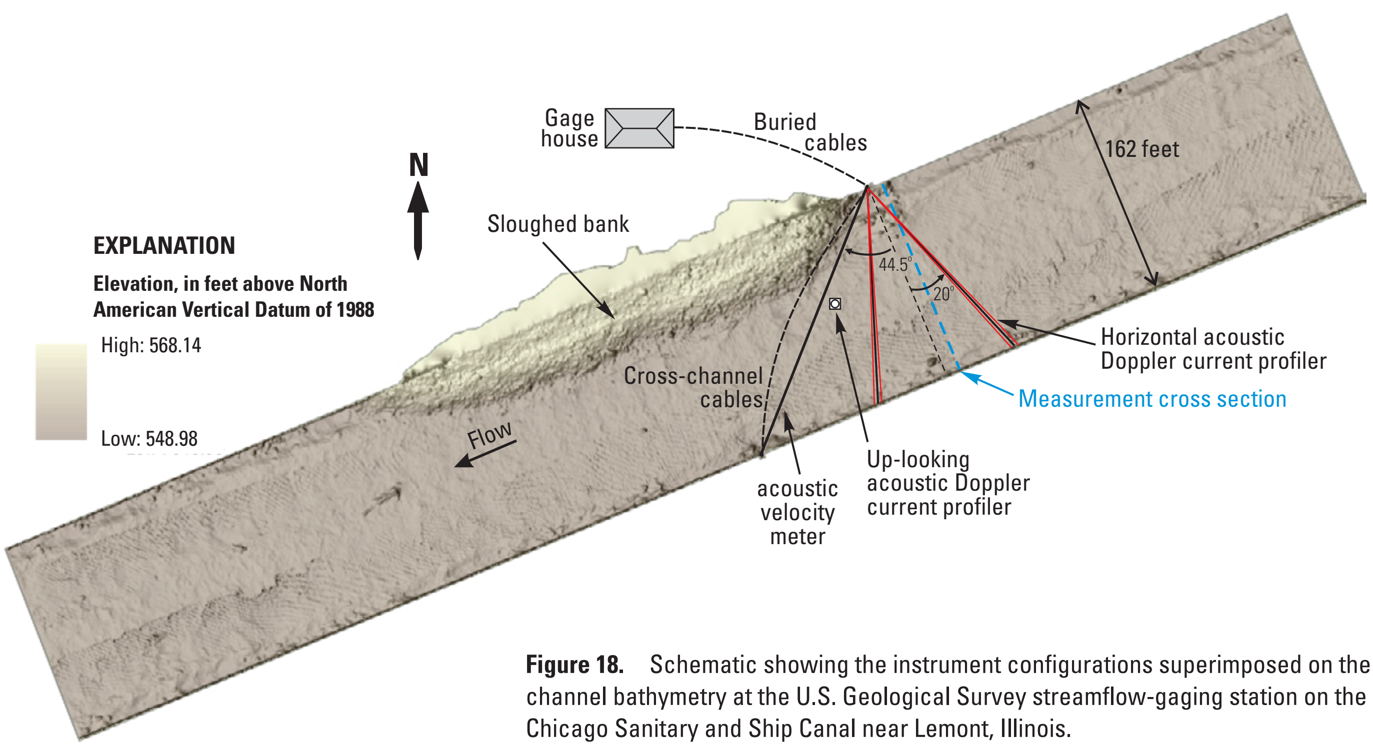


Figure 18. Schematic showing the instrument configurations superimposed on the channel bathymetry at the U.S. Geological Survey streamflow-gaging station on the Chicago Sanitary and Ship Canal near Lemont, Illinois.

adjacent to the right bank set of AVM transducers and is positioned at the same elevation as AVM path 2. The ADVM was installed during the initial construction setup at the site, but it experienced many problems during its first 2 years of operation; it did not produce reliable data until November 10, 2006, after receiving circuit-board replacements. The HADCP profiles across the full width of the channel from the right bank to the left bank. There is a space on the near side of the channel and far side of the channel that is not measured by the HADCP because of acoustic interference phenomena called "ringing" and "side lobe interference," respectively. The HADCP measures the reflection of acoustic energy off of particulates in the water column (called backscatter) to calculate the water velocity. The HADCP is deployed to collect velocity through nine 15-ft bins across the channel width. The velocity data for each bin are collected in a separate data logger from the AVM data and data logger, and the HADCP data are transmitted to the USGS database through a cellular-phone modem. No averaging of the velocity bins occurs in the data logger. The HADCP averaging occurs on a daily basis. A script file is run to export the HADCP velocity data from the USGS ADAPS database, average the individual bin velocity data, account for missing bins, then reload the averaged data back into the USGS ADAPS database. The HADCP measures the channel velocity as a 52-second average every minute. The averaged HADCP 1-minute values can then be used for analysis and rating development.

A total of 42 ADCP discharge measurements were available for analysis and development of the HADCP index-velocity rating. The linear index-velocity rating for the CSSC near Lemont, Ill., for the HADCP is

$$V_{I\text{-}CSSCL\text{-}HADCP} = 0.8718 \times V_{HADCP} + 0.0338 \qquad (13)$$

where

$V_{I\text{-}CSSCL\text{-}HADCP}$ is the mean channel velocity for the CSSC near Lemont, and

V_{HADCP} is the HADCP 9-bin averaged index velocity.

The computed discharge is a result of multiplying the rated area, $A_{CSSCL,}$ and the mean channel velocity, $V_{I\text{-}CSSCL\text{-}HADCP}$, for the 1-minute values. Both instruments (AVM and HADCP) and corresponding index-velocity equations utilize the same stage-area rating and result in equivalent discharge values. Jackson and others (2012) analyzed and compared the two instruments (AVM and HADCP) as deployed in the CSSC near Lemont, Ill.

Discharge Estimates

During the time in which the CSSC at Romeoville was the primary LMDA accounting streamgage and prior to 2001, there was only one set of equipment at a time installed in the channel. Discharge computed using the SonTek Argonaut SL ADVM never produced equivalent record to the AVM; therefore, if the equipment malfunctioned or the data were corrupted, the discharge data were missing. Melching and Oberg (1993) developed a method using multivariate regressions to estimate the daily discharge in the CSSC at Romeoville, Ill. These data were obtained from the monthly reports of daily flow data at Lockport, Ill., from the State of Illinois in the LMO6 report submitted by MWRDGC. These equations also were used as QA on flows computed at Romeoville. Multivariate regression equations were developed for the CSSC near Lemont to provide estimates of daily discharge in the event that both index-velocity instruments fail, and to provide a QA measure for Lemont flow records.

Development of the Lemont Regression Equations

The regression analysis required a sufficiently long discharge record at Lemont for comparison to the daily discharge data at Lockport. The measured daily discharges were obtained for the streamflow-gaging station CSSC near Lemont from December 8, 2004 (the beginning of published data) to June 30, 2008. Days in which the discharges were estimated were not used in developing the regression equations. Daily estimated discharges for the CSSC at Lockport were obtained from the LMO-6 forms for December 8, 2004, to June 30, 2008.

Following the approach used by Melching and Oberg (1993), regression equations were developed for three different discharge regimes at the MWRDGC Lockport powerhouse. Each regime is defined by a different combination of control operations. The first discharge regime is defined when flows are reported for turbine, lockage, and leakage (TLL) only. The second regime (TLL and sluice gate (SG)) is defined when flows are reported for both TLL and the SG. The third regime (TLL, SG, and controlling works (CW)) is defined when flows are reported for the TLL, SG, and the CW gate. Table 6 lists the number of days during the period analyzed when each regime was active.

The following set of regression equations were developed in order to use the Lockport estimated daily discharges for a particular discharge regime to predict the daily discharge in the CSSC near Lemont, Ill. The regression equations were developed such that the Lockport discharge coefficients remained constant from one equation to the other.

Table 6. Active flow regimes at the Chicago Sanitary and Ship Canal, Lockport, Illinois, December 8, 2004 to June 30, 2008.

[TLL, turbine, lockage and leakage only; SG, sluice gates; CW, controlling works]

Regime	Days active[1]
TLL	1,281
TLL and SG	335
TLL, SG, and CW	50

[1]Days active included partial days in which multiple regimes were implemented in 1 day.

Regression Equation for the TLL Regime

A univariate regression for regime TLL of the form

$$Q_{Lemont-TLL} = a_{00} + a_{10} \times Q_{TLL} \tag{14}$$

was performed to obtain the coefficients in equation 14. In equation 14, $Q_{Lemont\text{-}TLL}$ is the measured daily discharges at Lemont when the *TLL* only regime was occurring at Lockport, and Q_{TLL} is the discharge reported at Lockport during the *TLL* only regime. The regression equation for this regime is

$$Q_{Lemont\text{-}TLL} = 358.0 + 0.988 \times Q_{TLL} \tag{15}$$

Regression Equation for the TLL and SG Regime

A multivariate regression for regime TLL and SG of the form

$$Q_{Lemont-TLL\&SG} = a_{01} + \left(a_{00} + a_{10} \times Q_{TLL}\right) + a_{11} \times Q_{SG} \tag{16}$$

was performed to obtain the coefficients in equation 16. In equation 16, $Q_{Lemont\text{-}TLL\&SG}$ is the measured daily discharges at Lemont when the *TLL* and *SG* only regime was occurring at Lockport, Q_{TLL} is the *TLL* discharge reported at Lockport during the *TLL* and *SG* only regime, and Q_{SG} is the *SG* discharge reported at Lockport during the *TLL* and *SG* only regime. Subtracting the *TLL* part from each side of equation 16 leaves a univariate regression,

$$Q_{Lemont\text{-}TLL\&SG} - (358.0 + 0.988 \times Q_{TLL}) = a_{01} + a_{11} \times Q_{SG}. \tag{17}$$

The regression equation for this regime is

$$Q_{Lemont\text{-}TLL\&SG} - (358.0 + 0.988 \times Q_{TLL}) = 418.0 + 0.447 \times Q_{SG}. \tag{18}$$

Rearranging equation 18 yields

$$Q_{Lemont\text{-}TLL\&SG} = (358.0 + 0.988 \times Q_{TLL}) + 418.0 + 0.447 \times Q_{SG} \tag{19}$$

and simplifying equation 19 yields the multivariate regression equation for regime *TLL* and *SG*,

$$Q_{Lemont\text{-}TLL\&SG} = 776.0 + 0.988 \times Q_{TLL} + 0.447 \times Q_{SG}. \tag{20}$$

Regression Equation for the TLL, SG, and CW Regime

A multivariate regression for regime *TLL*, *SG*, and *CW* of the form

$$Q_{Lemont-TLL,SG,\&CW} = a_{02} + \left(a_{01} + \left(a_{00} + a_{10} \times Q_{TLL}\right) + a_{11} \times Q_{SG}\right) + a_{12} \times Q_{CW} \tag{21}$$

was developed to obtain the coefficients in equation 21.

where

$Q_{Lemont\text{-}TLL,SG,\&CW}$ is the measured daily discharges at Lemont when the *TLL*, *SG*, and *CW* regime was occurring at Lockport,

Q_{TLL} is the TLL discharge reported at Lockport during the *TLL*, *SG*, and *CW* only regime,

Q_{SG} is the SG discharge reported at Lockport during the *TLL*, *SG*, and *CW* only regime, and

Q_{CW} is the CW discharge reported at Lockport during the *TLL*, *SG*, and *CW* only regime.

Subtracting the *TLL* and *SG* part from each side of equation 21 leaves a univariate regression

$$Q_{Lemont\text{-}TLL,SG,\&CW} - (358.0 + 0.988 \times Q_{TLL}) + 418.0 + 0.447 \times Q_{SG} = a_{02} + a_{12} \times Q_{cw}. \quad (22)$$

The regression equation for this regime is

$$Q_{Lemont\text{-}TLL,SG,\&CW} - (358.0 + 0.988 \times Q_{TLL}) + 418.0 + 0.447 \times Q_{SG} = 323.8 + 0.827 \times Q_{cw}. \quad (23)$$

Rearranging equation 23 yields

$$Q_{Lemont\text{-}TLL,SG,\&CW} = (358.0 + 0.988 \times Q_{\mathrm{TLL}}) + 418.0 + 0.447 \times Q_{SG} + 323.8 + 0.827 \times Q_{cw} \quad (24)$$

and simplifying equation 24 yields the multivariate regression equation for regime *TLL*, *SG*, and *CW*

$$Q_{Lemont\text{-}TLL,SG,\&CW} = 1099.8 + 0.988 \times Q_{TLL} + 0.447 \times Q_{SG} + 0.827 \times Q_{cw}. \quad (25)$$

Equations 15, 20, and 25 were applied to the reported daily flow conditions from the Lockport LMO-6 report to obtain an estimate of discharge for missing days of record at the streamflow-gaging station CSSC at Lemont. According to Jim Yurik (Metropolitan Water Reclamation District of Greater Chicago, oral commun., September 2008), the operations at Lockport used the same methods of calculating daily flow totals for the TLL, SG, and CW for August 1998 through August 27, 2008. During July 2008, there were numerous problems with the AVMs in the fore bay of the turbines resulting in discontinued use of the AVMs. MWRDGC currently (2012) is using turbine-flow ratings in place of the AVM discharge ratings.

Conclusion

Since 1984, the U.S. Army Corps of Engineers has relied on the U.S. Geological Survey (USGS) for computations of mean annual flow at the Romeoville/Lemont, Illinois, acoustic velocity meter streamflow-gaging stations on the Chicago Sanitary and Ship Canal (CSSC), Lockport, Ill., for the Lake Michigan Diversion Accounting (LMDA) program. Table 7 lists the mean annual flows for the CSSC for water years 1985–2009.

The USGS–Illinois Water Science Center has made significant efforts to conform to the standards set forth in the 1967/1980 U.S. Supreme Court Decrees to use the best-engineering practices and scientific knowledge to measure streamflow and collect data at all of the LMDA program critical streamflow-gaging stations. This report serves as documentation of those practices and a history of streamflow measurements for LMDA prior to 2010.

Table 7. Mean annual flows for the Chicago Sanitary and Ship Canal, Lockport, Illinois, water years 1985–2009.

[cubic foot per second, ft^3/s]

Water year[1]	Mean annual flow, in ft^3/s
1985	3,789
1986	4,113
1987	4,028
1988	3,537
1989	3,515
1990	3,749
1991	3,790
1992	3,860
1993	4,074
1994	3,095
1995	3,235
1996	3,162
1997	3,222
1998	3,120
1999	2,926
2000	2,563
2001	2,710
2002	2,919
2003	2,342
2004	2,771
2005	2,725
2006	2,615
2007	3,167
2008	3,096
2009	3,267

[1]Water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.

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Appendix 1. 1967 U.S. Supreme Court Decree

U.S. Supreme Court

WISCONSIN v. ILLINOIS, 388 U.S. 426 (1967)

388 U.S. 426

WISCONSIN ET AL. v. ILLINOIS ET AL.

No. 1, Original.

Decree April 21, 1930.

Decree enlarged May 22, 1933.

Decree entered June 12, 1967.*

The Court, having reopened Nos. 1, 2 and 3, Original, and having granted leave to file No. 11, Original, entered this decree.

Decree reported, *281 U.S. 696* ; decree enlarged, *289 U.S. 395* .

Solicitor General Marshall for the United States.

Bronson C. La Follette, Attorney General, and William F. Eich, Assistant Attorney General, for the State of Wisconsin.

Douglas M. Head, Attorney General, and Raymond A. Haik, Special Assistant Attorney General, for the State of Minnesota.

William B. Saxbe, Attorney General, and Jay C. Flowers, for the State of Ohio.

William C. Sennett, Attorney General, and Thomas W. Corbett, Deputy Attorney General, for the Commonwealth of Pennsylvania.

Frank J. Kelley, Attorney General, Robert A. Derengoski, Solicitor General, and Nicholas V. Olds and Esther E. Newton, Assistant Attorneys General, for the State of Michigan.

Louis J. Lefkowitz, Attorney General, and Randall J. Leboeuf, Jr., Special Assistant Attorney General, for the State of New York.

William G. Clark, Attorney General, Thomas M. Thomas and Robert L. Stern, Special Assistant Attorneys General, and George A. Lane for the State of Illinois et al. [388 U.S. 426, 427]

DECREE.

This Court having reopened Original cases Nos. 1, 2, and 3, and having granted leave to file Original case No. 11, and having referred all such cases to a Special Master who has filed his Report, and the parties having agreed to the form of the decree, the Findings of Fact in the Report are hereby adopted, and it being unnecessary at this time to consider the Special Master's legal conclusions,

IT IS ORDERED, ADJUDGED, AND DECREED that:

1. The State of Illinois and its municipalities, political subdivisions, agencies, and instrumentalities, including, among others, the cities of Chicago, Evanston, Highland Park, Highwood and Lake Forest, the villages of Wilmette, Kenilworth, Winnetka, and Glencoe, the Elmhurst-Villa Park-Lombard Water Commission, the Chicago Park District and the Metropolitan Sanitary District of Greater Chicago, their employees and agents and all persons assuming to act under their authority, are hereby enjoined from

*Together with No. 2, Original, Michigan v. Illinois et al., No. 3, Original, New York v. Illinois et al., and No. 11, Original, Illinois v. Michigan et al.

diverting any of the waters of Lake Michigan or its watershed into the Illinois waterway, whether by way of domestic pumpage from the lake the sewage effluent derived from which reaches the Illinois waterway, or by way of storm runoff from the Lake Michigan watershed which is diverted into the Sanitary and Ship Canal, or by way of direct diversion from the lake into the canal, in excess of an average for all of them combined of 3,200 cubic feet per second. "Domestic pumpage," as used in this decree, includes water supplied to commercial and industrial establishments and "domestic use" includes use by such establishments. The water permitted by this decree to be diverted from Lake Michigan and its watershed may be apportioned by the State of Illinois among its municipalities, political subdivisions, agencies, and instrumentalities [388 U.S. 426, 428] for domestic use or for direct diversion into the Sanitary and Ship Canal to maintain it in a reasonably satisfactory sanitary condition, in such manner and amounts and by and through such instrumentalities as the State may deem proper, subject to any regulations imposed by Congress in the interests of navigation or pollution control.

2. The amount of water diverted into the Sanitary and Ship Canal directly from Lake Michigan and as storm runoff from the Lake Michigan watershed shall be determined by deducting from the total flow in the canal at Lockport (a) the total amount of domestic pumpage from Lake Michigan and from ground sources in the Lake Michigan watershed, except to the extent that any such ground sources are supplied by infiltration from Lake Michigan, by the State of Illinois and its municipalities, political subdivisions, agencies, and instrumentalities the sewage effluent derived from which reaches the canal, (b) the total amount of domestic pumpage from ground and surface sources outside the Lake Michigan watershed the sewage effluent derived from which reaches the canal, (c) the total estimated storm runoff from the upper Illinois River watershed reaching the canal, (d) the total amount of domestic pumpage from all sources by municipalities and political subdivisions of the States of Indiana and Wisconsin the sewage effluent derived from which reaches the canal, and (e) any water diverted by Illinois, with the consent of the United States, into Lake Michigan from any source outside the Lake Michigan watershed.

3. For the purpose of determining whether the total amount of water diverted from Lake Michigan by the State of Illinois and its municipalities, political subdivisions, agencies, and instrumentalities is not in excess of the maximum amount permitted by this decree, the amounts of domestic pumpage from the lake by the [388 U.S. 426, 429] State and its municipalities, political subdivisions, agencies, and instrumentalities the sewage and sewage effluent derived from which reaches the Illinois waterway, either above or below Lockport, shall be added to the amount of direct diversion into the canal from the lake and storm runoff reaching the canal from the Lake Michigan watershed computed as provided in paragraph 2 of this decree. The accounting period shall consist of the period of 12 months terminating on the last day of February. A period of five years, consisting of the current annual accounting period and the previous four such periods (all after the effective date of this decree), shall be permitted, when necessary, for achieving an average diversion which is not in excess of the maximum permitted amount; provided, however, that the average diversion in any annual accounting period shall not exceed one hundred ten (110) per cent of the maximum amount permitted by this decree. The measurements and computations required by this decree shall be made by the appropriate officers, agencies, or instrumentalities of the State of Illinois under the general supervision and direction of the Corps of Engineers of the United States Army.

4. The State of Illinois may make application for a modification of this decree so as to permit the diversion of additional water from Lake Michigan for domestic use when and if it appears that the reasonable needs of the Northeastern Illinois Metropolitan Region (comprising Cook, Du Page, Kane, Lake, McHenry, and Will Counties) for water for such use cannot be met from the water resources available to the region, including both ground and surface water and the water permitted by this decree to be diverted from Lake Michigan, and if it further appears that all feasible means reasonably available to the State of Illinois and its municipalities, political subdivisions, agencies, and instrumentalities [388 U.S. 426, 430] have been employed to improve the water quality of the Sanitary and Ship Canal and to conserve and manage the water resources of the region and the use of water therein in accordance with the best modern scientific knowledge and engineering practice.

5. This decree shall become effective on March 1, 1970, and shall thereupon supersede the decree entered by this Court in Nos. 1, 2, and 3, Original Docket, on April 21, 1930, as enlarged May 22, 1933, provided that for the period between January 1, 1970, and March 1, 1970, the amount of water diverted by Illinois into the Sanitary and Ship Canal (determined in accordance with paragraph 2 of this decree) shall not exceed an average of 1,500 cubic feet per second.

6. The complaint of the State of Illinois in No. 11, Original Docket, on behalf of its instrumentality, the Elmhurst-Villa Park-Lombard Water Commission, is hereby dismissed, without prejudice to that Commission sharing in the water permitted by this decree to be diverted from Lake Michigan.

7. Any of the parties hereto may apply at the foot of this decree for any other or further action or relief, and this Court retains jurisdiction of the suits in Nos. 1, 2, and 3, Original Docket, for the purpose of making any order or direction, or modification of this decree, or any supplemental decree, which it may deem at any time to be proper in relation to the subject matter in controversy.

8. All the parties to these proceedings shall bear their own costs. The costs and expenses of the Special Master shall be equally divided between the plaintiffs as a group and the defendants as a group in Nos. 1, 2, and 3, Original Docket. The costs and expenses thus imposed upon the plaintiffs and defendants shall be borne by the individual plaintiffs and defendants, respectively, in equal shares. [388 U.S. 426, 431]

Appendix 2. 1980 U.S. Supreme Court Decree

U.S. Supreme Court

WISCONSIN v. ILLINOIS, 449 U.S. 48 (1980)

449 U.S. 48

WISCONSIN ET AL. v. ILLINOIS ET AL. ON BILL IN EQUITY

No. 1. Original.

Decree April 21, 1930.

Decree enlarged May 22, 1933.

Decree entered June 12, 1967.

Decree amended December 1, 1980.*

Decree amended.

Decree reported: *281 U.S. 696*; decree enlarged: *289 U.S. 395*; decree entered: *388 U.S. 426*.

ORDERED:

A. Paragraph 3 of the Decree entered by the Court herein on June 12, 1967, is amended to read as follows:

3. For the purpose of determining whether the total amount of water diverted from Lake Michigan by the State of Illinois and its municipalities, political sub-divisions, agencies and instrumentalities is not in excess of the maximum amount permitted by this decree, the amounts of domestic pumpage from the lake by the State and its municipalities, political sub-divisions, agencies and instrumentalities the sewage and sewage effluent derived from which reaches the Illinois waterway, either above or below Lockport, shall be added to the amount of direct diversion into the canal from the lake and storm runoff reaching the canal from the Lake Michigan watershed computed as provided in Paragraph 2 of this decree. The annual accounting period shall consist of twelve months terminating on the last day of September. A period of forty (40) years, consisting of the current annual accounting period and the previous thirty-nine (39) such periods (all after the effective date of this decree), shall be permitted, when necessary, for achieving an average diversion which is not in excess of the maximum permitted amount; provided, however, that the average diversion in any annual accounting [449 U.S. 48, 49] period shall not exceed 3680 cubic feet per second, except that in any two (2) annual accounting periods within a forty (40) year period, the average annual diversion may not exceed 3840 cubic feet per second as a result of extreme hydrologic conditions; and, that for the first thirty-nine (39) years the cumulative algebraic sum of each annual accounting period's average diversion minus 3200 cubic feet per second shall not exceed 2000 cubic feet per second-years. All measurements and computations required by this decree shall be made by the appropriate officers, agencies or instrumentalities of the State of Illinois, or the Corps of Engineers of the United States Army subject to agreement with and cost-sharing by the State of Illinois for all reasonable costs including equipment, using the best current engineering practice and scientific knowledge. If made by the State of Illinois, the measurements and computations shall be conducted under the continuous supervision and direction of the Corps of Engineers of the United States Army in cooperation and consultation with the United States Geological Survey, including but not limited to periodic field investigation of measuring device calibration and data gathering. All measurements and computations made by the State of Illinois shall be subject to periodic audit by the Corps of Engineers. An annual report on the measurements and computations required by this decree shall be issued by the Corps of Engineers. Best current engineering practice and scientific knowledge shall be determined within six (6) months after implementation of the decree based upon a recommendation from a majority of the members of a three-member committee. The members of this committee shall be appointed by the Chief of Engineers of the United States

*Together with No. 2, Orig., Michigan v. Illinois et al., and No. 3, Orig., New York v. Illinois et al.

Army Corps of Engineers. The members shall be selected on the basis of recognized experience and technical expertise in flow measurement or hydrology. None of the committee members shall be employees of the Corps of Engineers or employees or paid consultants of any of the parties to these proceedings other than [449 U.S. 48, 50] the United States. The Corps of Engineers shall convene such a committee upon implementation of this decree and at least each five (5) years after implementation of this decree to review and report to the Corps of Engineers and the parties on the method of accounting and the operation of the accounting procedure. Reasonable notice of these meetings must be given to each of the parties. Each party to these proceedings shall have the right to attend committee meetings, inspect any and all measurement facilities and structures, have access to any data and reports and be permitted to take its own measurements.

B. Paragraph 5 of the said Decree entered by the Court herein is amended by adding thereto an additional sentence to read as follows:

The amendment to Paragraph 3 of this decree shall take effect on the first day of October following the passage into law by the General Assembly of the State of Illinois of an amendment to the Level of Lake Michigan Act providing that the amount used for dilution in the Sanitary and Ship Canal for water quality purposes shall not be increased above three hundred twenty (320) cubic feet per second, and that in allocations to new users of Lake Michigan water, allocations for domestic purposes be given priority and to the extent practicable allocations to new users of Lake Michigan water shall be made with the goal of reducing withdrawals from the Cambrian-Ordovician aquifer.

C. A certified copy of the above legislation shall be served upon the parties and filed with the Clerk of the Supreme Court by the State of Illinois. If no party raises an objection to the adequacy of the legislation within 30 days of service, Illinois will have complied with the requirements of the amendment made by this Order to paragraph 5 of the Decree entered by the Court herein on June 12, 1967. Any such objection shall be raised in the manner set forth in Paragraph 7 of said Decree. [449 U.S. 48, 51]

IT IS FURTHER ORDERED THAT:

Each of the parties to this proceeding shall bear its own costs. The expenses of the Special Master shall be borne by the State of Illinois and the Metropolitan Sanitary District of Greater Chicago, three-fifths thereof by the State of Illinois and two-fifths thereof by the Metropolitan Sanitary District of Greater Chicago.

JUSTICE MARSHALL took no part in the consideration or decision of this order.

STATEMENT OF INTENT AND TECHNICAL BASIS FOR PROPOSED AMENDMENTS TO 1967 DECREE

This statement sets forth the intent of the parties and the technical basis for the revisions to certain of the provisions of paragraphs 3 and 5 of the 1967 Decree.

The proposed change in the 1967 Decree has been designed to alter in part the provisions of the existing Decree that prevent Illinois from effectively utilizing and managing the 3,200 cubic feet per second (ft^3/s) of Lake Michigan water which Illinois was allocated.

Under the existing system, increasing amounts of impervious areas and increasing demand by domestic users elevate the risk that the language of the decree will be violated in any one or five year period if additional allocations are made by the State to domestic users for a period of years consistent with good management practice.

The proposed change accomplishes the following:

1. Increases the period for determining compliance with the 3200 ft^3/s limit from a five year running average to a forty year running average;

2. During the first thirty-nine years of the decree, allows Illinois to exceed the 3200 ft3/s limit by 2000 ft^3/s -years in the aggregate (one ft^3/s -year is the volume of water resulting from an average flow of one ft^3/s for a period of one year);
[449 U.S. 48, 52]

3. Limits the average diversion in any one accounting period to 115% of 3200 ft^3/s, but in two years of any forty year period permits the average diversion to reach 120% of 3200 ft^3/s, to allow for extreme hydrologic conditions.

The lengthening of the averaging period from five to forty years reduces the variability of the averaged figure, thus decreasing the amount of water that needs to be held in reserve for storm water runoff and increasing the amount of water that may be allocated for domestic purposes to reduce in part the pumpage from the Cambrian-Ordovician aquifer.

The lengthening of the averaging period also allows an increase in the planning period to a period of time that is more compatible with the life of certain types of water supply facilities, thus permitting more efficient use of the available diversion without increasing the total allowable diversion, and permitting better management of all the water resources of the region.

In establishing the limits of paragraph three of the amended decree, the available data and uncertainties as to the behavior of and interactions between the various elements of the hydrologic regime under current and future conditions were limiting factors.

To estimate maximum hydrologic variations that must be considered in the allocation accounting process, the forty-four year precipitation and runoff data contained in "Water Yield, Urbanization, and the North Branch of the Chicago River," a report by the Northeastern Illinois Planning Commission and Hydrocomp, Inc., dated October 14, 1976, were used. These data assumed a 30% imperviousness factor and were used by the parties to approximate the conditions of the entire Lake Michigan diversion watershed at the present time.

These data indicate that the maximum departure above the mean annual stormwater flow is 59%. Assuming, therefore, [449 U.S. 48, 53] that the mean annual stormwater flow is 683 ft^3/s, the maximum departure is 405 ft^3/s. This could result in a diversion of 13% above the allowable 3,200 ft^3/s maximum. Given the relatively short period of record and the likelihood of increased runoff resulting from urbanization, it was agreed that a 15% exceedance, to a maximum of 3680 ft^3/s, would be allowed in any year to accommodate high stormflows and that in any two years of the 40 year accounting period the diversion may be increased by 20%, to a maximum of 3840 ft^3/s, to accommodate extraordinary hydrologic conditions.

Because of year-to-year variations in storm runoff there will be series of years when the average annual diversion will need to exceed 3200 ft^3/s for best management, and some years when the diversion will be less than the 3200 ft^3/s average. Calculations of the cumulative sum of the annual departures show that the maximum cumulative exceedance of 3200 ft^3/s would be slightly below 1500 ft^3/s -years as indicated by the forty-four years of data that were used. The possibility exists that in the initial forty year period the cumulative exceedance may be greater than 1500 ft^3/s -years. Since the record used is relatively short and urbanization is likely to increase runoff, the maximum cumulative exceedance has been established at 2000 ft^3/s -years.

The goal of this amended Decree is to maintain the long-term average annual diversion of water from Lake Michigan at or below 3200 ft^3/s. [449 U.S. 48, 54]

Appendix 3. Water Resources Development Act (WRDA) 1986 (Public Law (PL) 99-662) Section 1142

SEC. 1142. MEASUREMENTS OF LAKE MICHIGAN DIVERSIONS.

(a) Beginning October 1, 1987, the Secretary, in cooperation with the State of Illinois, shall carry out measurements and make necessary computations required by the decree of the United States Supreme Court (388 U.S. 426) relating to the diversion of water from Lake Michigan and shall coordinate the results with downstate interests. The measurements and computations shall consist of all flow measurements, gauge records, hydraulic and hydrologic computations, including periodic field investigations and measuring device calibrations, necessary to compute the amount of water diverted from Lake Michigan by the State of Illinois and its municipalities, political subdivisions, agencies, and instrumentalities, not including water diverted or used by Federal installations.

(b) There are authorized to be appropriated $250,000 per fiscal year for each fiscal year beginning after September 30, 1986, to carry out this section, including those funds necessary to maintain the measurements and computations, as well as necessary capital construction costs associated with the installation of new flow measurement devices or structures declared necessary and appropriate by the Secretary.

Appendix 4. Station Descriptions

#05536995 Chicago Sanitary and Ship Canal at Romeoville, IL

Quad – Romeoville, 7-1/2' Series

Station Number: 05536995
Revised: 02-04-07
By: J.J. Duncker
Checked By: M.L. Harris

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' 27", long 88°03' 34" (NAD of 1983), in SE1/4SW1/4 sec. 35, T.37 N., R.10 E., Will County, Hydrologic Unit 07120004, on the left bank 40 ft upstream from Romeoville Road (135th Street), in Romeoville, 5.2 mi upstream from Lockport Lock and Dam, and at river mile 6.2.

To reach gage—Exit from I-80 at Richards St. in Joliet. Drive north on Richards St. approximately 0.9 mi to Jefferson St. (just past RR Viaduct). Proceed right on Jefferson St., which turns north and becomes Collins St., and later State Highway 171, for 5.5 mi to New Ave. (0.9 mi north of the intersection of State Highways 171 and 7). Turn left onto New Ave. and proceed 2.8 mi to 135th St. At 135th St. turn left and drive 0.6 mi to the Romeoville Rd. Bridge over the canal.

Before going over the bridge, turn right at the entrance to the refinery. Before entering the refinery gate, turn left on Chicks Rd. and follow the road beneath the new bridge west to the railroad tracks. Cross the railroad tracks and turn right onto the gravel access road that parallels the tracks. The gage is located approximately 150 ft north of the railroad crossing and immediately north of the bridge. The gage house is an 8 ft x 8 ft x 8 ft concrete block shelter.

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 were collected at the site during 1974–77 and during 1987–2006.

A Sarasota acoustic velocity meter (AVM) and a Type-A wire-weight gage (WWG) were installed 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 (ADR) were installed on April 3, 1984. The U.S. Army Corps of Engineers, Rock Island District, installed a data-collection platform (DCP) on October 28, 1986. A Campbell Scientific electronic data logger (CR10) was installed in October 1988. In June 1989, the ADR was removed.

The Sarasota AVM was replaced by a Ferranti ORE, Inc. AVM during the week of November 7–11, 1988. The ORE AVM was installed by M.P. DeVries, D.P. Morgan, J.J. Duncker, S.M. Robinson, and a representative from ORE. At the time of the ORE AVM installation, the downstream set of three transducers (upper, middle, and lower paths) was relocated 20 ft 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 ft downstream to a natural crevice in the canal wall.

On September 18, 1990, IDOT closed the bridge to road traffic and left the bridge in the open position. This made the WWG inoperable. A staff gage was installed on November 2, 1990.

A PVC stilling well with a Handar SDI-12 shaft encoder was installed during the week of July 6–9, 1992. The manometer was removed February 8, 1996, and a ParaScientific PS-2 pressure sensor (PS-2) was installed on April 26, 1996. Following the installation of the PS-2, the U.S. Army Corps of Engineers removed the DCP owing to incompatibility of instrumentation. The stilling wells for the shaft encoder float and the AVM uplooker transducer were removed on October 4, 2000. On November 29, 2000, a Design Analysis WaterLog H350 pressure sensor (H350) and an H355 gas-purge system (H355) were installed. The pressure sensor replaced the shaft encoder and AVM uplooker as backup instrument for the PS-2.

On May 11, 2001, a SonTek Argonaut-SL acoustic Doppler velocity meter (ADVM) was installed. The SonTek ADVM was a backup meter to the ORE AVM.

The ORE 7410 AVM malfunctioned on August 31, 2001. The transducers and mounting pipes were replaced and an ORE Accusonic 7510 AVM was installed during October 2001. The upper and middle paths for the 7510 AVM were made operational on April 1, 2002.

During water year (WY) 2003, the U.S. Army Corps of Engineers presented plans for installation of an electronic invasive species barrier to be located in the canal in close proximity to the AVM gaging station. The USGS conducted a series of field tests to evaluate the potential impact of the electric field on the gaging-station instrumentation. The results of these tests indicated adverse impacts. A site for the relocation of the AVM gaging station was found approximately 5 mi upstream near Lemont (river mile 302). The new gage became operational during fall 2004.

On Oct. 23, 2003, operation of the backup SonTek ADVM was discontinued and the meter was removed.

On December 1, 2004, the underwater cables for the ORE 7510 AVM were damaged and the orifice for the H350 was torn out. A SonTek ADVM was re-installed on December 10, 2004. At this time, the ORE 7510 and H350 were discontinued and removed from the gage, leaving the SonTek ADVM as the primary velocity meter and the PS-2 as the primary stage sensor.

On May 10, 2006, the station was discontinued and all instrumentation removed from the gage house. The station was discontinued owing to construction of the electronic invasive-species barrier immediately upstream of the bridge.

DRAINAGE AREA—739 mi^2

GAGE—the gage is discontinued and all equipment has been removed.

Prior to May 10, 2006: Campbell Scientific electronic data logger (CR10) with modem, SonTek Argonaut–SL acoustic Doppler velocity meter (ADVM), ParaScientific pressure sensor (PS-2), Design Analysis WaterLog H355 gas-purge system, staff gage, heater, and an air conditioner. The AVM velocity paths were configured and identified as follows: lower path (elevation 12.28), middle path (elevation 16.53), and upper path (elevation 19.54). The outside base gage was the staff gage on the canal wall in a natural niche where the orifice lines were located. The orifice line for the PS-2 was on the east (left) canal wall beneath the steel platform.

Power to the gage was supplemented by electrical service. The gage had a phone line.

Prior to December 1, 2004: A three-path ORE -Accusonic Flow meter Model 7510 acoustic-velocity meter (AVM) was used to obtain channel velocity. The AVM transducers were installed at two locations along the canal walls with one location on each bank with a path length of 239 ft (measured on January 15, 2002). The transducers were installed on 2-in. aluminum pipes, which were fabricated to be adjusted from the top of the canal wall. These pipes were located within chases cut into the limestone canal walls or within natural recessed openings. They were 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) was located along the east (left) bank approximately 130 ft upstream of the gage. The other set of three transducers was located along the west (right) bank near the upstream side of the bridge. Each pair (path) of transducers was at approximately the same elevation, across the canal from one another at a 44.5 degree angle to the canal sides, and at different vertical locations within the cross section. Each pair formed a velocity path. All transducers were linked to the acoustical velocity meter by individual electrical wires. The wires from the west (right) bank were attached to the canal wall, submerged along the canal bottom, attached to the east (left) wall within the chase, and buried underground to the gage house.

Prior to December 1, 2004: AVM transducer path, elevations, lengths, and angles were as follows:

Velocity path elevation	19.54
Velocity path elevation (formerly top)	16.51
Velocity path elevation (formerly middle)	12.28
Length of velocity paths	239.0 ft (January 15, 2002)
Angle of velocity paths	44.5 degrees

GAGE DATUM— Datum of gage is 551.76 ft NAVD 88. On April 17, 2006, D.J. Fazio and K.K. Johnson ran GPS levels from National Geodetic Survey bench mark ME1728 in the vicinity of the Lemont gage. The bench mark is the top of a copper bolt surrounded by the letters USPBM, leaded vertically into the wing wall of the railroad bridge near Lemont Rd., 4.4 mi upstream from the gage. The given elevation is 589.46 ft NAVD 88. The bench mark is described as: at Lemont, Cook County, at the Atchison, Topeka, and Santa Fe Railway bridge over the Chicago Sanitary and Ship Canal, in the wing wall of the south abutment, in the top of the west end stone of the second course above the ground, 2.2 ft from the west end of the stone, and 1.1 ft back from the face of the wing wall. USGS BM-2 (35.446 ft gage datum) was found to have an elevation of 587.204 ft NAVD 88.

Prior to 2006, the datum of gage was published as 551.89 ft above NGVD 29, determined from USAE BM 296.1 No. 113. The bench mark was 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 (595.064 ft above NGVD 29) was near the south end of coping and 0.95 ft west of east end. The bench mark has since been destroyed by bridge construction.

REFERENCE AND BENCH MARKS— (station discontinued May 10, 2006)

BM-2—Bronze gaging-station tablet in gage house concrete pad near landward side of gage door. Elev.=35.446 ft (basic point)

RM-2—Two file marks on top of metal post 10.5 ft upstream of metal walkway and 4 ft landward of canal wall. Elev.=33.925 ft

RM-3—chiseled Square on southwest corner of downstream concrete block 9 ft west of railroad tracks and 80 ft northwest of gage house. Elev.=38.338 ft

RM-4—Round head lag bolt at staff gage. Elev.=29.134 ft

RP-4—Carriage bolt in canal wall near top of staff board. Elevation = 29.352 ft

RP-6—Top of eyebolt on metal cap of permanent pipe fastened to canal wall on which the right downstream transducer assembly is mounted. Elev.=28.972 ft

RP-9—Two file marks 1.6 ft upstream of downstream end of metal handrail of metal walkway. Elev.=38.467 ft

RP-10—Top of bolt on staff plate. Elev.=29.884 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 Metropolitan Water Reclamation District of Greater Chicago 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 Metropolitan Water Reclamation District of Greater Chicago 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 forecast, the water surface is drawn down about 4 to 5 ft by opening the controlling works to temporarily lower the water level in the canal 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 using an acoustic Doppler current profiler (ADCP) mounted in a tethered boat. The boat can be pulled across the channel from the downstream side of the bridge. Moving-bed tests at low-, medium-, and high-flow conditions have not shown significant moving bed. Given the unsteady nature of the flow in the canal, 8–10 transects should be made in order to give a more accurate comparison to the AVM.

Possible variations in the flow should be checked by telephoning the Metropolitan Water Reclamation District, General Division for Maintenance and Operation, Supervising Civil Engineer, Jim Yurik at 312-751-5107.

BOAT ACCESS—Boat access is from the IDNR public boat ramp in Alsip, Illinois. The entrance drive to the boat ramp is located on 127th Street, approximately ¼-mi west of the Cicero St. / 127th St. exit ramp on Interstate 294. The entrance drive is marked by brown IDNR signs on the north side of 127th St., immediately east of the bridge over the Cal-Sag Channel and just west of the Budgetel Hotel. Follow the drive north and west as it parallels I-294 and passes by Volvo Truck Repair center. The boat ramp entrance is on the left-hand side as you pass the truck repair center.

After launching the boat, proceed downstream (northwest) past the confluence with the Chicago Sanitary and Ship Canal. At the confluence, bear left and continue several miles downstream to the AVM site, which is located immediately upstream of the Romeoville Road bridge. Barge traffic presents a significant safety hazard for boating operations at this site. Caution should be exercised near the barges and barge terminals along the channel. A marine radio is mandatory for communicating with barge captains. The travel time from the boat launch to the AVM site is typically 40–60 minutes. Spare 5-gallon fuel tanks should be carried on board for the roundtrip.

FLOODS—Maximum discharge, 19,466 ft^3/s, February 21, 1997, gage height, 23.95 ft; maximum gage height, 26.43 ft, February 4, 1996.

PEAKS ABOVE BASE—No peaks above base have been determined.

GAGE HEIGHT OF ZERO FLOW—Unknown.

WINTER FLOW—Free of ice formation.

REGULATION AND DIVERSION—Flow is diverted from Lake Michigan and is regulated by the Lockport Lock and Dam. The amount of diversion (3,200 ft^3/s) 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 were good. A quality-assurance plan for the computation of discharge records for this site was maintained in the USGS WSC office in Urbana, Illinois.

ESTIMATED RECORD—Discharges at this site can be estimated based upon a regression equation between this gage and the AVM located at the Lockport Controlling Works.

COOPERATION—U.S. Army Corps of Engineers, Chicago District has provided funding in the past.

OBSERVER—None

#05536890 Chicago Sanitary and Ship Canal near Lemont, IL

Quad – Sag Bridge, 7-1/2’ Series

Station Number: 05536890
Revised: 10-30-2008
By: K.K. Johnson
Checked By: J.K. LaTour

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Description of Gaging Station on **Chicago Sanitary & Ship Canal near Lemont, IL**

LOCATION—Lat 41°41' 29", long 87°57' 52" (NAD of 1983), in SE1/4NE1/4SW1/4 sec. 15, T.37 N., R.11 E., Du Page County, Hydrologic Unit 07120004, on right bank, 1.5 mi upstream from the Lemont Rd.(Stephen St.) bridge, and at mile 12.0 (Illinois Waterway mile 302.0).

To reach gage—Exit south from I-55 at Lemont Rd. near Bolingbrook. Drive south on Lemont Rd. 2.4 mi to a frontage road (just past Bluff Rd. and just before the Lemont Rd. Bridge). Turn right on the frontage road, cross over the low bridge over the Des Plaines River. Bear left beneath the Lemont Road (high bridge) and keep to the left as the road splits beneath the railroad bridge (the right lane is for large truck traffic only). At this point, the frontage road becomes Canal Bank Rd. Follow Canal Bank Rd. as it bends back to the north and then east along the Des Plaines River.

After approximately 1 mi, Canal Bank Rd. deteriorates to a bad gravel road. Continue to follow the gravel road as it leads east along the Des Plaines River and back into the Du Page County Forest preserve property. The gravel road ends and a paved bike path continue east towards the gaging station. The bike path is locked with a USGS 2640 key. The bike path turns sharply to the right at a Du Page County forest preserve sign and heads south for approximately 100 yd to the Chicago Sanitary and Ship Canal. Continue to follow the bike path as it bends to the east.

After 0.3 mi the bike path leads to a fenced enclosure for the tan brick building that houses the Argonne National Laboratory pumping station. A right turn just before the pump station leads to a gravel driveway and the USGS gaging station, located between the Argonne Pump Station and the Chicago Sanitary and Ship Canal. A chained access gate is locked with a USGS 2640 key.

The fenced enclosure surrounds a 10 ft x 20 ft shipping container that houses a 16-ft john boat. The fence key to remove the boat trailer from the enclosure is in the gage house.

The USGS gaging station is housed within an 8 ft x 8 ft green metal building located within the fenced enclosure. The key to the gage house is in a 2640 combination lock box in the shipping container that houses the john boat.

ESTABLISHMENT AND HISTORY—In January 2003, the U.S. Army Corps of Engineers held a meeting at Lockport Lock and Dam to discuss site selection for a second Invasive Species Barrier. At this time, the USGS was notified that the only suitable site for the second barrier was near the USGS gaging station on the Chicago Sanitary and Ship Canal at Romeoville (05536995). A series of tests were made by the USGS to evaluate the effects of the electrical field of the barrier on the instrumentation in the gaging station. The tests results indicated adverse impacts of the barrier electric field on the acoustic Doppler current profiler compass.

Discussions with the U.S. Army Corps of Engineers, Chicago District, in June 2003 led to the decision to relocate the Romeoville gage station to a site 5.9 mi upstream. The site for the new gaging station was reviewed and accepted by the USGS and members of the Fifth Technical Committee on Lake Michigan Diversion Accounting. A bathymetric survey was made at the new site on Oct. 29, 2003 by Jim Duncker, Gary Johnson, and Phil Dennis.

Construction at the site of the new gaging station began in January, 2004. The contract for site preparation and notching of the canal walls was awarded to Lakes and Rivers Contracting, Inc. A prefabricated gage house was delivered to the site and installed on a concrete foundation on Mar. 3, 2004. On Apr. 29, 2004, installed a ParaScientific pressure sensor (PS-2), two Campbell

Scientific electronic data loggers (CR10X), with a Teledyne RD Instruments ChannelMaster acoustic Doppler velocity meter (ADVM). On May 21, 2004, commercial divers installed the cross-channel cables for an acoustic velocity meter (AVM). A SonTek Argonaut SL AVM was installed on June 16, 2004. On July 1-2, 2004, AVM transducers were installed on aluminum pipes on both sides of the channel. An Accusonic ORE 7510 GS acoustic velocity meter was installed during August 2004. On Apr. 26, 2005, activated a Campbell Scientific high data rate satellite transmitter (DCP).

On Apr. 17, 2006, a GPS survey was conducted to coordinate the datum with the former gage at Romeoville. A common gage datum of 551.76 ft NAVD 88 was determined for the Lemont and Romeoville gages.

On Jan. 7, 2008, the AVM cross-channel cables were severed. The cables were replaced by commercial divers on May 20, 2008, and the AVM transducers were cleaned by the divers to ensure continued operation.

DRAINAGE AREA—738 mi^{2}.

GAGE—Two Campbell Scientific electronic data loggers (CR10X), Campbell Scientific high data rate satellite transmitter (DCP), ParaScientific pressure sensor (PS-2), three-path Accusonic O.R.E. 7510 GS Acoustic velocity meter, Teledyne RD Instruments Channel Master acoustic Doppler velocity meter (ADVM), and a staff gage. The base gage is the staff gage bolted to the north (right) canal wall, in the notch near the AVM transducers, velocity meters, and orifice lines. Orifice lines for the PS-2 are attached to the north (right) canal wall and run underground back to the gage house through the same 4in. PVC conduit as the AVM transducer cables.Six velocity transducers are at two locations along the canal walls with one location on each bank and a path length of 229.1 ft (July 8, 2004). The velocity transducers are on 2-in. aluminum pipes, which were fabricated to be adjusted from the top of the canal wall. These pipes are within the notches blasted into the limestone canal walls and formed with concrete above the water-line. They are secured to the canal walls by a horizontal strut and mounting brackets located above water surface to hold the pipes in a fixed position. One set of three transducers (upper, middle, and lower paths) is along the north (right) bank about 120 ft upstream from the gage. The other set of three transducers is along the west (left) bank. Each pair (path) of transducers are about the same elevation, across the canal from one another at a 45-degree angle to the canal sides, and at different vertical locations within the cross section. Each pair forms a velocity path. All transducers are linked to the AVM by individual electrical wires. The wires from the south (left) bank are attached to the canal wall, submerged along the canal bottom, attached to the north (right) wall within the notch, and buried under ground in 4-in. PVC conduit to the gage house.

Electrical service provides power to the gage. A heater in the gage house is used to maintain proper operation of the equipment.

Elevations, in feet, of prominent gage features are:

Velocity path 1 elevation	18.4
Velocity path 2 elevation	13.2
Velocity path 3 elevation	7.8
Channel Master elevation	13.3

AVM transducer path lengths and angles are as follows:

Length of velocity paths in AVM	234.8 ft (Aug. 18, 2004)
Angle of velocity path in AVM	44.5 degrees

NOTE: Repair work at this gage may require diving. Commercial divers, such as Lindahl Marine or Lakes and Rivers Contracting, Inc., should be contracted for all diving work.

GAGE DATUM—Datum of gage is 551.76 ft NAVD 88.

On July 8, 2004, an unsuccessful attempt was made to use differential GPS to establish the gage datum of the gaging station. The GPS survey was run from a first-order monument beneath the railroad bridge in Lemont.

On Apr. 17, 2006, D.J. Fazio and K.K. Johnson ran GPS levels from National Geodetic Survey bench mark ME1728 (USGS BM-1). The bench mark is the top of a copper bolt surrounded by the letters USPBM, leaded vertically into the wing wall of the railroad bridge near Lemont Rd., 2.0 mi downstream from the gage. The given elevation is 589.46 ft NAVD 88. The bench mark is described as: at Lemont, Cook County, at the Atchison, Topeka, and Santa Fe Railway bridge over the Chicago Sanitary and Ship Canal, in the wing wall of the south abutment, in the top of the west end stone of the second course above the ground, 2.2 ft from the west end of the stone, and 1.1 ft back from the face of the wing wall.

REFERENCE AND BENCH MARKS—

BM-1—Leaded bolt in southwest wing wall of Railroad Bridge over Canal, just upstream of Lemont Road (NGS ME1728). Elev.=37.70 ft

BM-2—Bronze tablet in gage house concrete pad on Canal side near gage door. Elev.=34.761 ft

RM-1—Chiseled square in concrete edge of upstream corner of downstream notch on left bank. Elev. not determined.

TRM-2—Rod in ground on north side of canal across from BM-1. (established for GPS levels to Romeoville and removed)

RP-1—Two file marks in aluminum angle bolted to wall of upstream notch on right bank. Elev.=32.386 ft

RP-2—Two file marks in top strut next to upstream pipe in upstream notch on right bank. Elev.=30.654 ft

RP-3—Two file marks in top strut in downstream notch on left bank. Elev. not determined.

RP-4—Two file marks in lower edge of concrete form in downstream notch on left bank. Elev. not determined.

RP-5—Two file marks on Argonne Lab discharge pipe downstream of notch on right bank. Elev.= 27.860 ft

RP-6—Bolt in staff gage board. Elev.=27.057 ft

CHANNEL AND CONTROL—The canal was constructed by using dynamite to cut an opening in the limestone outcrop, having near vertical walls 34 ft deep and a top width of 170 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 Metropolitan Water Reclamation District of Greater Chicago Dam and the U.S. Army Corps of Engineers Lock at Lockport, 11.1 mi downstream. High flow is controlled by the Lock and Dam and the Metropolitan Water Reclamation District of Greater Chicago Controlling Works, 8.9 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 forecast, the water surface is drawn down about 2–3 ft by opening the controlling works to temporarily lower the water level in the canal and to increase flows from the Chicago area. During these periods, the stage at the gage decreases and the velocity and discharge increase.

DISCHARGE MEASUREMENTS—Measurements are made using a boat-mounted acoustic Doppler current profiler (ADCP) and a tagline, or using an ADCP on a tethered-boat that is attached to manned lines at either side of the channel. The AVM should be set to collect 1-minute data and should be logged on a laptop computer. This is done so the AVM velocities and discharge can be compared with the ADCP measurements. Given the unsteady nature of the flow in the canal, ten to fourteen transects should be made in order to give a more accurate comparison to the AVM. All stage gages should be read at 2-minute intervals during the measurements. The AVM discharge during the time of the ADCP measurement shall be weighted based on data recorded during the discharge measurement.

Possible variations in the flow should be checked by telephoning the Metropolitan Water Reclamation District, General Division for Maintenance and Operation, Supervising Civil Engineer, Jim Yurik at 312-751-5107.

BOAT ACCESS—Boat access is from the excavated boat ramp at the gaging station. To launch larger boats there are two public boat ramps within 5 to 7 mi upstream at either Alsip or Summit.

After launching the boat, proceed upstream (northeast) approximately 100 ft to the midpoint of the AVM paths. Barge traffic presents a significant safety hazard for boating operations at this site. Caution should be exercised near barges. A marine radio is mandatory for communicating with barge captains.

FLOODS—Maximum discharge, 20,130 ft^3/s, Sept. 14, 2008, gage height, 28.81 ft; maximum gage height, 28.84 ft, Sept. 14, 2008, discharge 19,642 ft3/s.

PEAKS ABOVE BASE—No peaks above base have been determined due to regulation.

GAGE HEIGHT OF ZERO FLOW—Not applicable.

WINTER FLOW—Free of ice formation.

REGULATION AND DIVERSION—Flow is diverted from Lake Michigan and is regulated by the Lockport Lock and Dam. This gaging station provides flow data essential to determine Illinois' diversion of Lake Michigan water. A U.S. Supreme Court Decree of June 12, 1967, limits Illinois' diversion to an average of 3,200 ft3/s. Illinois' diversion includes stormwater runoff from a 673 mi2 diverted watershed area, and water diverted from the lake for domestic water supply, navigation and water-quality improvement in the Chicago Sanitary and Ship Canal system. Flows recorded at this station also include nondiversion flows.

ACCURACY—Discharge records are generally good. A quality-assurance plan for the computation of discharge records for this site is maintained in the USGS Water Science Center in Urbana, Ill.

ESTIMATED RECORD—Discharges for periods of missing record at this site are based upon a regression equation between this gage and the AVM located at the Lockport Controlling Works.

COOPERATION—U.S. Army Corps of Engineers, Chicago District

OBSERVER—None

SAFETY—

Traffic Safety—A traffic safety plan for making discharge measurements is not required at this site.

Hazards	Recommended Safety Procedures
Barge traffic	Keep a close look-out for barges and have a marine radio for communication with the tug captains.
Poison ivy	Spray weed killer around gage and paths. Use skin-treatment products. If exposed, wash immediately with non-moisturizing soap.

Recommended Protective Clothing and Equipment—Personal flotation device, long pants, long-sleeve shirts, work gloves, soap and wash water, ladder.

#05536123 Chicago River at Columbus Drive at Chicago, IL

Quad – Chicago Loop, 7-1/2' series

Station Number: 05536123
Revised: 04-23-09
By: K.K. Johnson
Checked By: M.L. Harris

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Description of Gaging Station on **Chicago River at Columbus Drive at Chicago, IL**

LOCATION—Lat 41° 53' 18", long 87°37'16" (NAD of 1983), in NW1/4NE1/4SW1/4 sec. 10, T. 39N., R. 14W., Cook County, Hydrologic Unit 07120003, on left downstream side of bridge within the Columbus Drive bridge structure in Chicago, 0.5 mi downstream from Chicago River Lock and Dam.

To reach gage—From the intersection of Columbus Drive and the Chicago River, drive 1 block south on Columbus Drive to the stoplight at South Water Street. Turn right onto the ramp leading down to the lower level of South Water Street. There is a stop sign at the bottom of the ramp. Turn right at the stop sign and proceed north 1 block to lowermost Wacker Drive. Park along lowermost Wacker Drive in the vicinity of the Columbus Drive Bridge.

The gage is located within the Columbus Drive Bridge building on the south side of the river. Access is through a series of locked doors (Jim Duncker has the only set of keys) at ground level located on the west side of the bridge building.

ESTABLISHMENT AND HISTORY—The gage was installed during November 1996 by Jim Duncker, Gerry Goddard (USGS-Wisconsin District), and Ken Koenig (USGS-Wisconsin District) and became operational on Dec. 2, 1996. The gage consisted of a Campbell Scientific electronic data logger (CR10) with phone modem, a four-path Stedtnitz Maritime Technology AFFRA acoustic velocity meter (AVM), and a Design Analysis WaterLog H350 pressure sensor.

For the initial gage installation in November 1996, the transducers were configured with a set of two transducers (paths 1 and 3) located along the south (left) bank approximately 200 ft upstream from the gage. The second set of two transducers (paths 2 and 4) was located along the north (right) bank near the upstream side of the bridge. Each pair (path) of transducers was at approximately the same elevation, across the canal from one another at approximately a 60 degree angle to the canal sides, and at different vertical locations [–8.00 ft and –15.00 ft Chicago City Datum (CCD)] within the cross section. Each pair formed a velocity path.

On Dec. 15, 1999 the AVM transducer configuration was modified to provide velocity paths at four different elevations in the channel, as opposed to a duplicate set of 2 velocity path elevations. The new configuration (–8.00 ft, –11.25 ft, –15.00 ft, –16.00 ft CCD) gave more detail on the vertical distribution of velocity in the channel.

An uplooker ADCP was installed on the bottom of the Chicago River at mid-channel and at a point in line with the east side of the Columbus Drive Bridge, and became operational in May 2003.

The AVM became unreliable on January 15, 2007. The AVM and 4-path transducers configuration were removed July 11, 2007.

A string of six temperature and conductance probes was installed September 19, 2007. Data was published starting on Oct. 1, 2007.

DRAINAGE AREA—Due to bi-directional flow at this location, a meaningful drainage area could not be determined.

GAGE— Campbell Scientific electronic data logger (CR10) with phone modem, a Design Analysis WaterLog H350 pressure sensor, a Teledyne RDI uplooker acoustic Doppler current profiler (ADCP), and a tape-down point (RP-TD). The ADCP is on the bottom of the Chicago River at mid-channel and at a point in line with the east side of the Columbus Drive Bridge.
The orifice is attached to the south (left) channel wall.

Adjacent to the orifice there is a string of six Campbell Scientific temperature and specific conductance probes that are connected to a separate Campbell CR-10X data logger that is located in a traffic-control box at the left edge of water. The probes are installed at different depths and are all referenced to Chicago City Datum as follows: from top to bottom –3.6 ft, –6.5 ft, –8.8 ft, –12.0 ft, –14.1 ft, and –15.7 ft.

An uplooker ADCP is installed on the bottom of the Chicago River at mid-channel and at a point in line with the east side of the Columbus Drive Bridge. The uplooker ADCP collects a single vertical profile every 5-seconds and records data to a PC located in the Columbus Drive bridge building. The PC is housed within an electrical enclosure. Due to the large volume of data, data from the uplooker ADCP is archived in files in the Water Science Center and is processed manually. Inquiries about the uplooker data should be directed to Kevin Johnson, Kevin Oberg, or Jim Duncker.

Prior to July 2007, eight velocity transducers were installed at four locations along the channel walls, with two locations on the south bank approximately 250 ft apart and 200 ft across from the other locations on the north bank. The velocity transducers were installed in, or attached to, 2-in. galvanized or aluminum pipes which were fabricated to be adjusted from the top of the channel wall. The transducers attached to the 2-in. pipe were secured by being directly inserted into pipe-fittings in the 2-in. pipe. They were secured to the channel walls by a steel bracket located above the water surface to hold the pipes in a fixed position.

The AVM transducer configuration provided velocity paths at 4 different elevations in the channel (–8.00 ft, –11.25 ft, –15.00 ft, –16.00 ft CCD) in order to give detail on the vertical distribution of velocity in the channel. All transducers were linked to the AVM by individual electrical wires. The wires from the north (right) bank were attached to the channel wall, submerged along the channel bottom, attached to the south (left) wall within 2-in. pipe, and buried underground to the gage house.

The AVM became unreliable on January 15, 2007. The AVM and 4-path transducers configuration were removed July 11, 2007.

Power to the gage is supplemented by electrical service.

For telephone repair service call SBC (877) 888-5622

Elevations, in feet, of prominent gage features are:

RP-2	2.97
RP-TD	5.40

GAGE DATUM— Datum of gage is 0.00 ft Chicago City Datum (CCD), which corresponds to 579.48 ft NGVD 29. On Oct. 24, 1996 personnel from the USGS Wisconsin Water Science Center ran levels to USGS RM-3 from City of Chicago bench mark number 4797.

Based on the U.S. Army Corps of Engineers VERTCON program, the datum of the gage in NGVD 29 converts to 579.20 ft NAVD 88. The NAVD 88 converted value is independent of Chicago City Datum.

REFERENCE AND BENCH MARKS—

RM-1—Bronze tablet set in the walkway on the south side of channel. Elev.= 5.394 ft (basic)

RM-2—Anchor bolt set in concrete sidewalk on the south side of the channel beneath bridge. Elev.= 5.383 ft

RM-3—Shoe bolt located in southwest corner of Columbus Drive Bridge. Elev.= 6.419 ft

RM-4—Bronze tablet set in top of channel wall on south side of channel, 150 ft west of gage. Elev.= 5.394 ft

RP-2—Three file marks in the top of orifice pipe bracket on channel wall. Elev.= 2.967 ft

RP-3—Top east side of downstream-most AVM transducer pipe C-channel. (not found August 2001)

RP-TD—Two file marks in 3-in. angle iron set in channel wall next to AVM transducer pipes. Elev.= 5.403 ft

CHANNEL AND CONTROL—The channel at this location consists of near vertical walls approximately 25 ft deep and a top width of approximately 200 ft. The channel bottom is almost horizontal with some rounding at the face of each bank. Flow in the Chicago River is controlled by structures both upstream and downstream of the ADCP gaging station. The downstream control for low and medium flows is the Metropolitan Sanitary District of Greater Chicago (MWRDGC) Dam and the U.S. Army Corps of Engineers Lock at Lockport, approximately 35 mi downstream. High flow is controlled by the Lock and Dam and the MWRDGC Controlling Works, approximately 32 mi downstream, which diverts water to the Des Plaines River. Upstream (towards Lake Michigan) from the ADCP gaging station is the MWRDGC Chicago River Controlling Works (CRCW). The CRCW consists of 8 sluice gates that are 10 ft wide and are used to divert flow both to and from Lake Michigan. Dispatchers at MWRDGC operate the sluice gates remotely from the MWRDGC headquarters at 100 East Erie Avenue in Chicago. The water surface elevation in the channel is maintained at about a –2.0 ft stage (CCD) at the gage. When heavy rains are forecasted the water surface is drawn down by opening the controlling works to temporarily lower flood waters and to increase the discharge from the Chicago area.

DISCHARGE MEASUREMENTS—Measurements are made from a tethered boat using an Acoustic Doppler Current Profiler (ADCP) by measuring across the channel. Tethered-boat ADCP measurements can be made from the east side of the Columbus Drive Bridge. Tethered-boat measurements need to be sure to keep boat speed less than water speed. It is also good practice to alert the Chicago Marine Police that work/measurements will be done from the bridge prior to making measurements.

BOAT ACCESS—Boat access is from the IDNR boathouse located on the turning basin wall to the south of the Chicago Lock. The closest public ramp for launching a boat is at Burnham Harbor, but the harbor will ice in during extremely cold winter periods.

FLOODS—Maximum daily discharge, 1,370 ft3/s, Aug. 6, 1997, minimum daily discharge, –2,450 ft3/s, Feb. 21, 1997, due to regulation.

GAGE HEIGHT OF ZERO FLOW—Can occur at any stage due to regulation.

WINTER FLOW—Ice forms in the channel during the winter months, but is generally broken into pans by the daily passage of the MWRDGC boat “Versiulus” or wave action.

REGULATION AND DIVERSION—Flow is diverted from Lake Michigan and is regulated by the CRCW and the Lockport Lock and Dam. The amount of diversion (3,200 ft3/s) is set by the Dec. 1, 1980 amendment to the Supreme Court of the United States Decree of June 12, 1967.

ACCURACY—Discharge records currently are not being computed due to unreliable velocity record. A quality-assurance plan for the computation of discharge records for this site is maintained in the USGS Illinois Water Science Center in Urbana, Illinois.

Temperature records are good.

Specific conductance records are good to fair, due to fouling of the probes.

ESTIMATED RECORD—Discharge for periods of missing record at the site can be determined via regression equations between the AVM and MWRDGC flow data for the CRCW.

COOPERATION—U.S. Army Corps of Engineers, Chicago District

OBSERVER—None.

HYDROGRAPHIC COMPARISON—Discharges can be compared to flow at CRCW obtained from MWRDGC.

SAFETY—Prior to any diving operation at this gage it is essential to obtain a permit from the Chicago Department of Transportation. No fee should be paid because of our status as a government agency. Also notify the Chicago Marine Police Unit that there will be divers at the given location at a specified date and time, and finally notify the US Coast Guard and the Chicago Lock that there will be divers.

Traffic Safety—A traffic safety plan for making discharge measurements is not required at this site.

Hazards	Recommended safety procedures
Lowering the tethered boat	Use proper lifting techniques
Panhandlers	Keep vehicles locked when not near and use personal caution
Chicago Police	Notify them o your activities to avoid hassle
Weather	Wear proper attire for the conditions
Ladder exposure to barges	If ladder access to channel wall is needed, a lookout should be posted to watch for barges
Poison ivy	Spray weed killer around gage and paths. Use skin-treatment products. If exposed, wash immediately with non-moisturizing soap.

Recommended Protective Clothing and Equipment—Personal flotation device, long pants, long-sleeve shirts, work gloves, soap and wash water.

#05536358 Calumet River below O'Brien Lock and Dam at Chicago, IL

Quad – Lake Calumet, 7-1/2' series

Station Number: 05536358
Revised: 02-03-2004
By: J.J. Duncker
Checked By: K.K. Johnson

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Description of Gaging Station on **Calumet River at O'Brien Lock and Dam at Chicago, IL**

LOCATION—Lat 41° 38' 53", long 87°33' 50" (NAD of 1983), in NW1/4 SE1/4 SE1/4sec. 36, T.37 N., R.14 W., Cook County, Hydrologic Unit 07120003, on the right bank 1,100 ft downstream from O'Brien Lock.

To reach gage—Exit from northbound I-94 (Bishop Ford Expressway) at 130th Street (East) in Chicago, Ill. Drive east on 130th Street approximately 1.0 mi to the entrance road for O'Brien Lock and Dam. The entrance road is located immediately west of the bridge over the Calumet River. Turn right onto the entrance road and follow the road across the railroad tracks and under the viaduct approximately 1.0 mi to the gated entrance to O'Brien lock and Dam. Check in with the lockmaster before proceeding to the gage. The gage is located at the downstream end of the lock guidewall, 1,100 ft below the downstream lock gates.

ESTABLISHMENT AND HISTORY—A two-path AFFRA acoustic velocity meter was installed by Jim Duncker and Gerry Goddard (USGS-Wisconsin District) during August-September 1996. The gage became operational on October 1, 1996.

DRAINAGE AREA—Bi-directional flow occurs at this site, so drainage area was not determined.

GAGE—A two path AFFRA acoustic velocity meter, Campbell Scientific CR-10 data logger with a temperature thermocouple, Handar SDI-12 shaft encoder operated over a float within the USACE stilling well, and a cell-phone telemetry system within a 4 ft x 2 ft x 2 ft aluminum instrument shelter. A 10 ft meteorological tower supports an anemometer and a tipping-bucket rain gage. AC power is available to run the equipment, telephone modem.

Four velocity transducers are installed at two locations along the lockwall and on the H-pile near the left bank. The four transducers comprise 2 velocity paths, paths 1 and 2. The velocity transducers are installed in 2-in. galvanized pipes. They are secured to the lock wall and Hpile by 4-in. steel channel with brackets located above the water surface to hold the pipes in a fixed position. The first velocity path (path 1) consists of a transducer that is located on the lock guidewall approximately 400 ft upstream of the gage and a second transducer that is located on the upstream side of the H-pile. The second velocity path (path 2) consists of transducer that is located on the downstream side of the H-pile and a second transducer that is located on the lock guidewall near the instrument shelter. All transducers are linked to the acoustical velocity meter by individual electrical cables. Cables to the transducers on the lock guidewall are buried in conduit that parallels the guidewall. Pull boxes are spaced intermittently along this conduit run. The cables from the H-pile transducers run through a stainless-steel junction box on the piling into a 2-in. galvanized pipe on the east side of the piling. The cables exit the piling at the bottom of the channel and are submerged across the river channel. On the right bank, the cross-channel cables come up the guidewall within 2-in. galvanized pipe and through burial conduit to the instrument shelter.

A staff gage is mounted to the downstream end of the lock guidewall near the instrument shelter. A float operated SDI-12 shaft encoder is located within the USACE stilling well. The USACE stilling well is the brown box-like structure near the end of the lock guidewall. The shaft encoder is linked to CR10 data logger by buried cable. The USACE stilling well also houses float-operated stage sensors for the USACE and MWRDGC. The AC power outlet within the USGS instrument shelter originates from an electrical circuit in the USACE stilling well.

A headwater stage sensor is located in the USACE stilling well on the upstream-side of the lock. A float operated SDI-12 shaft encoder is linked to a Campbell-Scientific CR500 data logger to record the headwater stage. The CR500 is located in a white electrical enclosure mounted to the north side of the USACE stilling well. A solar panel powers the CR500. A data storage module is connected to the CR500 as there is no telemetry to the headwater stilling well. A solar panel recharges the 12 volt battery that powers the CR500.

Elevations, in feet, of prominent gage features are:

Velocity path no. 1 guidewall transducer	–6.0 ft CCD
Velocity path no. 1 guidewall transducer	–6.0 ft CCD
Velocity path no. 2 H-pile transducer	–4.0 ft CCD
Velocity path no. 2 H-pile transducer	–4.0 ft CCD

Note that the velocity path elevations indicate sloping velocity paths, from –4.0 ft CCD on the H-pile to –6.0 ft CCD on the guidewall. This configuration was specified by Wolfgang Stedtnitz, Stedtnitz Maritime Technology, Ltd. to give a better representation of the channel mean velocity due to a sloping bed profile.

AVM transducer path lengths and angles are as follows:

Length of velocity path 1	390.65 ft
Length of velocity path 2	349.10 ft
Angle of velocity path 1	52 degrees
Angle of velocity path 2	62 degrees

For telephone repair services call SBC (877) 888-5622

GAGE DATUM—Datum of gage is 579.48 ft above NGVD 29. Chicago City Datum (MSL 1929).

REFERENCE AND BENCH MARKS—

BM-3—Bronze disk, (U.S. Army Corps of Engineers). Located 3 ft streamward of the first lamp post south of the riverside lock gates, labeled 319 + 7681. Elev. = 7.016 ft CCD

BM-4—Bronze disk, (U.S. Army Corps of Engineers), Located 4 ft landward of channel, next to the southern-most capstan, labeled 341 0455. Elev. = 4.815 ft CCD

RM-3—Two file marks on the landward side of the southern-most lamp post. Elev. = 7.468 ft CCD

RM-4—Two file marks on the landward side of the steel plate on top of the retaining wall and even with the upstream edge of the stilling well. Elev. = 4.974 ft CCD

RP-3—Top of lag bolt in 2” x 4” located in the inside southeast corner of the stilling well. Elev. = 6.137 ft CCD

RP-4—Square etched into the top of the MWRDGC recorder, located in the inside northeast corner of the stilling well. Elev. = 8.330 ft CCD

CHANNEL AND CONTROL—The river channel at this location has a vertical right bank at the lock guidewall and a sloping left bank. The channel bottom slopes, with the deeper water near the lock guidewall and the shallower water near the left bank. Depths are approximately 15 ft along the guidewall sloping to 10 ft at the H-pile. The channel shallows immediately east of the H-pile to a depth of approximately 2 ft. Two structures control the flow of water in the river channel at this location. The downstream control for low and medium flows is the MWRDGC Dam and the U.S. Army Corps of Engineers Lock at Lockport, approximately 35 mi downstream. High flow is controlled by the Lock and Dam and the Greater Chicago Metropolitan Sanitary District Controlling Works, approximately 32 mi downstream, which diverts water to the Des Plaines River. The water surface elevation in the river is maintained at about a −2 ft stage at the gage. When heavy rains are forecast, the water surface is drawn down by opening the controlling works to temporarily lower flood waters and to increase the discharge from the Chicago area. Flow at this site is also affected by sluice gates located at the O’Brien Lock and Dam 1,100 ft upstream of the gaging station. Sluice-gate openings are determined by dispatchers at the MWRDGC headquarters in Chicago (100 East Erie St.). Changes to the sluice gate settings are made by USACE personnel at the lock after instruction from the MWRDGC dispatcher.

DISCHARGE MEASUREMENTS—Measurements are made from a boat using an Acoustic Doppler Current Profiler (ADCP) by measuring across the channel at a point halfway between the upstream and downstream transducers. This midpoint is located between the 900 ft marker on the lock guidewall and the H-pile. Given the nature of the flow in the channel eight to ten transects should be made in order to give a more accurate comparison to the AVM to make sure it is working properly.

BOAT ACCESS—Boat access is from the public boat ramp opposite the downstream end of the lock. The entrance drive to the boat ramp is located off of Torrence Avenue at 135th Street. There is normally a $5 fee to launch at this ramp, but the fee is waived for USGS working at the lock. A marine radio is mandatory for communicating with the lockmaster and barge captains.

FLOODS—Heavy rains can raise the water level in this reach and necessitate a reverse flow through the sluice gates and lock.

POINT OF ZERO FLOW—Can occur at any stage.

WINTER FLOW—Heavy ice forms along the left bank near the H-pile and can damage the AVM transducers.

REGULATION AND DIVERSION—Flow is diverted from Lake Michigan and is regulated by the Lockport Lock and Dam. The amount of diversion (3,200 ft^3/s) 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 are rated fair. A quality-assurance plan for the computation of discharge records for this site is maintained in the USGS district office in Urbana, Illinois.

ESTIMATED RECORD—Discharges for periods of missing record at this site are based upon record for a partial day , if available, or two regression equations developed with the mean daily flows for the Obrien Lock and Dam as reported by the Metropolitan Water Reclamation District of Greater Chicago.

COOPERATION—U.S. Army Corps of Engineers, Chicago District

OBSERVER—None.

SAFETY—

Traffic Safety—A traffic safety plan for making discharge measurements is not required at this site.

Hazards	Recommended safety procedures
Discharge measurements	A marine radio is mandatory for communicationg with the lockmaster and barge captains.
Confined space	Refer to Job Hazard Analysis for confined spaces and WRD Policy Memo No. 2000.10—Policy & Guidelines for Surface-Water Gaging Station Stilling Wells That Meet OSHA's Definition of Confined Space

Reccommended Protective Clothing and Equipment—Personal flotation device.

#05536101 North Shore Channel at Wilmette, IL

Quad – Evanston, 7-1/2' series

Station Number: 05536101
Revised: 1/16/04 By: J.J. Duncker
Checked By: K.K. Johnson

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Description of Gaging Station on **North Shore Channel at Wilmette, IL**

LOCATION—Lat 42° 04'16", long 87°41'09" (NAD of 1983), in NE1/4NE1/4SW1/4 sec. 35, T. 42N., R. 13W., Cook County, Hydrologic Unit 07120003

To reach gage—From the intersection of Sheridan Road and Maple Avenue in Wilmette, drive 1 block west on Maple Avenue to the bridge over the North Shore Channel. The gage is located in a silver traffic control box adjacent to the sidewalk on the east side of the channel.

ESTABLISHMENT AND HISTORY—The AVM gage was installed during August 1999 by Jim Duncker and became operational on Sept. 7, 1999. A SonTek Argonaut-SL velocity meter was installed on Sept. 13, 2001. During the 2002 WY the original Affra acoustic velocity meter was taken out of operation for stream velocity readings, but is still maintained for acoustic stage readings.

DRAINAGE AREA—Due to bi-directional flow at this location, a meaningful drainage area could not be determined.

GAGE—A SonTek Argonaut-SL velocity meter, Campbell Scientific CR-500 data logger with a temperature thermocouple, acoustic (Affra uplooker) stage sensor, and a telephone telemetry system. AC power is available to run the equipment and telephone modem.

The SonTek Argonaut SL is installed on the downstream side of the Maple Avenue bridge approximately 20 ft downstream of the bridge and 10 ft from the left bank. The SonTek Argonaut SL is attached to a 2-in. pipe, driven into the channel bottom.

The Affra acoustic velocity meter is located approximately 100 ft upstream of the Maple Avenue Bridge. An acoustic stage sensor is attached to the downstream Affra transducer pipe assembly, which is along the left bank. All transducers are linked to the acoustic velocity meter by individual electrical wires.

Elevations, in feet, of prominent gage features are:

Velocity path (upstream assembly) transducers –8.0 ft CCD

AVM transducer path lengths and angles are as follows:

Length of Affra AVM velocity path	94.2 ft
Angle of Affra velocity path	45.1 degrees

For telephone repair service call SBC (877) 888-5622

GAGE DATUM—Datum of gage is 579.48 ft, CCD

REFERENCE AND BENCH MARKS—

CHANNEL AND CONTROL—The channel at this location consists of sloping banks and is approximately 9 ft deep at the normal pool elevation and a top width of approximately 67 ft. Flow in the North Shore Channel is controlled by structures both upstream and downstream of the AVM gaging station.

DISCHARGE MEASUREMENTS—Measurements are made from a boat using an acoustic Doppler current profiler (ADCP) by measuring across the channel. Given the nature of the flow in the channel 8 to 10 transects should be made in order to give a more accurate comparison to the AVM to make sure it is working properly.

BOAT ACCESS—

FLOODS—

POINT OF ZERO FLOW—Can occur at any stage.

WINTER FLOW—Ice forms in the channel during the winter months.

REGULATION AND DIVERSION—Flow is diverted from Lake Michigan and is regulated by the Wilmette Controlling Works, the CRCW, and the Lockport Lock and Dam. The amount of diversion (3,200 ft^3/s) 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 are good. A quality-assurance plan for the computation of discharge records for this site is maintained in the USGS district office in Urbana, Illinois.

ESTIMATED RECORD—Discharges for periods of missing record at this site are based upon record for a partial day. Correlation between the AVM and MWRDGC flow data have not been determined at this time.

COOPERATION—U.S. Army Corps of Engineers, Chicago District

OBSERVER—None.

SAFETY—

Hazards	Recommended safety procedures
Discharge measurements	A marine radio is mandatory for communicationg with the lockmaster and barge captains.

Recommended Protective Clothing and Equipment—

Appendix 5. Quality-Assurance Plans

#05536995 Chicago Sanitary and Ship Canal at Romeoville, IL

ROMEOVILLE AVM QUALITY-ASSURANCE PLAN
REV. 08/04/04

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 logbook will be maintained 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 logbook.

1. All stage-gage readings shall be read and recorded before and after the discharge measurements (staff gage, pressure transducer, float, and AVM depth gage).
2. 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 gage house. 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.
3. The 5-minute data 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 staff gage, and pressure transducers, and to log the AVM data. 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 four per year and should cover the range in discharge experienced at the site during the year.
3. Measurements are made from a tethered boat or a manned-boat a boat using an acoustic Doppler current profiler (ADCP) by measuring across the channel at the downstream end of the bridge.
4. The AVM report should be set-up to one minute output and captured in a computer log file. This is so the AVM velocities, can be compared with the ADCP transects/measurements.
5. Given the nature of the flow in the canal 10 to 14 transects should be made in order to give a more accurate comparison to the AVM to make sure it is working properly. Special attention should be made during the ADCP measurements to keep boat velocities less than water velocities.

ROUTINE MAINTENANCE—

1. Routine station levels shall be run every 2 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 re-measured if physical changes to the transducer locations are made.
4. Telemetry (telephone) shall be operated and maintained to facilitate reception of daily real-time data and to minimize AVM down time.

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:

$$\text{Channel Flow Area} = (\text{GH} \times 162) + 251.0$$
$$\text{Mean Channel Vel.} = 0.92 \times (\text{Mean AVM Vel.})$$

   where

$$\text{GH} = \text{gage height, in feet}$$
$$\text{Mean AVM Vel.} = (\text{Vel-U} + \text{Vel-M} + \text{Vel-X} + \text{Vel-L})/4 \text{ if all four paths are working, or}$$

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

$$(\text{Mean AVM Vel})/(\text{Vel-U}) = 0.967$$
$$(\text{Mean AVM Vel})/(\text{Vel-M}) = 0.990$$
$$(\text{Mean AVM Vel})/(\text{Vel-X}) = 1.003$$
$$(\text{Mean AVM Vel})/(\text{Vel-L}) = 1.049$$

5. 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 reported flows at Lockport by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC), provided by the U.S. Army Corps of Engineers, Chicago District.

Development of the Romeoville Regression Equations

Melching and Oberg (1993) developed regressions to compare CSSCR Accusonic ORE AVMs to the LMO-6 Lockport reported daily discharge.

CSSCR Regression for Published Daily Values

The series of regression equations that were used to estimate missing daily values at CSSCR are not well documented as to how they were derived, the R^2 value of the equation, or the standard error of the slope and intercept. Only an Excel spreadsheet that was used for the discharge calculations was found to support these equations being used. The method of calculations differed slightly with respect to maintaining the different parameters as constants throughout the different flow scenarios. The TLL flow equation was kept constant through the TLL & SG, and the TLL, SG, & CW flow scenarios, but the SG slope varied from one equation to the other.

The univariate regression for scenario TLL is

$$Q_{CSSCR\text{-}TLL} = 75.48 + 1.127 \times Q_{TLL}$$

where

$Q_{CSSCR\text{-}TLL}$ is the estimated daily discharges at Romeoville when the TLL only scenario was occurring at Lockport and

Q_{TLL} is the discharge reported at Lockport during the TLL only scenario.

The multivariate regression for scenario TLL and SG is

$$Q_{CSSCR\text{-}TLL\&SG} = 219.7 + 1.127 \times Q_{TLL} + 0.6842 \times Q_{SG}$$

where

$Q_{CSSCR\text{-}TLL\&SG}$ is the estimated daily discharges at Romeoville when the TLL & SG only scenario was occurring at Lockport,

Q_{TLL} is the TLL discharge reported at Lockport during the TLL & SG only scenario, and

Q_{SG} is the SG discharge reported at Lockport during the TLL& SG only scenario.

The final multivariate regression for scenario TLL, SG, and CW is

$$Q_{CSSCR\text{-}TLL,SG\&CW} = 1086 + 1.127 \times Q_{TLL} + 0.4361 \times Q_{SG} + 0.3228 \times Q_{CW}$$

where

$Q_{CSSCR\text{-}TLL,SG,\&CW}$ is the measured daily discharges at Romeoville when the TLL, SG, & CW scenario was occurring at Lockport,

Q_{TLL} is the TLL discharge reported at Lockport during the TLL, SG, & CW only scenario,

Q_{SG} is the SG discharge reported at Lockport during the TLL, SG, & CW only scenario, and

Q_{CW} is the CW discharge reported at Lockport during the TLL, SG, & CW only scenario.

A Second Multivariate CSSCR Regression for Daily Values

The measured daily discharges calculated from the three-path acoustic velocity meter (AVM) rating were obtained for the CSSCR gaging station from December August 1, 1998 (near the beginning of the Lockport AVM use in the turbine fore bays) to November 30, 2004. Days where the discharge was estimated were not used in developing the regression equations. Daily estimated discharges at Lockport were obtained from the LMO-6 forms for August 1, 1998 to November 30, 2004.

The number of days during the period analyzed when scenario TLL only occurred was 1572. The number of days during the period analyzed when scenario TLL & SG only occurred was 640. The number of days during the period analyzed when scenario TLL, SG, & CW occurred was 102. Following the same procedure that was used at CSSCL for developing the three flow scenario equations, the 8 years of AVM operation at CSSCR were used to develop the following regressions.

The univariate regression for scenario TLL is

$$Q_{CSSCR\text{-}2\text{-}TLL} = 305.57 + 0.9317 \times Q_{TLL}$$

where

$Q_{CSSCR\text{-}2\text{-}TLL}$ is the estimated daily discharges at Romeoville when the TLL only scenario was occurring at Lockport and

Q_{TLL} is the discharge reported at Lockport during the TLL only scenario.

The multivariate regression for scenario TLL and SG is

$$Q_{CSSCR\text{-}2\text{-}TLL\&SG} = 568.33 + 0.9317 \times Q_{TLL} + 0.4545 \times Q_{SG}$$

where

$Q_{CSSCR\text{-}2\text{-}TLL\&SG}$ is the estimated daily discharges at Romeoville when the TLL & SG only scenario was occurring at Lockport,

Q_{TLL} is the TLL discharge reported at Lockport during the TLL & SG only scenario, and

Q_{SG} is the SG discharge reported at Lockport during the TLL & SG only scenario.

The final multivariate regression for scenario TLL, SG, and CW is

$$Q_{CSSCR\text{-}2\text{-}TLL,SG\&CW} = 954.55 + 0.9317 \times Q_{TLL} + 0.4545 \times Q_{SG} + 0.2618 \times Q_{CW}$$

where

$Q_{CSSCR\text{-}2\text{-}TLL,SG,\&CW}$ is the measured daily discharges at Romeoville when the TLL, SG, & CW scenario was occurring at Lockport,

Q_{TLL} is the TLL discharge reported at Lockport during the TLL, SG, & CW only scenario,

Q_{SG} is the SG discharge reported at Lockport during the TLL, SG, & CW only scenario, and

Q_{CW} is the CW discharge reported at Lockport during the TLL, SG, & CW only scenario.

Multivariate CSSCR Argonaut-SL (SL) Regression for Daily Values

The measured daily discharges calculated from the three-path AVM rating were used for the CSSCR gaging station until November 30, 2004. On December 1, 2004, the cross-channel cables were damaged and not repaired. On December 12, 2004, a SonTek Argonaut SL (SL) ADVM was reinstalled and used to compute daily discharge at CSSCR until it was removed on May 9, 2006. Days where the discharge was estimated were not used in developing the regression equations. Daily estimated discharges at Lockport were obtained from the LMO-6 forms for December 1, 2004 to May 9, 2006. The SL had been installed and operated for a time prior to the AVMs being destroyed; however, the data appeared to be bias high during the overlapping period and were not used in this analysis.

The number of days during the period analyzed when scenario TLL only occurred was 446. The number of days during the period analyzed when scenario TLL & SG only occurred was 56. The number of days during the period analyzed when scenario TLL, SG, & CW occurred was 4.

Following the same procedure that was used at CSSCL for developing the three flow-scenario equations, 506 days of SL operation at CSSCR were used to develop the following regressions.

The univariate regression for scenario TLL is

$$Q_{CSSCR\text{-}SL\text{-}TLL} = 752.75 + 0.8559 \times Q_{TLL}$$

where

$Q_{CSSCR\text{-}SL\text{-}TLL}$ is the estimated daily discharges at Romeoville when the TLL only scenario was occurring at Lockport and

Q_{TLL} is the discharge reported at Lockport during the TLL only scenario.

The multivariate regression for scenario TLL and SG is

$$Q_{CSSCR\text{-}SL\text{-}TLL\&SG} = 744.96 + 0.8559 \times Q_{TLL} + 1.0959 \times Q_{SG}$$

where

$Q_{CSSCR\text{-}SL\text{-}TLL\&SG}$ is the estimated daily discharges at Romeoville when the TLL & SG only scenario was occurring at Lockport,

Q_{TLL} is the TLL discharge reported at Lockport during the TLL & SG only scenario, and

Q_{SG} is the SG discharge reported at Lockport during the TLL & SG only scenario.

The final multivariate regression for scenario TLL, SG, and CW is

$$Q_{CSSCR\text{-}SL\text{-}TLL,SG\&CW} = 0.8559 \text{ x } Q_{TLL} + 1.0959 \text{ x } Q_{SG} - 1.9250 \text{ x } Q_{CW} - 104.2$$

Where

$Q_{CSSCR\text{-}SL\text{-}TLL,SG,\&CW}$ is the measured daily discharges at Romeoville when the TLL, SG, & CW scenario was occurring at Lockport,

Q_{TLL} is the TLL discharge reported at Lockport during the TLL, SG, & CW only scenario,

Q_{SG} is the SG discharge reported at Lockport during the TLL, SG, & CW only scenario, and

Q_{CW} is the CW discharge reported at Lockport during the TLL, SG, & CW only scenario.

RECORD REVIEW—

1. The AVM discharge records shall be reviewed annually by someone other than the Project Chief.
2. A comparison shall be made annually between the AVM computed daily discharges and those provided by the U.S. Army Corps of Engineers, Chicago District (estimates based on 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.

Revised by: J.J. Duncker,
August 6, 2004

#05536890 Chicago Sanitary and Ship Canal near Lemont, IL

CSSC NEAR LEMONT AVM QUALITY-ASSURANCE PLAN
10/30/2008

For the Acoustic Velocity Meters in the **Chicago Sanitary and Ship Canal near Lemont, 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) and the backup acoustic Doppler velocity meter (ADVM) on the Chicago Sanitary and Ship Canal near Lemont, Illinois, also referred to as Lemont. Procedures will be presented for the collection, analysis, computation, and review of AVM records for Lemont.

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 near Lemont. The plan describes procedures to be followed and steps to be taken to insure the quality of the record for this site.

DOCUMENTATION—A logbook will be maintained to document all activities related to the operation and maintenance of the AVM and ADVM. 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 and ADVM will be noted. Standard USGS Inspection and Measurement sheets must also be filled out according to standard USGS practice as outlined in WSP 2175. Significant changes to the station will also be documented in the station description as part of the official station record.

GAGE INSPECTIONS—During visits to the AVM, the following tasks should be performed and recorded in the logbook and on official measurement or inspection sheets.

1. All gage readings shall be read and recorded before and after each discharge measurement (staff gage, pressure transducer, ADV, ADVM and ADVM depth gage).
2. 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 gage house. The master list also includes a printout of the configuration file from the ADVM that details the blanking distance, number of bins, bin size, and the number of ensembles to be averaged. 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.
3. The 10-minute data should be scanned to insure readings are reasonable and path velocities are not anomalous.
4. After a measurement is completed, download the two storage modules for the 1-minute data that were collected by the AVM and the ADVM. When downloading the data through the Campbell Scientific software, PC208, the file should be saved as "**ASCII with Array ID**" to facilitate DECODES processing and upload to ADAPS.

DISCHARGE MEASUREMENTS—

1. During the measurement read and record the staff gage height and time at the beginning/end of each transect.
2. Discharge measurements will be made at the rate of 4 to 6 per year and should cover the range in discharge experienced at the site during the year.
3. Measurements are made from a remote control boat or a manned-boat a boat using an Acoustic Doppler Current Profiler (ADCP) by measuring across the channel at the upstream end of the right bank equipment notch. A climbing anchor bolt is mounted to the set blocks on each side of the channel to mark the measurement cross section and to facilitate quick connecting of taglines.
4. Given the unsteady nature of the flow in the canal 10 to 14 transects should be made in order to give a more accurate comparison to the AVM to make sure it is working properly. At times more transects could also be merited to document a large wave of changing discharge. Standard USGS ADCP measurement protocol states that four transects within 5 percent of each other are acceptable to constitute a measurement and if one of more are outside of 5 percent then four additional transects should

be made and the average of all eight are averaged as the measurement (WRD Memo No. 2002.02). The memo also states that a single transect may be used as a discharge measurement but whenever possible use reciprocal pairs to avoid possible directional bias. Special attention should be made during the ADCP measurements to keep boat velocities less than water velocities.

ROUTINE MAINTENANCE

1. Routine station levels shall be run every three years, as per standard USGS streamgaging practices.
2. Levels shall be run to the transducers every 3 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 aluminum speed-rail pipe and (or) to each transducer.
3. Transducer path lengths and angles shall be measured and re-measured if physical changes to the transducer locations are made.
4. Telemetry (DCP) shall be operated and maintained to facilitate reception of daily real-time data and to minimize AVM down time.
5. Additional telemetry (Raven Modem) shall be operated and maintained for the redundant velocity and stage data to facilitate the backup record and to minimize ADVM down time.

DATA ANALYSIS—

1. The AVM and ADVM data that are being recorded by the two separate CR10s shall be loaded on a computer and checked for anomalies prior to departing the gage to ensure that both instruments are operating properly.
2. Velocity and depth unit values shall be graphically plotted to identify possible anomalous data.
3. Official discharge records shall be computed using a velocity-velocity rating for the AVM and a stage-area rating in ADAPS. The stage-area and velocity-velocity ratings are given by the following equations

$$\text{Stage Area Rating 1.0 for channel flow area} = (\text{GH} \times 139.83) + 670.39$$
$$\text{Velocity-Velocity Rating 1.0 for mean channel velocity} = 0.8933 \times (\text{Mean AVM Vel.}) - 0.0202$$

where

GH = gage height, in feet

Mean AVM Vel. = (Vel-U + Vel-M + Vel-L)/3 if all three paths are working.

If one or two paths are not working then the mean AVM velocity is computed by first correcting each working path velocity by a correction ratio and then taking their arithmetic mean. The correction ratios are documented in the following paragraphs.

Derivation of the AVM Path Coefficients

The 10-minute data from December 19, 2005 to January 3, 2007, was used in developing the path coefficients. The 10 minute periods with valid data for all paths gave 93,070 sets of valid velocities from paths 1–3. For each 10-minute period, the velocities from paths 1–3 were averaged together to determine an average AVM velocity. Path coefficients 1–3 were then determined for each valid 10minute period by dividing the average AVM velocity for that 10-minute period by the velocity corresponding to the path coefficient.

$$\frac{V_{avg}}{V_i} = AVM\ Coefficient$$

where

$i = 1,2,3$

When a path velocity is equal to zero, the path coefficient would equal infinity. Since a velocity of zero is still physically possible, the zero velocity was used in computing the average AVM velocity, but it was not used in computing the path coefficients. Not including the value of zero in computing the AVM path coefficients gave 93,029 values for path 1, 93,004 values for path 2, and 93,000 values for path 3. The computed path coefficients were then averaged together to obtain average AVM path coefficients. The average AVM path coefficients are

Path 1 = 0.9300
Path 2 = 1.0134
Path 3 = 1.0836

Application of the AVM Path Coefficients to obtain an Index Velocity

The Perl script calcav averages the 10-minute AVM velocities from paths 1–3 together and reports a mean velocity. When one of the paths report bad values the other two paths are multiplied by their respective path coefficients then averaged together for a mean velocity. When two paths report bad values the remaining path is multiplied by its path coefficient and reported as the mean velocity. When all paths are bad calcav flags the mean velocity as blank. The path coefficients are only applied when one or two of the AVM paths report bad velocities. The mean velocity from calcav is loaded back into ADAPS for application of the velocity-velocity rating equation to obtain the index velocity. The index velocity is multiplied by the rated area, derived from the stage-area rating, to obtain the rated discharge.

Missing AVM Record

Missing record for the AVM shall first be filled in, to the extent possible, with velocity and discharge record from the backup ADVM. The ADVM discharge record will be computed using the same stage-area rating as the AVM, and a velocity-velocity rating developed specifically for the ADVM. The ADVM Velocity-Velocity Rating 1.1 is given by the following equation:

$$\text{Velocity-Velocity Rating 1.1 for mean channel velocity} = 0.8718 \times (\text{Mean ADVM Vel.}) + 0.0338$$

where:

GH = gage height, in feet
Mean ADVM Vel. = the average of all nine velocity bins.

If both the AVM and the ADVM fail then the daily discharge is estimated by using multivariate regression equations based on reported flows at Lockport by the MWRDGC, provided by the U.S. Army Corps of Engineers, Chicago District. The derivations of the multivariate regression equations are described in a separate report, but the equations are as follows:

$$Q_{CSSCL\text{-}TLL} = 358.0 + 0.988 \times Q_{TLL}$$
$$Q_{CSSCL\text{-}TLL\&SG} = 776.0 + 0.988 \times Q_{TLL} + 0.447 \times Q_{SG}$$
$$Q_{CSSCL\text{-}TLL,SG\&CW} = 1099.8 + 0.988 \times Q_{TLL} + 0.447 \times Q_{SG} + 0.827 \times Q_{CW}$$

where

$Q_{CSSCL\text{-}TLL}$ is the estimated daily discharges at Lemont when the turbine, lockage, and leakage (TLL) scenario was occurring at Lockport and

Q_{TLL} is the discharge reported at Lockport for TLL flow.

$Q_{CSSCL\text{-}TLL\&SG}$ is the measured daily discharges at Lemont when the TLL & sluice gate (SG) only scenario was occurring at Lockport. Q_{SG} is the SG discharge reported at Lockport.

$Q_{CSSCL\text{-}TLL,SG,\&CW}$ is the measured daily discharges at Lemont when the TLL, SG, & controlling works (CW) scenario was occurring at Lockport.

Q_{CW} is the CW discharge reported at Lockport.

These equations are only valid through July 2008 because of changes in the measurement methods at Lockport (Jim Yurik, Metropolitan Water Reclamation District of Greater Chicago, oral commun., September 2008).

Constant vigilance with gage transmissions and record quality is necessary to reduce the number of missing data days, and to reduce the need for estimating record with Lockport reported flows.

A comprehensive comparison and analysis of discharge between Lemont and the controlling works at Lockport has been documented in a companion paper. However, as noted above this will only be useful for the first 4 years of the Lemont record. The comparison analysis will need to be repeated in the future for the mew methods of measuring discharge at Lockport. There should also be formal documentation of the comparison analysis of discharge for Romeoville and Lemont in the form of a USGS Scientific Investigations Report. The comparison should be made in a manner similar to the 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.

Each water year there should be an extensive and detailed station analysis written to describe the measurements, quality of the data, and what methods were used to estimate missing record, if any.

RECORD REVIEW—

1. The AVM discharge records shall be reviewed annually as the primary record. The ADVM backup discharge record will also be worked and checked for accuracy, use on estimated days in primary record, and as a comparison check to the AVM record.
2. A comparison shall be made annually between the AVM computed daily discharges and those provided by the U.S. Army Corps of Engineers, Chicago District (estimates based on regression with Lockport records ‘LMO-6’).
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 IDN-OWR shall review and document this record annually.

Prepared by: K.K. Johnson
October 30, 2008

Appendix 6. Perl Script for Averaging the Three Velocity Paths

```
#!/usr/bin/perl
use warnings;

#This script processes 3 velocity path files, each containing 10-minute
#(edited) unit values, from NWTS2RDB, generating one file of averaged values.

my @mth = (32, 29, 32, 31, 32, 31, 32, 32, 31, 32, 31, 32);
#sub stepcalc
#     input:      @nextvalue from main script (see below)
#    output:      array back to @newdatapoint, incrementing date/time by number of
#           minutes specified in $timeincrement, leaving velocity
#           value alone
sub stepcalc
{
 my($yearcounter, $mthcounter, $daycounter, $timestamp, $datavalue) = @_;
 my $timeincrement = 10;
 my $leapyrflag = 0;
 if($mthcounter==2 &&($yearcounter % 400==0 || ($yearcounter %4==0 && $yearcounter
%100!=0)))
      {$leapyrflag = -1;}
 $timestamp = ($timestamp + $timeincrement)%1440;
 if($timestamp==0)
      {
       if($daycounter==29 && $mthcounter==2)
             {
             $leapyrflag = 0;
             $daycounter = 1;
             $mthcounter = 3;
             }
       else
            {
             $daycounter = ($daycounter+1)%$mth[$mthcounter - 1];
             if($daycounter==0)
                  {
                   if($mthcounter==2 && $leapyrflag!=0)
                        {$daycounter = 29;}
                   else
                        {
                         $daycounter++;
                         if($mthcounter==12)
                              {
                               $mthcounter = 1;
                               $yearcounter++;
                               if($yearcounter%400==0 ||($yearcounter%4==0 &&
$yearcounter%100!=0))
                                    {$leapyrflag = -1;}
                              }
                         else
                              {$mthcounter++;}
                        }
                  }
```

```
            }
      }
 $timestamp = sprintf("%04d", $timestamp);
 $daycounter = sprintf("%02d", $daycounter);
 $mthcounter = sprintf("%02d", $mthcounter);
 my @newdatapoint = ($yearcounter, $mthcounter, $daycounter, $timestamp, $dat-
avalue);
 return @newdatapoint;
}
#END SUBROUTINE

#sub datecompare
#input: date to compare against (checkmth, checkday, checkyear, checktime)
#      and date to be compared (givenmth, givenday, givenyear, giventime)
#output: 0 if dates are equal, -1 if check*<given*, 1 if check*>given*
#
sub datecompare
{
 my $dateequal;
 my ($checkmth, $checkday, $checkyear, $checktime, $givenmth, $givenday, $given-
year, $giventime) = @_;
 if($checkyear!=$givenyear)
      {
       if($checkyear<$givenyear) {$dateequal = -1;}
       else {$dateequal = 1;}
      }
 elsif($checkmth!=$givenmth)
      {
       if($checkmth<$givenmth) {$dateequal = -1;}
       else {$dateequal = 1;}
      }
 elsif($checkday!=$givenday)
      {
       if($checkday<$givenday) {$dateequal = -1;}
       else {$dateequal = 1;}
      }
 elsif($checktime!=$giventime)
      {
       if($checktime<$giventime) {$dateequal = -1;}
       else {$dateequal = 1;}
      }
 else {$dateequal = 0;}
 return $dateequal;
}
#END SUBROUTINE

my $yearcell = 0;
my $monthcell = 1;
my $daycell = 2;
my $timecell = 3;
my $datacell = 4;

my @inputfile;
```

```
my @pathfile1;
my @pathfile2;
my @pathfile3;

my $dirname="/usr/opt/decodes/satin/edl_il";
#my $dirname=$ENV{HOME};
my $outputfilename;

my @param = (0.9300, 1.0134, 1.0836);
my $paths = 3;
my $divpaths;

#check input arguments
if ($#ARGV + 1 == 0)
      {
       print "\nUsage: calcav.pl <data_filename1> <data_filename2> <data_filename3>
<output_filename> <start_date> <end_date>\n";
       print "\t    <data_filename1>, <data_filename2>, <data_filename3>: contains
path values to be averaged,\n";
       print "\t     NOTE: <data_filename1> corresponds to path 1, <data_filename2>
to path 2, etc.\n";
       print "\t  <output_filename>: file storing output from this script\n";
       print "\t  <start_date> and <end_date>: MUST be typed in \"mm dd yyyy\"
format\n\n";
       print "\t    ALL FILES REQUIRED!\n";
       print "\t    Typing \"calcav.pl\" without arguments prints this
message.\n";
       die("\n");
      }
elsif ($#ARGV + 1 != 10 && $#ARGV + 1 > 0)
      {die("Invalid number of arguments.\n");}

$inputfile[0] = $ARGV[0];
$inputfile[1] = $ARGV[1];
$inputfile[2] = $ARGV[2];

#check if input files of correct format
for($inputfilecount = 0; $inputfilecount < 3; $inputfilecount++)
      {
       if (! -e $inputfile[$inputfilecount])
            {die("Data file: $!\n");}
       else
            {
             open(INPUT, $inputfile[$inputfilecount]);
             my $counter = 1;
             $counter++ while <INPUT>;
             close(INPUT);
             if($counter < 18)
                  {die("File size too small!\n");}
             else
                  {
                   open(INPUT, $inputfile[$inputfilecount]);
                   for($linecount = 1; $linecount<10; $linecount++)
```

```
                    {my $scrapline = <INPUT>;}
               my $checkline = <INPUT>;
               if($checkline !~ m/.*DD DDID="  4"/ && $inputfilecount == 0)
                    {
                     close(INPUT);
                     die("Incorrect file type: path $inputfilecount\n");
                    }
               elsif($checkline !~ m/.*DD DDID="  5"/ && $inputfilecount == 1)
                    {
                     close(INPUT);
                     die("Incorrect file type: path $inputfilecount\n");
                    }
               elsif($checkline !~ m/.*DD DDID="  6"/ && $inputfilecount == 2)
                    {
                     close(INPUT);
                     die("Incorrect file type: path $inputfilecount\n");
                    }
               else
                    {close(INPUT);}
              }
         }
    }
for($inputfilecount = 0; $inputfilecount < 3; $inputfilecount++)
    {
     print "Accessing file ",$inputfilecount + 1,"...\n";
     open(INPUT, $inputfile[$inputfilecount]);
     for($linecount = 1; $linecount < 18; $linecount++)
          {my $scrapline = <INPUT>;}
     my $startmth = $ARGV[4];
     chomp $startmth;
     my $startday = $ARGV[5];
     chomp $startday;
     my $startyear = $ARGV[6];
     chomp $startyear;
     my @finaldatapoint = ($ARGV[9], $ARGV[7], $ARGV[8], 1430);
     my @nextdatapoint = ($startyear,$startmth,$startday,"0000",0);
     while(<INPUT>)
          {
           my @data = split(/\t/, $_);
           if(@data<8)
                {
                 close(INPUT);
                 die("Error: Malformed line of data on $inputfilecount.\n");
                }
           my @currdatapoint;
           $currdatapoint[$yearcell] = substr $data[0], 0, 4;
           $currdatapoint[$monthcell] = substr $data[0], 4, 2;
           $currdatapoint[$daycell] = substr $data[0], 6, 2;
                 my $hours = substr $data[1], 0, 2;
                 my $minutes = substr $data[1], 2, 2;
                 my $totalmin = $hours*60+$minutes;
                 my $formattedtime = sprintf("%04d",$totalmin);
           $currdatapoint[$timecell] = $formattedtime;
```

```
            $currdatapoint[$datacell] = $data[3];
            my $isdateequal = datecompare($nextdatapoint[$monthcell],
$nextdatapoint[$daycell], $nextdatapoint[$yearcell], $nextdatapoint[$timecell],
$currdatapoint[$monthcell], $currdatapoint[$daycell], $currdatapoint[$yearcell],
$currdatapoint[$timecell]);
            #print "isdateequal: $isdateequal\n";
            while($isdateequal<0)
                 {
                  $nextdatapoint[$datacell] = -9999;
                  if($inputfilecount==0)
                       {push @pathfile1, [@nextdatapoint];}
                  if($inputfilecount==1)
                       {push @pathfile2, [@nextdatapoint];}
                  if($inputfilecount==2)
                       {push @pathfile3, [@nextdatapoint];}
                  #print "$nextdatapoint[$monthcell] $nextdatapoint[$daycell]
$nextdatapoint[$yearcell] $nextdatapoint[$timecell] $nextdatapoint[$datacell]\n";
                  @nextdatapoint = stepcalc(@nextdatapoint);
                  $isdateequal = datecompare($nextdatapoint[$monthcell],
$nextdatapoint[$daycell], $nextdatapoint[$yearcell], $nextdatapoint[$timecell],
$currdatapoint[$monthcell], $currdatapoint[$daycell], $currdatapoint[$yearcell],
$currdatapoint[$timecell]);
                  #print "isdateequal: $isdateequal\n";
                 }
            $nextdatapoint[$datacell] = $currdatapoint[$datacell];
            #print "$nextdatapoint[$monthcell] $nextdatapoint[$daycell]
$nextdatapoint[$yearcell] $nextdatapoint[$timecell] $nextdatapoint[$datacell]\n";
            if($inputfilecount==0)
                 {push @pathfile1, [@nextdatapoint];}
            if($inputfilecount==1)
                 {push @pathfile2, [@nextdatapoint];}
            if($inputfilecount==2)
                 {push @pathfile3, [@nextdatapoint];}
            @nextdatapoint = stepcalc(@nextdatapoint);
           }
      close(INPUT);
      $isdateequal = datecompare($nextdatapoint[$monthcell],
$nextdatapoint[$daycell], $nextdatapoint[$yearcell], $nextdatapoint[$timecell],
$finaldatapoint[$monthcell], $finaldatapoint[$daycell], $finaldatapoint[$yearcell],
$finaldatapoint[$timecell]);
      #print "isdateequal: $isdateequal\n";
      while($isdateequal<0)
           {
            $nextdatapoint[$datacell] = -9999;
            #print "$nextdatapoint[$monthcell] $nextdatapoint[$daycell]
$nextdatapoint[$yearcell] $nextdatapoint[$timecell] $nextdatapoint[$datacell]\n";
            if($inputfilecount==0)
                 {push @pathfile1, [@nextdatapoint];}
            if($inputfilecount==1)
                 {push @pathfile2, [@nextdatapoint];}
            if($inputfilecount==2)
                 {push @pathfile3, [@nextdatapoint];}
            @nextdatapoint = stepcalc(@nextdatapoint);
```

```
             $isdateequal = datecompare($nextdatapoint[$monthcell],
$nextdatapoint[$daycell], $nextdatapoint[$yearcell], $nextdatapoint[$timecell],
$finaldatapoint[$monthcell], $finaldatapoint[$daycell], $finaldatapoint[$yearcell],
$finaldatapoint[$timecell]);
            }
      }
print "Data read from files.\n";

#simple error check for above for-loop
#if($#pathfile1 != $#pathfile2 || $#pathfile2!= $#pathfile3)
#     {die("Bad file reads--one array is not of correct size: $#pathfile1 $#pathfile2
$#pathfile3\n");}

print "Creating output file...\n";
$outputfilename = $ARGV[3];
chomp $outputfilename;
if (! -d $dirname) {mkdir $dirname;}
open (OUTPUT, ">$dirname/$outputfilename\.dat") or die("Cannot open specified file:
$!\n");
print "Writing to output file...\n";

#The next line is header for DECODES to grab the file.
print OUTPUT "//SOURCE DILCHM DCP\n//STATION 05536890\n//DEVICE FILE-4\n//
DATA\n";

for($rowcount = 0; $rowcount <= $#pathfile1; $rowcount++)
      {
       my @outputline;
       $outputline[$yearcell] = $pathfile1[$rowcount][$yearcell];
       $outputline[$monthcell] = $pathfile1[$rowcount][$monthcell];
       $outputline[$daycell]  = $pathfile1[$rowcount][$daycell];
       my $temptime = $pathfile1[$rowcount][$timecell];
            $tempmin = sprintf("%02d",$temptime%60);
            $temphr = sprintf("%02d",($temptime-$tempmin)/60);
       $outputline[$timecell]  = $temphr.$tempmin;
       my @weightedvel;
       my @unweightedvel;
       $divpaths = $paths;
       for($currpath = 0; $currpath <$paths; $currpath++)
       {
       if($currpath==0)
            {
             $unweightedvel[$currpath] = $pathfile1[$rowcount][$datacell];
             $weightedvel[$currpath] = $pathfile1[$rowcount]
[$datacell]*$param[$currpath];
            }
       if($currpath==1)
            {
             $unweightedvel[$currpath] = $pathfile2[$rowcount][$datacell];
             $weightedvel[$currpath] = $pathfile2[$rowcount]
[$datacell]*$param[$currpath];
            }
       if($currpath==2)
```

```
            {
             $unweightedvel[$currpath] = $pathfile3[$rowcount][$datacell];
             $weightedvel[$currpath] = $pathfile3[$rowcount]
[$datacell]*$param[$currpath];
            }

       if($unweightedvel[$currpath] < -5 || $unweightedvel[$currpath] > 5)
            {
             $weightedvel[$currpath] = 0;
             $unweightedvel[$currpath] = 0;
             $divpaths--;
            }
       }

       my $avg1 = 0;
       my $avg4 = 0;
       for($pathcount = 0; $pathcount<$paths; $pathcount++)
            {
             $avg1 += $weightedvel[$pathcount];
             $avg4 += $unweightedvel[$pathcount];
            }
       if($divpaths!=0)
            {
             if($divpaths==$paths)
                  {$outputline[$datacell] = sprintf("%2.4f", $avg4/$divpaths);}
             else
                  {$outputline[$datacell] = sprintf("%2.4f",$avg1/$divpaths);}
             print OUTPUT "$outputline[$yearcell],$outputline[$monthcell],$outputl
ine[$daycell],$outputline[$timecell],$outputline[$datacell]\n";
            }
      }
close(OUTPUT);
print "Closing output file...\n";
print "Script finished. Goodbye!\n\n\n";
```

USGS

Johnson, Duncker, and Jackson—**The Role of the U.S. Geological Survey in Lake Michigan Diversion Accounting in Illinois, 1984–2010**—Open-File Report 2012–1243