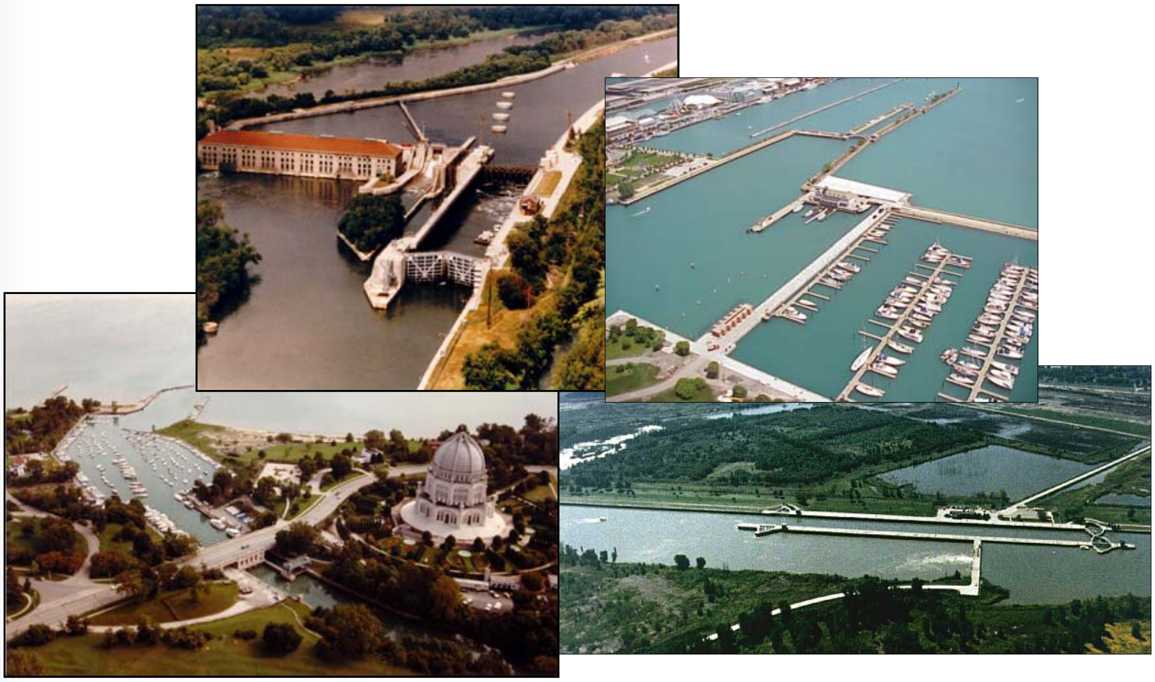
Final Report

LAKE MICHIGAN DIVERSION
Findings of the Fifth Technical Committee for Review of Diversion Flow Measurements and Accounting Procedures



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ACKNOWLEDGEMENTS

During the course of the Fifth Technical Committee's work, a number of individuals and organizations were extremely helpful in assisting the Fifth Technical Committee to accomplish its tasks. The Committee would like to express its appreciation for the assistance of the U.S. Army Corps of Engineers (USACE), Chicago District, and specifically Mr. Thomas Fogarty and Dr. Tzuoh-Ying Su, for their contribution in providing numerous reports and data, and arranging and assisting the Committee in the various workshops and field trips. The Committee also acknowledges the assistance of Mr. Daniel Injerd, Illinois Department of Natural Resources, Office of Water Resources and Mr. Sergio Serafino, Metropolitan Water Reclamation District of Greater Chicago in providing the Committee with information. Mr. Richard Figurelli, City of Evanston, and Mr. Michael Sturtevant and Mr. Conrad Bazylewski, both of the Chicago Department of Water Management were very helpful in arranging tours of the Evanston Water Treatment Plant, James W. Jardine Water Purification Plant, and Chicago Avenue Pumping Station, respectively. Ms. Nancy E. Westcott, Illinois State Water Survey assisted the Fifth Technical Committee by arranging a tour of the network precipitation gages. Additionally, the Committee acknowledges the invaluable assistance from the U.S. Geological Survey especially from Mr. James Duncker, Dr. Thomas Over, and Mr. Kevin A. Oberg. The Fifth Technical Committee acknowledges Ms. Alisa Patterson, Ms. Christina Peterson, and Mr. Kevin Krhovjak for their invaluable assistance in preparation of this report. In addition, Dr. Arthur R. Schmidt assisted the Committee.

EXECUTIVE SUMMARY

The Fifth Technical Committee (Committee) was appointed by the U.S. Army Corps of Engineers (USACE) in December of 2002 to conduct an assessment and evaluation of the accounting procedures and methodology used in the determination of diversion from Lake Michigan, and to ascertain whether or not the methods are in accordance with the "best current engineering practice and scientific knowledge," as stipulated by the 1967 Supreme Court Decree and the 1980 modifications. Such a review is to be performed by a Technical Committee appointed every five years, and a report evaluating the accounting and operational procedures is to be presented to the USACE and to other interested parties. This report is the culmination of the Fifth Technical Committee's review.

The key topics reviewed by the Fifth Technical Committee include the following: recent accounting results for Water Years (WYs) 1996, 1997, 1998, and 1999; current diversion-related measurement techniques at the Romeoville and 3 lakefront acoustic velocity meter (AVM) sites, 5 conventional stream-gaging stations, precipitation gages, and other pertinent structures including 18 water-supply facilities; procedures used to calculate and verify flows that are not directly measured; and status of recommendations from previous Committees. In addition, the Fifth Technical Committee's work scope included the following priority tasks: evaluation of the uncertainty in annual diversion calculated using alternative accounting systems (Romeoville versus Lakefront), evaluation of approaches that might be used to better quantify consumptive use, and advising the U.S. Geological Survey (USGS) on the establishment of a new AVM gage on the Chicago Sanitary and Ship Canal (CSSC) to mitigate the future placement of a fish barrier at the current Romeoville AVM site.

The Fifth Technical Committee recognizes that because the State of Illinois has exceeded Lake Michigan diversion limits as stipulated by the 1967 Supreme Court Decree as modified in 1980, efforts have been initiated since December of 1995 to mediate a resolution. The Great Lakes Mediation Memorandum of Understanding (July 29, 1996) sets forth a transition period of Lake Michigan Diversion Accounting and a possible shift to Lakefront Diversion Measurement and Accounting. The Fifth Technical Committee recognizes the critical importance of various technical and accounting issues in shifting to the Lakefront Accounting for Lake Michigan diversion. We have, therefore, reviewed various lakefront measurement and accounting issues as an integral part of our review. Our evaluation is an attempt to resolve some of these issues in terms of recommendations and to possibly assist in the resolution of these issues in the mediation process.

In general, the Fifth Technical Committee has found, based on our review that the Lake Michigan Diversion Accounting is in compliance with the 1980 Modified Decree, with respect to the "best current engineering practices and scientific knowledge." No significant changes have been made to the diversion accounting system and associated data-collection programs that support the accounting. Data-collection efforts have focused primarily on improving instrument reliability and the accuracy of the records being collected. The progress in improving the diversion accounting procedures and measurements has been significant and is reflected in a number of areas: basic diverted watershed system data and understanding; hydrologic modeling; and flow measurements. The Fifth Technical Committee also acknowledges that the USACE has made progress in implementing many of the Fourth Technical Committee's recommendations. The Fifth Technical Committee is impressed by the efforts made to improve the accuracy of the diversion record, particularly at the AVM lakefront gages. The Fifth Technical Committee is in general agreement with the findings and recommendations made by the Fourth Technical Committee. In most instances, actions have been taken to comply with the recommendations made by the Fourth Technical Committee.

The Fifth Technical Committee's opinion based on a consideration of overall uncertainty estimated for the average diversion calculated using the two accounting systems that neither accounting system can be rejected on the basis of unacceptable uncertainty. Other factors such as those related to the operation, maintenance, quality assurance, and accessibility of the primary monitoring locations associated with each accounting system may warrant greater consideration. It is anticipated that the current Romeoville Accounting System and continued operation of a calibrated AVM system on the Chicago Sanitary and Ship Canal (CSSC) near Romeoville would ensure that the Lake Michigan diversion accountable to the State of Illinois continues to be determined in a manner consistent with the 1967 Supreme Court Decree and the 1980 modifications.

Annual Report (1997, 1998 and 1999) and Diversion Accounting Report Status

The 1997 annual report centered on the WY 1996 diversion accounting. In WY 1996, the USACE began the change over to using the measured solar radiation data collected at Argonne National Labs from computing solar radiation data using O'Hare Airport meteorological data. The WY 1996 accounting report details the changes to the TNET modeling because of changes to the Tunnel and Reservoir Plan (TARP) tunnels and solar radiation.

The 1998 annual report centered on the completion of the WY 1997 diversion accounting. Work continued on the changes to the TNET files for the Calumet TARP tunnel to reflect WY 1996 conditions. The USACE continued the change over from computing radiation data using O'Hare Airport meteorological data to using the measured solar radiation data collected at Argonne National Labs. The WY 1996 accounting report details the changes to the TNET modeling and solar radiation. The land use breakdown into pervious and impervious cover in the hydrologic models of the diverted Lake Michigan watershed and the Des Plaines watershed also was substantially revised in WY 1997 to account for overestimated CSO flows that began with the re-mapping of the watersheds in the WY 1990 diversion accounting. The efforts relating to the changes to the Calumet modeling and the computation of the solar radiation were carried over into FY 1999 and were a primary reason for the delay in the release of the WY 1996 accounting report.

The 1999 Annual Report focused on completing the WY 1998 and 1999 accounting reports, ongoing mediation activities related to the Great Lakes Mediation Committee, coordination of activities related to the Fourth Technical Committee, and the USGS installation of an AVM gage on the North Shore Channel at Wilmette. Finally, the USACE completed a hydraulic analysis of various alternatives for Navigation Makeup Reduction and a contract was initiated for work on detailed QA/QC of 12 primary water supply pumping stations in Chicago and 6 water treatment plants in the northern Chicago suburbs.

Lake Michigan Diversion Accounting Modeling

The Hydrologic/Hydraulic (H&H) models applied in the diversion accounting are state of the art for the purposes of diversion accounting and generally are applied in a proper manner. However, the actual model calibration/verification was done for data from 1965-1974. A more thorough evaluation of model performance may be in order at this time to better distinguish between runoff, base flow and combined sewer inflow, which may help to refine estimates of consumptive use. Review should be performed at the USGS streamflow gages on Tinley Creek at Palos Park (11.2 mi^2), Midlothian Creek at Oak Forest (12.6 mi^2), and North Branch Chicago River at Albany Avenue (113 mi^2, which is 13 mi^2 downstream from the USGS gage North Branch Chicago River at Niles). Previous attempts to consider flows at the North Branch and Racine Avenue Pumping Stations were done on an event-by-event basis and poor results were obtained. However, it might be useful to consider annual totals at these locations. Further with the Tunnel and Reservoir Plan (TARP) tunnels in place there are fewer overflows and, thus, some of the problems encountered in earlier studies may be less important.

If consumptive use increases from the current assumption of 10 percent, the H&H models need to be adjusted. To compensate for decreased wastewater flow because of increased consumptive use, infiltration to sewer systems must increase. Such an increase would be consistent with a) past infiltration and inflow studies done by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC), b) physical reality of drainage density of the sewer systems, and c) evidence that indicates that Des Plaines Watershed flows may be underestimated including limited comparisons to flow at the Upper Des Plaines Pumping Station and comparison with flows scaled by area from Midlothian and Tinley Creeks to simulated flows from the ungaged lower Des Plaines River basin.

Other issues related to H&H modeling that require further review and analysis include a) Land use has been changed three times during the history of the use of the modeling in the diversion accounting and care must be taken to see that the current land use is correct and not merely a "fitted" value, and b) Calumet TARP groundwater infiltration appears to be too small.

In Lakefront Accounting the H&H models were used to estimate the long-term annual average runoff to be set to a fixed value and subtracted from the allowable annual diversion of 3,200 cfs. The period of record analysis has several potential flaws that call into question the long-term average flow of 800 cfs. Adjustment of measured flows on the North Branch and Little Calumet Rivers cannot be done on the basis of results from event simulation. Double mass analysis of observed annual flows and regional precipitation may allow correction factors to be estimated. Midway Airport and University of Chicago may not be the best reference gages to fill in precipitation data for O'Hare Airport for the period before June 1, 1962.

Lake Michigan Diversion Accounting Measurements

The technology that has evolved with respect to acoustical flow measurements has not only met the standard of "best current engineering practice and scientific knowledge," but the USACE and the USGS are establishing a higher, "state of the art" standard for the diversion accounting. The USGS leadership in this technical area is to be commended. Preliminary review of the O'Brien Lock and Dam (L&D) AVM/ADCP (Acoustical Doppler Current Profiler) records suggests leakage through the control structure that continued gaging will help to better quantify. This has been demonstrated on the Chicago River where the AVM system at Columbus Drive has measured a substantial reduction in flow that is presumed to be associated with the repair of the Chicago River Controlling Works (CRCW) and Lock, and construction and repairs to the lock and turning basin walls (completed Summer 2000).

New current profiler technology should improve the accuracy of flow measurements in shallow channels such as the North Shore Channel at Wilmette and approach channels to the O'Brien L&D control structure. Improved ADCP measurement accuracy will lead to improved index-velocity ratings and a better record of discharge. However, challenges remain at O'Brien L&D and Columbus Drive, particularly at low flows when bi-directional flow occurs due to factors such as wind, lockages, boat traffic, and water-temperature related density gradients.

For the acoustic stream-gaging stations, the record reported for the Romeoville station during WY's 1997 – 1999 is the most accurate. A draft report by the USGS indicates that the coefficient of variation associated with the annual average discharge of the Chicago Sanitary and Ship Canal (CSSC) at Romeoville is approximately 24 percent, followed by Columbus Drive (18 percent), O'Brien L&D (24 percent), and Wilmette (47 percent).

The planned construction of an electronic fish barrier in the vicinity of the existing Romeoville gage will potentially interfere with the existing AVM system. The installation of an acoustic (bubble) barrier, which is still being evaluated. The Fifth Technical Committee recommended that the USGS install and calibrate an alternative AVM system on the CSSC as soon as practicable. Furthermore, the existing and alternative AVM systems should be operated concurrently for the foreseeable future to establish a reliable correlation between daily flows at the two locations. The Fifth Technical Committee is pleased that an alternate site has been secured and the installation of an AVM system is scheduled for the summer 2004.

Consumptive Use

For Lakefront Accounting, the long-term average consumptive use of water pumped from Lake Michigan has been fixed at 168 cfs through the year 2010 as part of the mediation agreement, which represents approximately 5 percent of the diversion. The Fifth Technical Committee concludes that the determination of consumptive use from a water budget analysis based on water-supply pumpage and treatment plant (waste and water supply) flow records, LMO-2, and simulation results would be consistent with best current engineering practice. Analysis of Illinois Department of Natural Resources (IDNR) LMO-2 data suggests consumptive losses could be significantly higher than the range of 8 – 12 percent determined by the USACE (1996) in the Lakefront Technical Analysis and the 10 percent used in the H&H modeling.

The nature of the value of Lake Michigan Pumpage Accountable to the State of Illinois listed in Column 11 of the Diversion Accounting Report is unclear. The values listed in Column 11 are a summation of withdrawals submitted by the water supply utilities to IDNR in the monthly LMO-3 reports. The problem is that some communities report raw water pumpage and others report finished water pumpage on the LMO-3 reports. The bottom line is that if LMO-3 and, thus, Column 11, contains a mixture of raw and finished water numbers, a single, system-wide average value for consumptive use is not appropriate.

Lakefront Measurements

For Lakefront Accounting, the long-term average runoff from the diverted Lake Michigan watershed has been fixed at 800 cfs through the year 2020 as part of the 1996 Great Lakes Mediation Memorandum of Understanding (MOU). In order to re-evaluate the fixed runoff value (800 cfs) in 2020, the capability to accurately simulate the hydrology of the watershed needs to be maintained. The current precipitation data collection program run by the Illinois State Water Survey (ISWS) for the USACE meets the appropriate standards for accurate data collection and analysis. Modeling recommendations described above relative to the current diversion accounting system are even more relevant if Lakefront Accounting is adopted because runoff computations directly affect 25 percent of the Lakefront Accounting versus about 7 percent of the Romeoville Accounting.

Great Lakes Mediation Memorandum of Understanding, July 1996

The July 1996 Great Lakes Mediation Memorandum of Understanding prescribes a three-water-year transition period during which a dual reporting system will be operated. The purposes of the transition period are to assess the technical feasibility of moving the diversion measurement system to the lakefront and give additional time for AVM calibration and opportunity to complete the QA/QC program. The MOU describes this transition period as “beginning after the installation and initial calibration of the AVMs at the lakefront (WY 1997).”

The USGS is continuing to refine the instrumentation for the lakefront AVMs to: (a) reduce the noise in the velocity data; (b) develop methods to better distinguish between water velocities and noise; (c) improve the index-velocity ratings; and (d) develop backup equations for these sites. These refinements by the USGS to the Lakefront AVM instrumentation have the potential for improvement in the accuracy of the Lakefront AVM measurements.

In view of the on-going efforts to improve the AVM record from these sites, the Fifth Technical Committee agrees with the Fourth Technical Committee regarding the data reliability during the initial phase of the transition period. The USGS is using state-of-the-art technology to measure the velocities and develop the ratings at these AVM sites. The Fifth Technical Committee recommends that the USGS continue to use data from on-going measurements with different instruments to attempt to develop methods to screen or filter the data already collected. These methods should define the accuracy of the records thus developed, as well as the accuracy that is achievable with the improved instrumentation and methodology. This will provide additional data needed to assess the technical acceptability of lakefront accounting.

For the three-water-year transition period (Great Lakes Mediation Memorandum of Understanding, July 29, 1996) beginning in WY 1997, comparisons of Lakefront to Romeoville diversion accounting indicate a 1.42 percent difference in 1997, a 0.25 percent difference in 1998, and a -4 percent difference in 1999 (see the following table).

Water Year	Romeoville Diversion (cfs)	Lakefront Diversion (cfs)	Lakefront/ Romeoville (percent difference)
1997	3,112	3,156	1.41
1998	3,057	3,065	0.26
1999	2,917	2,800	-4.01
2000	2,563		
2001	2,710		

The small relative difference between the annual diversions calculated with both methods is largely attributable to the small difference between the actual (simulated) runoff and 800 cfs.

The annual runoff simulated using H&H models for these years is 777 cfs in 1997, 774 cfs in 1998, and 759 cfs in 1999, all of which are less than the 800 cfs prescribed by the MOU. If the computed runoff is used instead of the long-term average annual runoff of 800 cfs in the Lakefront Accounting, the comparison of Romeoville and Lakefront Accounting would be as follows.

Water Year	Romeoville Diversion (cfs)	Lakefront Diversion with computed runoff (cfs)	Lakefront Modeled/ Romeoville (percent difference)
1997	3,112	3,133	0.67
1998	3,057	3,039	-0.59
1999	2,917	2,759	-5.42

The Fifth Technical Committee estimated the uncertainties in the various components of the diversion-accounting flow associated with the Romeoville and Lakefront Accounting systems for WY's 1997 through 1999. The annual flow-component estimates were combined using standard statistical procedures to estimate the overall uncertainty in annual diversions calculated using both accounting procedures. The uncertainty in annual diversion was used to estimate the uncertainty associated with 5- and 40-year average values for diversion.

Uncertainties associated with the runoff and consumptive use components of the Lakefront Accounting system were addressed in three ways – deterministically with no uncertainty, "actual" values with assumed variability, and fixed values (prescribed by the MOU) with natural variability. It is the Fifth

Technical Committee's opinion that the latter approach (fixed with natural variability) best represents the intent of the MOU. However, it also is the Committee's opinion that the other approaches to consider runoff uncertainty provide a more consistent scientific comparison of the bases of the Romeoville and Lakefront Accounting Systems.

The Committee's analysis indicates that the difference between uncertainties associated with the two accounting system is expected to diminish such that there is no distinguishable difference between the two in a comparison of 40-year averages. The Lakefront Accounting system evidences a somewhat greater uncertainty in averages for shorter averaging periods, but the differences are such that neither accounting system can be rejected on the basis of unacceptable uncertainty. Other factors such as those related to the operation, maintenance, quality assurance, accessibility of the primary monitoring locations may warrant greater consideration.

The cumulative deviation of Lake Michigan diversion increased from 1983 until 1994, when the trend reversed. The Lake Michigan Diversion is estimated through WY 2003, based on flow at the USGS Romeoville gage. The Lake Michigan diversion was estimated at 98 percent of the Romeoville flow and based on the data provided by the USGS and the USACE for 2000-2003, the cumulative deviation has decreased dramatically to approximately 500 cfs. This in part can be attributed to the levels of Lake Michigan and the reduction in leakage at the CRCW as a result of the repairs made to the lock gates and completion of a new turning basin wall by the summer of 2000. Furthermore, based on the historical flow trends over the past six years the Fifth Technical Committee estimates the Romeoville flow for WY 2004 resulting in approximately "zero" cumulative diversion deficit projected by the end of WY 2004.

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1.0 INTRODUCTION

1.1 HISTORY OF LAKE MICHIGAN DIVERSION

When Maj. Stephen H. Long described the Chicago River on March 4, 1817, he said of it (Hill, 2000):

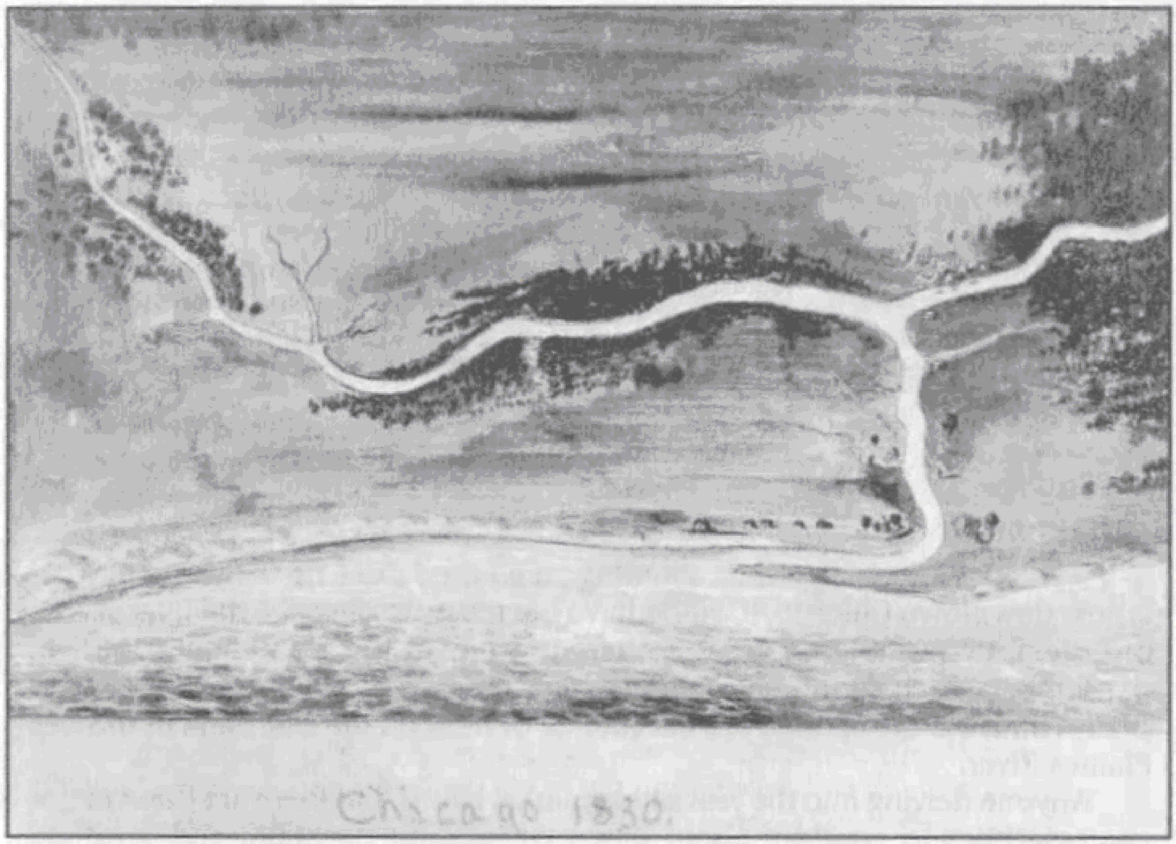
> "The Chicago River is but an arm of the lake [Lake Michigan], dividing itself into two branches, at the distance of one mile inland from its communication with the lake. The north branch extends along the western side of the lake about thirty miles, and receives some few tributaries. The south branch has an extent of only 5 or 6 miles, and receives no supplies, except from the small lake of the prairie [Mud Lake, at the portage connection with the Des Plaines]… the river and each of its branches are of variable widths, from 15 to 50 yards and, for 2 or 3 miles inland, have a sufficient depth of water to admit of almost any burden."

Presented in Figure 1.1-a and 1.1-b is a map of the Chicago River outlet at Lake Michigan from 1830.

Eventually, the demands of growing commerce led to changes in the river from the complete removal of the sandbar at its mouth to the replacement of the portage route with the Illinois and Michigan Canal, the fulfillment of a centuries-old dream. As the city grew, the river became polluted by the waste-disposal needs of both people and industry, requiring further changes to the river. The river became a sewer. Humans turned the river into a sewer, but the river rebelled and began to threaten the life force of the growing metropolis. It stank. It violently overflowed its banks, carrying the seeds of devastating illnesses out into Lake Michigan and polluting the city's drinking water supply. Several attempts, very early in the young city's history, did make the water go away from Lake Michigan, at least some of the time, and run unnaturally in the direction of St. Louis on the Mississippi. The demands for change culminated in the construction of a public-works project of unprecedented scope, the Chicago Sanitary and Ship Canal (CSSC). It permanently changed the river to flow from its former mouth in Lake Michigan upstream through its South Branch and eventually into the Mississippi River. As the city and suburbs expanded, residential and agricultural needs led to major drainage projects and other artificial canals. All branches of the river became increasingly channelized. For further details on the history of modifications made to the Chicago River system readers should consult (Hill, 2000).

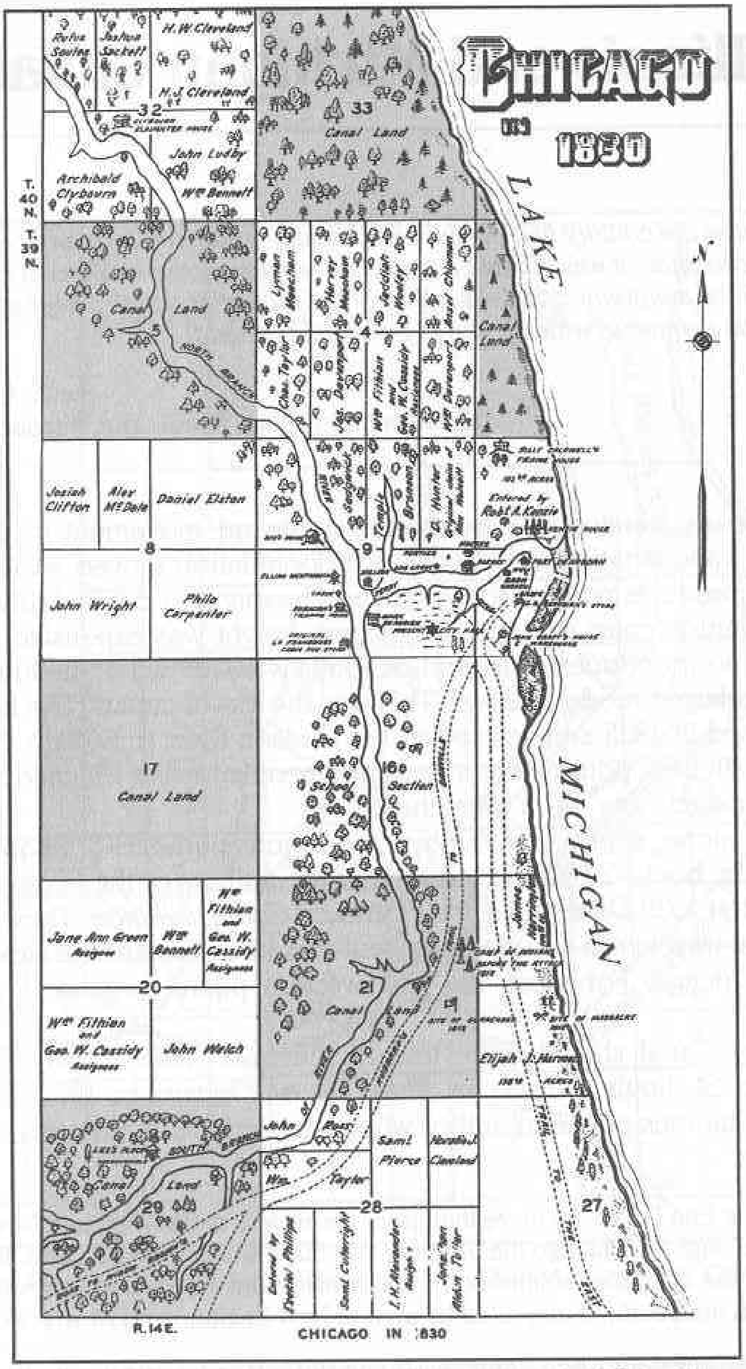
Figure 1.1-a: Chicago River -1830

12 The Chicago River



Courtesy of Chicago Historical Society ICHi-26982, annotations removed.

Figure 1.1-b: Chicago River



Map based on an original drawn by J.L. Dobson and published by J.C. Elder & Co., Surveyors and Map Publishers. It was retraced on February 14, 1934, by C. A. Erickson and printed by the U.S. Engineer Office, Chicago, Illinois. Courtesy of the Army Corps of Engineers Chicago office.

As a solution to the sanitation and flooding problems, the CSSC was built (Figure 1.1-c). The construction of the CSCC reversed the flow direction of the Chicago River (Figure 1.1-d). The CSSC was completed in 1900 by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). Prior to approximately 1982 the MWRDGC was known as Metropolitan Sanitary District of Greater Chicago (MSDGC).

In 1901 the MSDGC was authorized by the Secretary of War to divert 4,167 cfs in addition to domestic pumpage. In 1908 and again in 1913, the United States brought actions to enjoin the MSDGC from diverting more than the 4,167 cfs previously authorized in 1901. The two actions were consolidated, and the Supreme Court entered a Decree on January 5, 1925 allowing the Secretary of War to issue diversion permits. In March of the same year, a permit was issued to divert 8,500 cfs in addition to domestic pumpage, which was about the average then being used.

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

In 1967, a U.S. Supreme Court Decree limited the diversion of Lake Michigan water by the State of Illinois and its municipalities, including sewage and sewage effluent derived from domestic pumpage, to a five-year average of 3,200 cfs, effective March 1, 1970. This Decree gave full responsibility to the State of Illinois for diversion measurements and computations. The U.S. Army Corps of Engineers (USACE) was to have a role of "general supervision and direction." The 1967 Decree limited the diversion, including domestic pumpage, to an average of 3,200 cfs over a five-year running accounting period. The first five-year accounting period began March 1, 1970 and ended to February 28, 1975. During this period, the average diversion was 3,183 cfs. The next accounting period began March 1, 1975 and ended February 29, 1980. During this period, the average diversion was 3,044 cfs. The U.S. Supreme Court amended its 1967 Decree on December 1, 1980. The amendment changes, in part, provisions of the 1967 Decree that prevented the State of Illinois from effectively utilizing and managing the 3,200 cfs of Lake Michigan water, which had been allocated previously by the U.S. Supreme Court. This amendment forms the current diversion criteria this report addresses. These criteria can be summarized as follows:

1. An increase in the period for determining compliance with the diversion rate limit of 3,200 cfs from a 5-year running average to a 40-year running average,

2. Changing the beginning of the accounting year from March 1 to October 1,

3. limit on the average diversion in any annual accounting year shall not exceed 3,680 cfs, except that in any two (2) annual accounting periods within a forty (40) year period, the annual average diversion may not exceed 3,840 cfs, and

4. limit on the cumulative algebraic sum of the average annual diversions minus 3,200 cfs during the first 39 years to 2,000 cfs-years.

Figure 1.1-c: Development of Chicago Sanitary and Ship Canal System – Before Canal System Construction

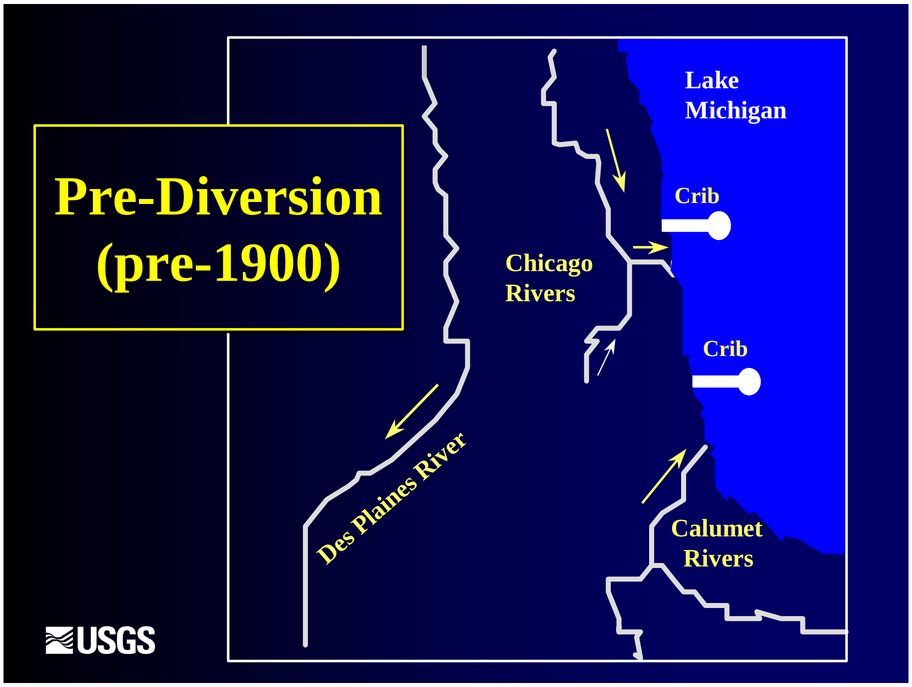
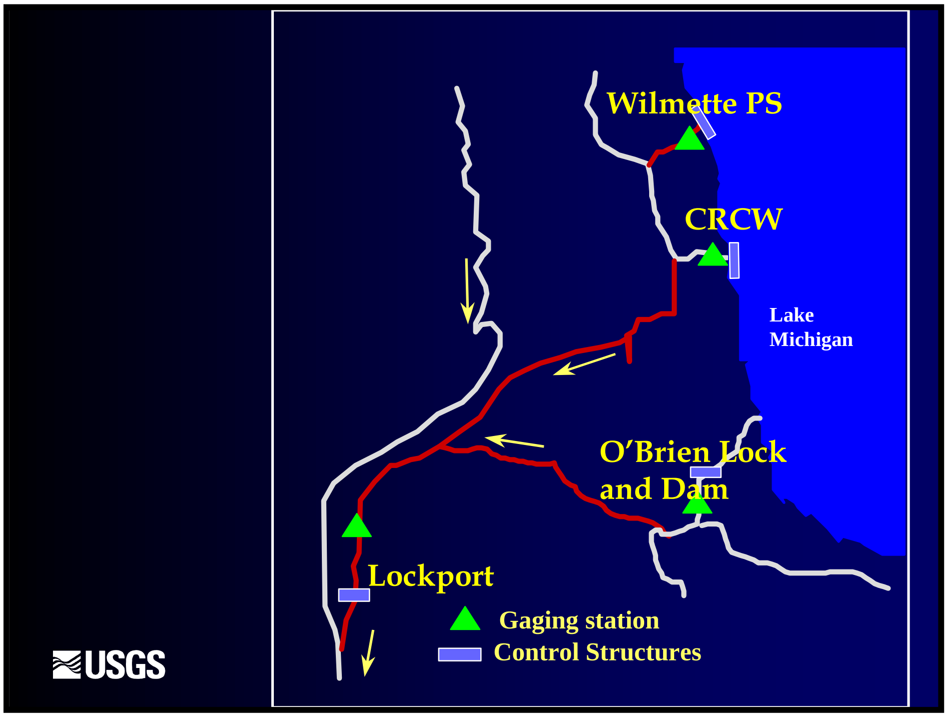


Figure 1.1-d: Development of the Chicago Sanitary and Ship Canal System – Chicago Sanitary and Ship Canal System Completed



In addition, the modified U.S. Supreme Court Decree for the Lake Michigan Diversion at Chicago, Illinois, adopted by the Court on December 1, 1980, stipulates that the USACE convene a three-member Technical Committee at least once every five years to review and report on the methods of flow measurement and procedures for diversion accounting. The Committee review is to include: 1.) an evaluation of the current procedures used for the measurement and accounting of diversion in accordance with the best current engineering practice and scientific knowledge; and 2.) recommendations for any appropriate changes to those procedures.

1.2 COMPONENTS OF LAKE MICHIGAN DIVERSION

The average annual value for each of the primary components of the Lake Michigan Diversion for accounting years 1996 through 1999 are presented in Figure 1.2-a and Table 1.2-a. The primary components of Lake Michigan Diversion accounting are:

- water supply taken from Lake Michigan intake cribs and discharged into the river and canal system (in the greater Chicago area) as water reclamation plant effluent and occasional combined-sewer overflows;
- storm runoff from the diverted watershed area of Lake Michigan, draining to the river and canal system in the greater Chicago area; and
- water from Lake Michigan entering directly into the river and canal system in the greater Chicago area. This component consists of the following three parts:
    - water required for lockage at the Chicago Harbor Lock and the Thomas J. O'Brien Lock;
    - leakages occurring at the Chicago River Controlling Works, Lock, and turning basin walls (Chicago Harbor), O'Brien Lock and Dam, and Wilmette Pump Station and Sluice Gate; and
    - direct diversions for navigational make-up and discretionary purposes made at the Chicago River, O'Brien, and Wilmette Controlling Works.

Figure 1.2-a: Total Average Annual Flow of Different Components of the Lake Michigan Diversion, 1996 – 1999.

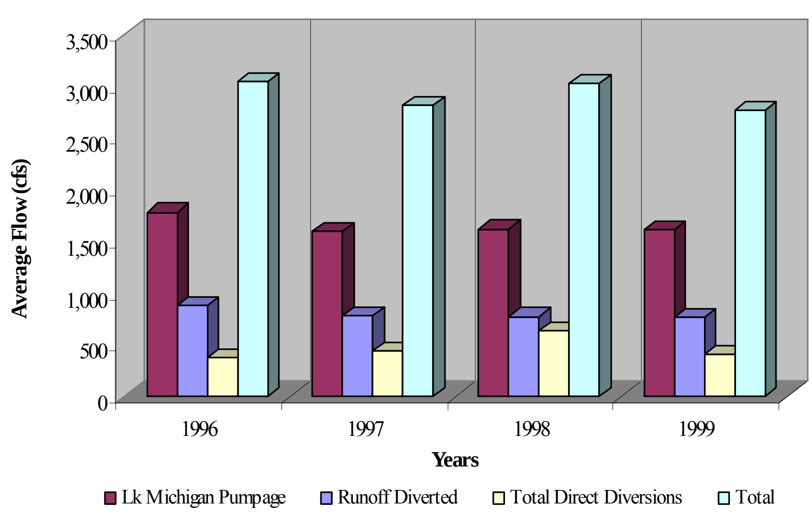


Table 1.2-a: Primary Components of Lake Michigan Diversion, 1996-1999

Description	1996 Average Flow (cfs)	1996 Percentage of Total Flow	1997 Average Flow (cfs)	1997 Percentage of Total Flow
Lake Michigan Pumpage by the State of Illinois	1,782.0	58.6	1,596.6	56.7
Runoff for Diverted Lake Michigan Watershed	882.0	29.0	776.6	27.6
Total Direct Diversions*	378.8	12.4	441.0	15.7
- Lockages	100.3	3.3	125.4	4.5
- Leakages	34.8	1.1	44.3	1.6
- Navigation Makeup Flow	16.1	0.5	23.5	0.8
- Discretionary Flow	227.5	7.5	247.8	8.8
Total	3,042.8		2,814.2	

Description	1998 Average Flow (cfs)	1998 Percentage of Total Flow	1999 Average Flow (cfs)	1999 Percentage of Total Flow
Lake Michigan Pumpage by the State of Illinois	1,620.6	53.5	1,605.3	57.9
Runoff for Diverted Lake Michigan Watershed	773.6	25.6	759.3	27.4
Total Direct Diversions*	633.0	20.9	408.0	14.7
- Lockages	140.2	4.6	61.2	2.2
- Leakages	60.7	2.0	30.2	1.1
- Navigation Makeup Flow	67.1	2.2	50.8	1.8
- Discretionary Flow	365.0	12.1	265.8	9.6
Total	3,027.2		2,772.6	

Description	Average: Average Flow (cfs)	Average: Percentage of Total Flow
Lake Michigan Pumpage by the State of Illinois	1,651.1	56.7
Runoff for Diverted Lake Michigan Watershed	797.9	27.4
Total Direct Diversions	465.2	15.9
- Lockages	106.8	3.7
- Leakages	42.5	1.5
- Navigation Makeup Flow	39.4	1.3
- Discretionary Flow	276.5	9.5
Total	2,914.2	

*Records reported by the MWRDGC in IDNR's LMO-6 were used to determine Total Direct Diversions for all lakefront locations during WY 1996, and for the entire time at Wilmette Controlling Works and about two-thirds of the time at the O'Brien Controlling Works during WYs 1997 through 1999. Total Direct Diversions were measured at other times using AVMs installed near the controlling works.

1.3 SUMMARY OF TECHNICAL COMMITTEE'S FINDINGS

The Technical Committee has convened five times since the modified U.S. Supreme Court Decree was adopted on December 1, 1980 for the purpose of reviewing flow measurement methods and procedures for diversion accounting. Each review has been documented in a final report that describes the review and associated findings, and provides recommendations. Each subsequent Committee reviews the preceding committee reports and investigates activities undertaken by the various parties involved in the accounting process to address the recommendations offered by previous committees.

Like the accounting methods and procedures, the findings and recommendations of the Technical Committee have evolved over time. The following sections summarize the primary findings and recommendations provided by each of the previous Technical Committees. The specific action taken by the USACE is discussed in each individual committee report.

1.3.1 First Technical Committee

The first three-member Technical Committee convened in June 1981, and issued their final report, dated October 1981. The committee's report presented a discussion of the history of diversion, the various components of the diversion, and the various flow measurements and computations used to determine Lake Michigan diversion as defined by the 1980 Modified Supreme Court Decree. The First Committee found virtually every aspect of the program to account for diversion from Lake Michigan to be in need of improvement. The diversion, measurement and accounting process "lacked credibility." The Lockport flow components, the cornerstone for diversion accounting, at that time, were determined to be deficient "in practically every aspect." The First Committee report was reviewed to establish a base of reference for the evaluation of diversion activities since 1981. The following is a brief summary of recommendations made by the First Committee:

1. Preparation of a Master Plan for diversion accounting,

2. Establishment of a Quality-Assurance program including an Operational Procedure Manual,

3. Consideration of alternatives to measurement at Lockport facilities,

4. Modifications and improvements to flow measurement practice for Lockport facilities, and

5. Modifications to flow measurement practices for Lockport Lock leakage.

1.3.2 Second Technical Committee

The Second Technical Committee was convened in July 1986 and reviewed accounting for Water Years (WYs) 1981 through 1983. The following is a brief summary of the major conclusions and recommendations of the Second Committee:

1. The Second Technical Committee was in general agreement with the findings and recommendations made by the First Committee (1981),

2. The Master Plan for diversion accounting and the Quality Assurance program are essential elements of the diversion accounting program that were still lacking,

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

4. At some appropriate time, probably no earlier than after the completion of WY 1987, the diversion records for water years after 1980, should be reviewed, and if appropriate, revised as necessary to account for the apparent errors in the Lockport discharge rating used during WYs 1981-1984,

5. Columns 7 and 9 of the *Diversion Accounting Procedures* representing the so-called sewer induced groundwater inflow should be withdrawn from the diversion accounting format,

6. Action should be initiated to address the deficiencies in the data bases for parameter values and model calibration, verification, and simulation, especially as they pertain to those drainage areas used directly in computing diversion,

7. Examine the constancy of the relation between water-supply pumpage and sewage-treatment-plans inflows and its applications for the purpose of estimating the infiltration and inflow deduction for the Des Plaines watershed,

8. Reconsider the alternatives (modeling, etc.) for estimating the annual runoff from the Lake Michigan watershed,

9. The effort by the USGS to establish guidelines to promote improvement in the quality of the AVM records should be continued,

10. The current regressions of the daily discharges for the AVM against MSDGC's records for flow at Lockport, used for the AVM back-up, should be reconsidered, specifically giving attention to the actual Lockport operating configurations,

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

12. The flow records for the AVM and flows at Lockport reported by MSDGC should be reviewed and compared for consistency on an annual basis,

13. The mean bed elevation for the canal in the reach delimited by the AVM transducer location should be determined, as well as along the transducer paths,

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

15. Execute a set of field measurements designed to verify the ratings developed by the USACE Waterways Experiment Station (WES) for both the Lockport Powerhouse sluice gates and the Lockport controlling works,

16. Infiltration and inflow of groundwater into the Tunnel and Reservoir Plan (TARP) tunnels should be treated as a deduction to the flows measured at Lockport, and

17. The runoff to the TARP system for the Lower Des Plaines combined sewer system should be determined and included as a deduction.

1.3.3 Third Technical Committee

The Third Technical Committee was convened in February of 1993 and reviewed WYs 1984 through 1989. This Third Technical Committee was gratified by the improvement achieved in the accounting procedures, particularly in the quality of the AVM records. The primary reason for the diversion exceeding the flow limits of the Supreme Court Decree as modified in 1980 is the improved accuracy of the accounting procedures. A major part of this improved accuracy can be attributed to the AVM system at Romeoville. In most instances, actions have been taken to comply with the recommendations and significant progress has been made.

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

1. The draft of the Master Plan for the Lake Michigan Diversion Accounting Program (Master Plan) should be finalized,

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

3. The draft – Plan (draft – October 1988) should be updated and finalized based on the present status of Lake Michigan diversion computational procedures and measurements,

4. Update the AVM Quality-Assurance Plan,

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

6. The mean bed elevation of the canal at the AVM measuring reach should be surveyed periodically,

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

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

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

10. Annual Lake Michigan diversion results should be published in a more timely fashion, and field investigations of flow characteristics of the Upper Des Plaines Pumping Station,

including bypass flow, should be conducted to improve the accuracy of inflow and infiltration characteristics used in the hydrologic simulation.

1.3.4 Fourth Technical Committee

The Fourth Technical Committee was appointed July 1998 and held the first workshop in September 1998 and reviewed WYs 1990 through 1995. The Fourth Technical Committee was gratified by the improvement achieved in the accounting procedures, particularly in the quality of the AVM records. Some of the recommendations and findings made by the Fourth Technical Committee are summarized as follows:

1. The draft quality assurance plan (October 1988) has not been updated as recommended by the Third Technical Committee. The draft quality-assurance plan (October 1988) should be updated and finalized based on the present status of Lake Michigan diversion computational procedures and measurements (1999 conditions).

2. Before implementing lakefront accounting, a manual of procedures for lakefront accounting should be written.

3. The Lake Michigan accounting procedures should be modified to begin with an initial set of template files rather than begin with the previous year's files, which are copied and modified to represent the current year's data.

4. Results from statistical analyses of the six years of record considered in this review indicate that Budgets 9, 10, 11, and 13 may contain significant long-term biases.

5. The regression analysis used to develop backup equations to estimate flows when the Romeoville AVM is not functioning properly should be repeated to develop new backup equations for periods when the turbine AVMs are the reported flows at Lockport.

6. Potential bias error in the annual mean discharge from the Romeoville AVM for the six years reviewed in this report is ±93 cfs.

7. The USGS is continuing to revise and update the instrumentation, rating, and backup equations for the AVM on the Calumet River at O'Brien Lock and Dam. The record from this station, through WY 1998, has not been published and is still considered 'Provisional' and subject to revision. The AVM velocities show significant noise and variation among paths. The accuracy of the mean annual discharge at this site, cannot be determined by the current records.

8. The USGS is continuing to revise and update the instrumentation, rating, and backup equations for the AVM on the Chicago River at Columbus Drive. The record from this station, through WY 1998, has not been published and is still considered 'Provisional' and subject to revision. The AVM velocities show significant noise and variation among paths. The accuracy of the annual mean discharge at this site, based on current records, is approximately ±190 cfs. The committee anticipates that the accuracy of the calculated discharges at this site should be improved from this value as a result of the continuing efforts to improve the instrumentation and discharge-calculation procedures.

9. The USGS is currently installing an AVM on the North Shore Channel at Wilmette, Illinois. This site may experience many of the difficulties encountered at Columbus Drive and O'Brien Lock and Dam, and the Committee recommends:

10. Consecutive discharge measurements for a fixed flow condition should be grouped and averaged for rating analysis. Statistical tests for serial correlation should be a standard part of the regression analysis.

11. Backup equations should be developed to estimate flow for periods at missing AVM record based on the position of the sluice gate and the lake and channel stages. Measurements to develop this equation should be done with an ADCP. The lake and channel stage and gate-opening measurements should be verified as part of these measurements.

12. For Lakefront Accounting, the long-term average runoff from the diverted Lake Michigan watershed has been fixed at 800 cfs through the year 2020 as part of the mediation agreement. This runoff number was established as part of the mediation and has its basis from long-term simulation and streamflow separation of historical records. In order to re-evaluate this value in 2020, the capability to accurately simulate the hydrology of the watershed needs to be maintained.

13. For Lakefront Accounting the long-term consumptive use of water pumped from Lake Michigan has been fixed at 168 cfs through the year 2010 as part of the mediation agreement. Based on a review of the available data, the Committee concluded that consumptive use cannot practically be determined directly. The Committee, therefore, concluded that an indirect determination of consumptive use from a water budget analysis based on water-supply pumpage and treatment plant flow records and simulation results is consistent with best current engineering practice.

14. Water-supply pumpage accounts for about 80 percent of the measured components of Lake Michigan Diversion under the proposed Lakefront Accounting System. The USACE has initiated quality-assurance reviews of three of the water-supply facilities. These reviews were done to provide a protocol and format for subsequent review of the remainder of the water-treatment facilities and pumping stations. The reviews from the three prototype studies do not adequately document the accuracy of the pumpage records from these plants.

15. The Fourth Technical Committee was concerned regarding the data viability during the initial part of the three-water-year transition period. The USGS is using state-of-the-art technology to measure the velocities and develop the ratings at these sites. The Fourth Technical Committee believed the accuracy for the record currently available for these sites does not reflect the potential of the current technology to measure flows at these sites.

2.0 LAKE MICHIGAN DIVERSION ACCOUNTING – WATER YEAR 1996-1999

Both measured and estimated flows are used to determine the annual diversion of water from Lake Michigan that is accountable to the State of Illinois pursuant to provisions of the U.S. Supreme Court Decree in the Wisconsin, et al. vs. Illinois, et al. 388 U.S. 426, 87 S.Ct. 1774 (1967) as modified in 449 U.S. 48, 101 S.Ct. 557 (1980), hereinafter referred to as the 1980 Modified Decree. Continuous flow monitoring is performed whenever possible to directly measure components of the diversion budget. Hydrologic and Hydraulic (H&H) computer models use meteorological data to simulate flows for those components of the diversion budget that cannot be directly measured. When possible, continuous flow monitoring is performed to test the validity of the computer models.

The 1980 Modified Decree prescribes that the measurements and computations required by the Decree shall be made using “best current engineering practice and scientific knowledge.” Furthermore, the USACE shall periodically convene a Technical Committee to review and report to the USACE “on the method of accounting and the operation of the accounting procedure.”

The Fifth Technical Committee was appointed by the USACE in December 2002 to conduct the court-mandated assessment of the accounting procedures and methodology used to quantify diversion. The assessment performed by the committee focused on the following primary topics:

1. The accounting of annual diversions for WYs 1996, 1997, 1998, and 1999 (Sections 2.1-2.3),

2. Measurement methods implemented at primary flow-monitoring locations (Chapter 6),

3. Procedures used to calculate and verify flows that are not directly measured such as the H&H models (Chapter 4),

4. The status of recommendations offered by previous technical committees (Section 1.3),

5. Comparison of the anticipated relative accuracy or uncertainty in the estimates of diversion calculated using the Romeoville and Lakefront Accounting Systems (Chapter 5), and

6. Evaluation of approaches that might be used to quantify consumptive use (Section 4.6).

The Committee addressed its goal by means of meetings with key participants in the accounting process, reviewing technical reports, and inspecting site conditions. These activities are more specifically summarized as follows:

Committee Meetings

The following is a summary of the Fifth Technical Committee activities, including workshops, field trips and reviewed reports (Appendix B).

1. Workshop #1 (January 6 – 10, 2003) in Chicago – Introductions and overviews,

2. Workshop #2 (February 24 – 28, 2003) in Urbana and Chicago – Review acoustic metering station records, history, and uncertainty; MWRDGC discharge records; and University of Illinois numerical and physical modeling of density gradients in the Chicago River Mainstream.

3. Workshop #3 (August 4 – 8, 2003) in Chicago – Romeoville gage relocation, water-supply metering and recording, rainfall monitoring, and overall and gage-specific uncertainty, and

4. Meeting #4 (October 15 – 17, 2003) in Chicago – Committee presentation of preliminary findings and recommendations.

Water data and interpretive reports were reviewed including:

1. USACE annual accounting reports for WYs 1997 through 1999,

2. USGS WYs 1997 through 1999 discharge computation report and associated error analysis, and

3. Variety of supporting technical documents related to Lakefront Accounting, domestic water-supply metering accuracy, rainfall monitoring and hydrologic modeling, and acoustic metering quality assurance.

Field trips were made to inspect noteworthy aspects of the accounting process:

1. Primary gages and MWRDGC Chicago River Controlling Works,

2. University of Illinois Ven Te Chow Hydrosystems Laboratory (Dr. Marcelo Garcia),

3. Evanston and Jardine Water Treatment Plants,

4. ISWS precipitation gages,

5. MWRDGC control center,

6. Alternative Romeoville gage locations, and

7. RD Instruments field inspection and demonstration of acoustic meter.

The Lake Michigan Diversion draft Accounting Manual of Procedures (U.S. Army Corps of Engineers, 2001a) lists the sources of data compiled in Table 2-a that are required to perform diversion accounting using the currently accepted Romeoville Accounting System. The discharge of the CSSC at Romeoville represents the majority of flow diverted from Lake Michigan and its watershed. As such, the gaging station maintained by the USGS along the CSSC at Romeoville is the most important source of data used in the Romeoville Accounting System.

Table 2-a: Nature and Source of Data Used for Diversion Accounting at Romeoville

[Sources denoted as USGS (U.S. Geological Survey), MWRDGC (Metropolitan Water Reclamation District of Greater Chicago), IEPA (Illinois Environmental Protection Agency), IDEM (Indiana Department of Environmental Management), CIW (Consumer Illinois Water Company), ISWS (Illinois State Water Survey), Illinois and Indiana Departments of Natural Resources (DNR), NOAA (National Oceanic and Atmospheric Administration), and ANL (Argonne National Laboratory).

Type of Data	No. of Locations	Source of Data
Discharge of the Chicago Sanitary and Ship Canal	1	USGS and MWRDGC (1 each)
Streamflow	5	USGS
Direct diversion flows	3	USGS and MWRDGC (3 each)
Lake Michigan water-supply withdrawals	39	Illinois DNR (26), Indiana DNR (2), and several private and federal (3)
Industrial withdrawals or discharges	17	IEPA (2) and individual industries
Groundwater withdrawals	Not noted	ISWS
Water reclamation plant flows	21	MWRDGC (10), IDEM (4), CIW (3), and other utilities (4)
Meteorological data	45	NOAA (3), ANL (1), ISWS (1)
Precipitation data	25	ISWS

The Lakefront Accounting System, which is still undergoing evaluation by the various stakeholders, is based on a subset of these data, more specifically the direct diversion flows and Lake Michigan water-supply withdrawals. Flow monitoring performed by water-supply facilities and at three gaging stations established in the late 1990’s near the lakefront along the Chicago River at Columbus Drive, Calumet River at O’Brien Lock and Dam, and North Shore Channel at Wilmette will have a much greater importance in the documentation of the diversion.

Presented in Table 2-b is a summary of chronological events regarding the Technical Committee’s activities and Lake Michigan Diversion events for the period 1980-1998.

Table 2-b: Chronological Summary of Technical Committee and Lake Michigan Diversion Events

FIRST TECHNICAL COMMITTEE Convened June 1981, Final Report – October 1981 (Espey et al., 1981) Reviewed Status of Diversion Computation as Stipulated by the 1980, Modified Decree of the U.S. Supreme Court		
SECOND TECHNICAL COMMITTEE Convened July 1986, Final Report – November 1987 (Espey et al., 1987) Reviewed Status of Diversion Computation as Stipulated by the 1980, Modified Decree of the U.S. Supreme Court		
Annual Report	Water Year Diversion Results	Remarks
1981, 1982 Annual Report 11/1983 – Released	1981/1982	• Lockport Measurement Site – First Committee Report (Espey et al., October 1981) • Harza report proposed new diversion accounting program (Harza Engineering, 1981) • WY 81-82 Diversion certified despite Technical Committee (1981) concerns regarding Lockport rating.
1983, 1984, 1985 Annual Report 2/1986 – Released	1983	• New Accounting System (Northeastern Illinois Planning Commission, NIPC, 1985), Used hydrologic computer models. • WES Report (Hart and McGee, 1985) Powerhouse and Controlling Works sluice gate – new rating resulted in a reduced diversion (180 cfs) for WY 1983. • Romeoville AVM installation (March 18-23, 1984), AVM data suggest Lockport Turbine low flows are consistently low. • 1983 diversion certified despite concerns on Lockport rating (Technical Committee, 1981) findings. • Second Committee convenes (July 1986)
1986 Annual Report 3/1987 – Released	No diversion results	• Mainstream and Calumet Tunnel and Reservoir Plan (TARP) tunnels become operational – Began new accounting system, development of a computerized water budget, HEC analysis of Hydrologic Simulation Procedures. • Second Committee Report (Espey et al., November 1987)

THIRD TECHNICAL COMMITTEE Convened February 1993, Final Report – July 1994 (Espey et al., 1994) Reviewed Status of Diversion Computation as Stipulated by the 1980, Modified Decree of the U.S. Supreme Court		
Annual Report	Water Year Diversion Results	Remarks
1987 Annual Report 9/1988 – Released	No diversion results	• The Water Resource Development Act of 1986 gave USACE responsibility for the computation of diversion flow (effective October 1987)
1988 Annual Report 3/1989 – Released	No diversion results	• Continuing problems with AVM; new AVM system to be installed. • Diversion Accounting certification suspended in WY 1988 pending revision of hydrologic modeling parameters as per Second Technical Committee's suggestion. • Second Technical Committee Final Report (November 1987)
1989 Annual Report 11/1993 – Released	1984-1985	• November 1988 – ORE, Inc. AVM installed • First Annual Report that USACE assumes responsibility for the computation of diversion • Diversion Accounting report developed by NIPC, reviewed and updated by USACE • USACE updated hydrologic model parameters and revised 1984-1985 flows based on AVM records
1990-92 Annual Report 1/1994 - Released	1986-1987 1988 - 1989	• New regression equations (USGS, Melching and Oberg, 1993) (WY 1986, 1987, 1988, and 1989) • Modeling update – Mainstream and Camulet TARP • USACE Lakefront measurements • New 25-gage precipitation gage network – installed (October 1990) • Grand Calumet River West Branch gage established (October 1991) • Diversion results indicated State of Illinois exceeded allowable diversion – 1988 • 1986 problem with AVM • 1987 AVM – little missing record • 1988-89 Solar Radiation Correction

<table>
<tr><td colspan="3">FOURTH TECHNICAL COMMITTEE
Convened September 1998, Final Report (May 2001)
Reviewed Status of Diversion Computation as Stipulated by the 1980, Modified Decree of the U.S. Supreme Court</td></tr>
<tr><td>Annual Report</td><td>Water Year Diversion Results</td><td>Remarks</td></tr>
<tr><td>1993 Annual Report
9/1994 – Released</td><td>1990</td><td>• Modification to the hydrologic runoff models and hydraulic sewer routing models to incorporate the 25-gage precipitation network into the WY 90 diversion accounting. This includes revision to map delineation for combined sewer contributing areas, delineation of area assigned for the 25-gage network, revision and update of land-use/land-cover delineations.
• Third Technical Committee – convened February 1993
• Third Technical Committee final report (Espey et al., 1994)</td></tr>
<tr><td>1994 Annual Report
10/1995 – Released</td><td>1991
1992</td><td>• During WY 1994 and continuing into WY 1995 the hydrologic runoff and hydraulic sewer models were modified in order to utilize the Data Storage System (DSS) database of the USACE as the sole database in all diversion accounting computations. The modified models were used for WY 1991 and WY 1992 accounting.</td></tr>
<tr><td>1995 Annual Report
3/1997 – Released</td><td>1993
1994</td><td>• Beginning in June 1993 the southern and middle portions of the Des Plaines TARP system became operational. These tunnels were added to the modeling of the TARP system of WY 1993.
• The estimate of the Grand Calumet River portion of the water supply pumpage from Indiana that reaches the Chicago Sanitary and Ship Channel (CSSC) was revised to better account for the unique hydraulics of the river.
• Prior to WY 1993 there existed a double accounting of a portion of the runoff from the ungaged Calumet watershed. The flow that was double accounted was the infiltration into the separate sanitary sewers within the ungaged Calumet watershed. This revision only impacts Column 12, the diverted runoff from the Lake Michigan watershed, which is used as a component verification of the overall diversion contained in Column 10.</td></tr>
<tr><td>1996 Annual Report
10/1998 – Released</td><td>1995</td><td>• The USACE supported the Great Lakes Mediation Committee with respect to various special studies: 1) runoff and 2) consumptive use.</td></tr>
</table>

FIFTH TECHNICAL COMMITTEE Convened January 2003, Draft Report (June 2004) Reviewed Status of Diversion Computation as Stipulated by the 1980, Modified Decree of the U.S. Supreme Court		
Annual Report	Water Year Diversion Results	Remarks
1997 Annual Report	1996	• Work began on changing the TNET files for the Calumet TARP tunnel. • Christopher Burke Engineering, Ltd. hired to review the model to ensure consistency with as-built plans and update the TNET model to account for new Calumet tunnel legs. • Started changing over from computing solar radiation data using O'Hare meteorologic data to using the measured solar radiation data collected at Argonne National Labs. • The efforts relating to the changes to the Calumet modeling and the computation of the solar radiation were carried over into the FY 1998 and FY 1999 and were a primary reason for the delay in the release of the WY 1996 accounting report.
1998 Annual Report 7/2001 - Released	1997	• USGS AVM gages at Columbus Drive and O'Brien Lock and Dam established in December and October 1996, respectively. • The efforts relating to the changes to the Calumet modeling and the computation of the solar radiation were carried over from FY 1996 and were the primary reason for the delay in the release of the WY 1996 accounting report. • Percentages of pervious and impervious areas adjusted in the hydrologic modeling to correct for suspected overestimate of combined sewer overflow discharges. • Contracting efforts occurred related to the establishment of the Fourth Technical Committee. The first workshop of the Fourth Technical Committee was in September 1998.
1999 Annual Report 4/2004 - Released	1998-1999	• USGS installation of an AVM gage at Wilmette (September 1999). • Contract initiated for work on a detailed QA/QC of ten primary water supply diverters in Chicago and five in the northern Chicago suburbs. (work completed in 2003). • USACE completed a hydraulic analysis of various alternatives for Navigation Makeup Reduction.

2.1 WATER YEAR 1997 ANNUAL REPORT (WY 1996 ACCOUNTING REPORT)

The activities for FY 1997 centered on the WY 1995 diversion accounting modeling and initiating the data collection and input activities for the WY 1996 analysis. Work also began on the changes to the TNET files for the Calumet TARP tunnel. Christopher Burke Engineering, Ltd. was hired by the USACE to review the model to ensure consistency with the as-built plans for the Calumet tunnel system and its dropshafts and update the TNET model to account for the new Calumet tunnel legs that went on-line during WY 1996. The USACE began the change over to using the measured solar radiation data collected at Argonne National Labs from computing solar radiation data using O'Hare meteorologic data. The WY 1996 accounting report details the changes to the TNET modeling and solar radiation. The efforts relating to the changes to the Calumet modeling and the computation of the solar radiation were carried over into FY 1998 and FY 1999 and were a primary reason for the delay in the release of the WY 1996 accounting report. Ongoing work related to the potential switch to Lakefront Accounting continued. The USGS work with the lakefront gages at Columbus Drive on the Chicago River and O'Brien Lock and Dam on the Calumet River. Ongoing mediation activities related to the Great Lakes

Mediation Committee including technical support and detailed analyses of long-term runoff and consumptive use values. The U.S. Water Conservation Laboratory performed detailed QA/QC analysis of three pumping stations.

2.2 WATER YEAR 1998 ANNUAL REPORT (WY 1997 – ACCOUNTING REPORT)

The activities centered on the completion of the WY 1996 diversion accounting modeling and the release of the WY 1996 annual report. In FY 1998, the data collection and input activities for the WY 1996 and WY 1997 analyses were initiated. In addition, work continued on the changes to the TNET files for the Calumet tunnel to reflect WY 1996 conditions. Christopher Burke Engineering, Ltd. continued to review the model to ensure consistency with the as-built plans for the Calumet tunnel system and its dropshafts and update the TNET model to account for the new Calumet tunnel legs that went on-line during WY 1996. The USACE continued the change over from computing solar radiation data using O'Hare meteorologic data to using the measured solar radiation data collected at Argonne National Labs. The WY 1996 accounting report details the changes to the TNET modeling and solar radiation. The efforts relating to the changes to the Calumet modeling and the computation of the solar radiation were carried over into FY 1999 and were a primary reason for the delay in the release of the WY 1996 accounting report. The Lakefront Accounting activities for FY 1997 continued in FY 1998. Finally, contracting efforts related to establishment of the Fourth Technical Committee occurred during FY 1998. The first workshop of the Fourth Technical Committee was held in September 1998.

2.3 WATER YEAR 1999 ANNUAL REPORT (WY 1998 AND 1999 – ACCOUNTING REPORTS)

The activities in FY 1999 focused on completing the WY 1996 accounting report, beginning activities related to WY 1997 diversion accounting, ongoing mediation activities related to the Great Lakes Mediation Committee, and coordination of activities related to the Fourth Technical Committee. In addition to the continuation of the lakefront activities listed for FY 1997, FY 1999 also included the USGS installation of an AVM gage at Wilmette. Finally, the USACE completed a hydraulic analysis of various alternatives for Navigation Makeup Reduction and a contract was initiated for work on a detailed QA/QC of ten primary water supply diverters in Chicago and five in the northern Chicago suburbs.

2.4 LAKE MICHIGAN CUMULATIVE DIVERSION DEFICIT (ESTIMATED THROUGH WY 2004)

The cumulative deviation of Lake Michigan diversion had increased from 1983 until 1994, when the trend reversed. The Lake Michigan Diversion is estimated through WY 2003, based on flow at the USGS Romeoville gage. The Lake Michigan diversion was estimated at 98 percent of the Romeoville flow (USACE Verbal Communication). Summarized in Table 2.4-a and Figure 2.4-a is a comparison of various Lake Michigan components: 1) Romeoville flow; 2) diverted watershed runoff (Column 12); 3) Lake Michigan pumpage (Column 11); 4) direct diversion (column 13); 5) Lake Michigan/Huron Levels; 6) total diversion (Column 10); and 7) cumulative deviation as defined by the 1980 Modified Supreme Court Decree. Based on the data provided by the USGS and the USACE for 2000-2003 the cumulative deviation has decreased dramatically to approximately 500 cfs (2003). This in part can be attributed to the levels of Lake Michigan and the reduction in leakage at the CRCW as a result of the repairs made to the lock gates and completion of the new turning basin wall by the summer of 2000. The substantial reduction in Lake Michigan pumpage in 2000 and 2001 reflects an aggressive campaign by the City of Chicago to repair leaky water mains. The Fifth Technical Committee obtained provisional monthly flow at Romeoville for October 2003 through May 2004 and estimated the remaining four months (June, July, August and September) for WY 2004 based on recent monthly flow trends (1998-2003). The resulting estimated flow at Romeoville for WY 2004 results in approximately "zero" cumulative diversion deficit by the end of WY 2004.

Table 2.4-a: Lake Michigan Lake Levels, Components of the Lake Michigan Diversion, and Cumulative Deviation from the Allowable Diversion

Year	Romeoville (cfs)	Diverted Watershed Runoff (Column 12) (cfs)	Lake Michigan Pumpage (Column 11) (cfs)	Direct Diversion (Column 13) (cfs)	Lake Michigan /Huron Levels (ft MSL)	Total Diversion (cfs)	Cumulative Deviation
1990	3,749	873	1,579**	450	-----	3,531	2,520
1991	3,790	1,041	1,639**	472	-----	3,561	2,875
1992	3,860	848	1,607**	452	-----	3,409	3,084
1993	4,074	1,505	1,619**	519	-----	3,841	3,725
1994	3,088	681	1,698**	497	579.7	3,058	3,589
1995	3,235	798	1,645**	480	579.4	3,197	3,586
1996	3,162	882	1,604**	379	579.3	3,108	3,494
1997	3,231	777	1,597	440	580.6	3,114	3,408
1998	3,120	774	1,621	633	580.2	3,059	3,268
1999	2,945	759	1,605	408	578.6	2,909	2,977
2000	2,563	-----	1,532	285	577.5	2,512*	2,289*
2001	2,710	-----	1,525	350	577.2	2,656*	1,745*
2002	2,919	-----	-----	-----	577.9	2,861*	1,405*
2003	2,342	-----	-----	-----	577.5	2,295*	500*

* Estimated based on Romeoville flow.
** Starting in 1997 a consumptive use factor or 10 percent was incorporated in the calculations for Column 11 (Lake Michigan Pumpage), prior to 1997 Column 11 did not account for consumptive use. The values prior to 1997 in the table above have been modified to incorporate a 10 percent consumptive use factor.

The USACE (Figure 2.4-b) presents the long-term record (1918 to 2003) of Lake Michigan-Huron lake levels. Lake levels for Lake Michigan/Huron during the period of review have been low compared to the historical average, hence leakage is expected to be low. Higher lake levels will lead to the potential for higher leakage. The continuation of Lakefront AVM gaging would be useful in further characterizing how effective the repairs made at the CRCW in 1997-2000 have been.

Figure 2.4-a: Lake Michigan Cumulative Deviation from the Allowable Diversion, Annual Lake Michigan Pumpage, Diverted Watershed Runoff, Direct Diversion and Romeoville Annual Flows, and Lake Michigan/Huron Levels for 1990-2003

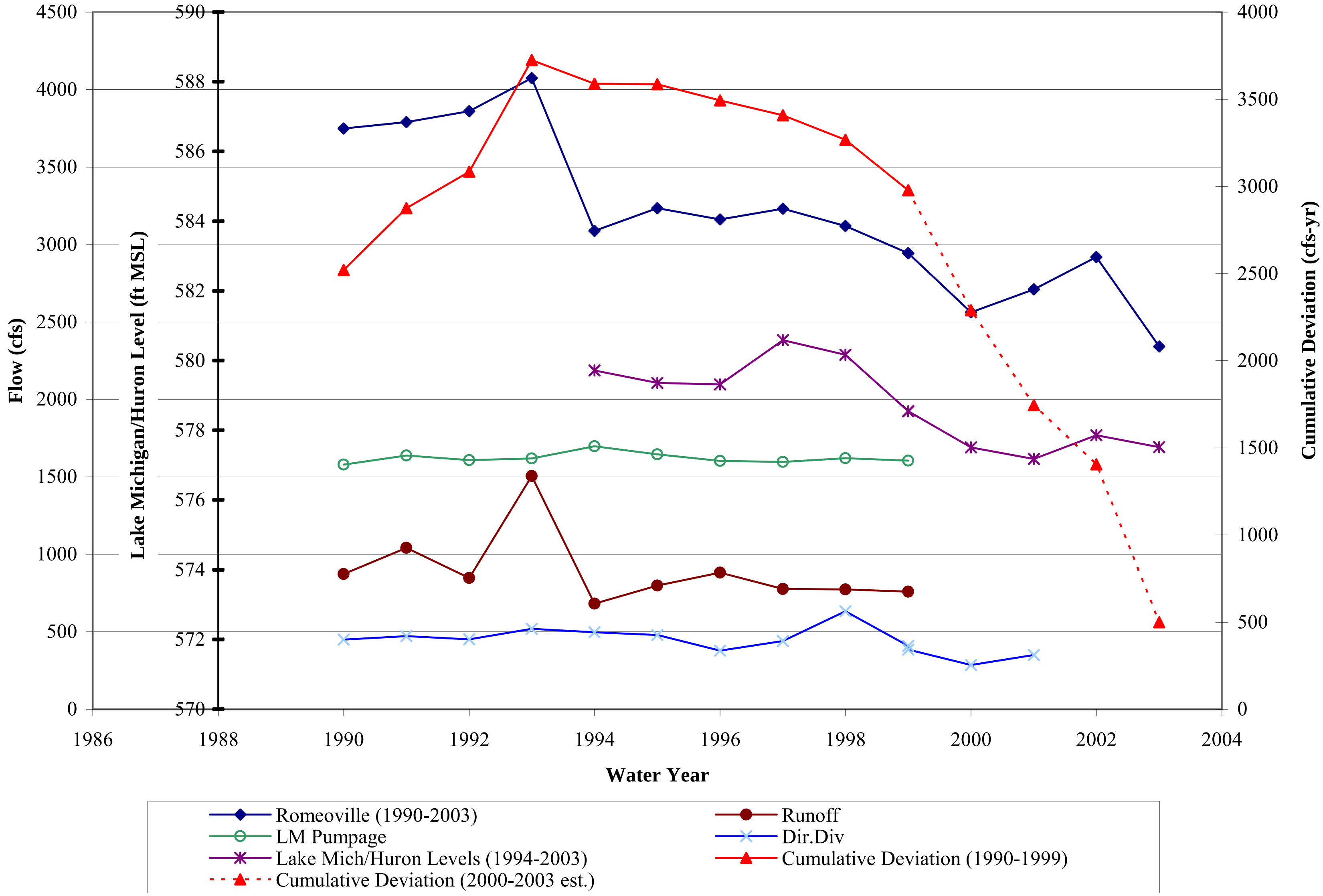


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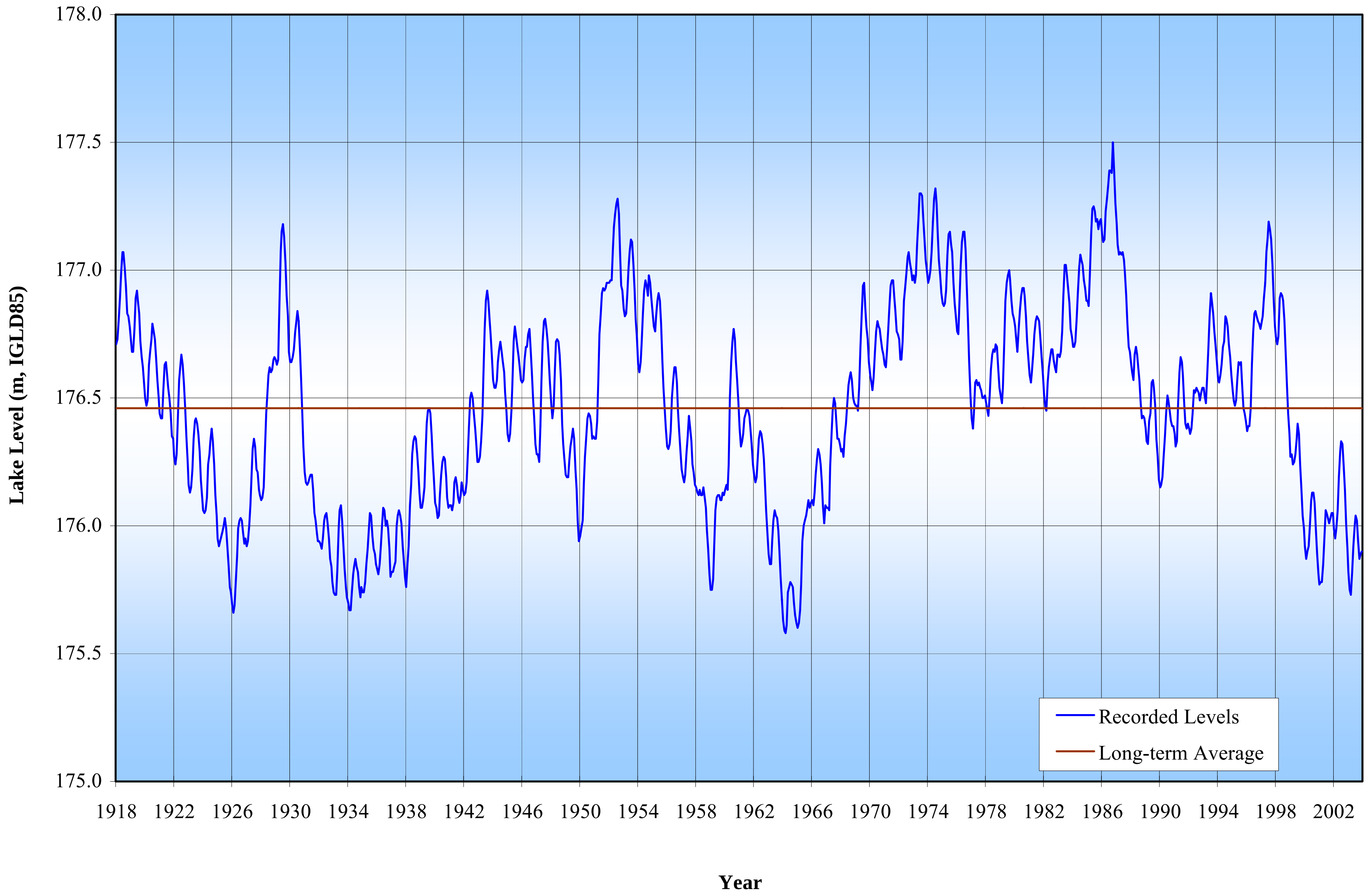
Figure 2.4-b: Lake Michigan-Huron Hydrograph (1918 – 2003)



3.0 REVIEW OF CURRENT ACCOUNTING SYSTEM

3.1 ACCOUNTING REPORT

A sample diversion accounting table for 1998 is shown in Table 3.1-a. A summary of the column entries is shown in Table 3.1-b. Columns 1 through 3 are the total flow entering the CSSC. Column 4 through Column 7 are the deductions from the CSSC flows. The total deduction is in Column 8. Column 9 is the Lake Michigan pumpage not discharged to the CSSC, and, thus, that it is not measured at Romeoville, and which represents an addition to the CSSC flow. Column 10 is the Lake Michigan diversion accountable to Illinois and is equal to the CSSC flow (Column 3) minus the deductions (Column 8) plus the additions (Column 9). Columns 11 through 13 are independent flow estimates for the three sources of diversion: water-supply pumpage from Lake Michigan; runoff from the diverted Lake Michigan watershed; and direct diversion through the lakefront structures. Columns 11 through 13 are not used in the diversion calculation but are included to verify the diversion calculation and to estimate the three diversion components. The sum of the Columns 11 through 13 should theoretically equal the flow in Column 10, but errors in the simulation of runoff, the estimate of consumptive use, and the measurement of leakage and flow past the sluice gates may cause this number to be different.

Table 3.1-a: Diversion accounting table for 1998 (note: reference to Appendix B below refers to the diversion accounting report (U.S. Army Corps of Engineers, 2004))

LAKE MICHIGAN DIVERSION ACCOUNTING WY 1998	ROMEOVILLE AVM GAGE RECORD	DIVERSIONS ABOVE THE GAGE	TOTAL FLOW THROUGH THE CANAL	GROUNDWATER PUMPAGE DISCHARGED INTO THE CANAL	WATER SUPPLY PUMPAGE FROM INDIANA REACHING THE CANAL	RUNOFF FROM THE DES PLAINES RIVER WATERSHED REACHING THE CANAL	LAKE MICHIGAN PUMPAGE BY FEDERAL FACILITIES DISCHARGED TO THE CANAL	TOTAL DEDUCTION FROM THE ROMEOVILLE GAGE RECORD	LAKE MICHIGAN PUMPAGE NOT DISCHARGED TO THE CANAL	**TOTAL DIVERSION ACCOUNTABLE TO THE STATE OF ILLINOIS**	PUMPAGE FROM LAKE MICHIGAN ACCOUNTABLE TO THE STATE OF ILLINOIS	RUNOFF FROM THE DIVERTED LAKE MICHIGAN WATERSHED	DIRECT DIVERSION ACCOUNTABLE TO THE STATE OF ILLINOIS
DATE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Oct-97	2,619.7	3.3	2,623.0	72.1	79.6	58.7	1.1	211.5	244.8	2,656.3	1,569.4	305.0	821.9
Nov-97	2,008.8	2.5	2,011.3	67.5	64.9	65.9	0.9	199.2	225.1	2,037.2	1,482.7	261.7	292.9
Dec-97	2,125.2	2.3	2,127.5	88.4	50.1	97.3	0.9	236.7	223.0	2,113.8	1,464.5	481.5	114.1
Jan-98	3,111.8	1.5	3,113.3	118.6	47.9	236.3	1.0	403.8	226.5	2,936.0	1,471.4	1,162.9	223.7
Feb-98	2,986.7	1.8	2,988.5	96.5	47.8	200.9	1.0	346.2	220.8	2,863.1	1,449.2	998.4	161.4
Mar-98	3,721.3	1.1	3,722.4	129.4	50.7	300.5	1.0	481.6	223.3	3,464.1	1,467.3	1,606.6	195.8
Apr-98	3,420.0	1.8	3,421.8	113.0	76.5	216.9	1.0	407.4	225.1	3,239.5	1,456.3	1,043.4	290.3
May-98	3,610.3	1.9	3,612.2	94.3	78.1	228.7	1.0	402.1	263.2	3,473.3	1,628.9	1,138.7	462.4
Jun-98	3,299.9	3.3	3,303.2	102.5	51.0	135.9	1.4	290.8	293.9	3,306.3	1,824.8	634.9	951.1
Jul-98	3,500.7	3.2	3,503.9	86.4	54.8	53.4	1.5	196.1	327.8	3,635.6	2,024.3	389.7	1,500.2
Aug-98	4,026.1	3.5	4,029.6	124.2	61.8	183.4	1.3	370.7	304.0	3,962.9	1,864.5	939.5	1,471.1
Sep-98	2,966.0	2.9	2,968.9	90.6	44.7	127.8	1.4	264.5	279.3	2,983.7	1,727.3	315.9	1,068.5
Averages	3,119.6	2.4	3,122.0	98.7	59.1	158.7	1.1	317.6	255.0	3,059.4	1,620.6	773.6	633.1

Computations:

1. Column 3 equals the sum of Columns 1 and 2.
2. Column 8 equals the sum of Columns 4 through 7.
3. Column 10 = Column 3 - Column 8 + Column 9.

Note: The averages presented in the final row are calculated from the daily values contained in Appendix B.

Deductions from the Romeoville Gage Record (columns 4–7, shaded purple)

Additions to the Romeoville Gage Record (column 9, shaded green)

3.1.1 Description of Columns in Diversion Accounting Table

Table 3.1-b: Description of diversion accounting columns

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

The following is a brief description of each column:

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

Column 1 represents the discharge at the Romeoville gage located on the CSSC approximately 5.2 miles upstream of the Lockport Lock and Powerhouse. Records are computed by the USGS using the AVM gage at this station location. Records were based on a Sarasota AVM from June 12, 1984 to November 3, 1988. A new AVM manufactured by ORE became operational on November 17, 1988. This AVM stopped collecting data correctly on August 31, 2001. A new Accusonic AVM became operational April 1, 2002.

Column 2: Diversion from the CSSC above the Gage

Column 2 is municipal or industrial diversions from the CSSC upstream of the Romeoville gage. Presently, only Argonne National Laboratories and Citgo Petroleum Corporation divert water from the CSSC upstream of the Romeoville gage.

Column 3: Total Flow through the CSSC

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

Column 4: Groundwater Discharge to the CSSC and Adjoining Canals

Column 4 is the groundwater pumped by communities, industrial users, and other private users as reported by the Illinois State Water Survey (ISWS). Column 4 also includes groundwater seepage into the TARP tunnels that is discharged to the canal. Groundwater discharge is determined by summing all reported groundwater sources in the area tributary to the canal and the estimated groundwater seepage into the Mainstream, Des Plaines, and Calumet TARP systems. This total flow is then adjusted by subtracting the groundwater normally tributary to the canal that is contained in the combined-sewer overflows that discharge to the Des Plaines River and other water courses not tributary to the CSSC. Groundwater seepage into the TARP system was determined through simulation and pumpage records. The groundwater constituent of combined-sewer overflows is determined entirely through simulation. Groundwater pumpage whose effluent is discharged to the canal is a deduction. The portion of the value of Column 4 for Groundwater Pumpage Discharged to the Canal is based on water-supply pumpage records and beginning in WY 1997 these records were reduced by 10 percent to account for consumptive use.

Column 5: Water-Supply Pumpage from Indiana Reaching the CSSC

Column 5 is the water supply pumpage by the State of Indiana that reaches the canal as effluent. This water is not charged to Illinois' allotment. It is a deduction from the flow measurement at Romeoville.

Column 6: Runoff from the Des Plaines River watershed (DPW) Reaching the CSSC

Column 6 consists of the following components, which are determined by simulation:

1. Infiltration and inflow from the DPW discharged to the WRPs,

2. Infiltration and inflow from the DPW reaching the CSSC through combined sewer overflows,

3. Direct runoff, including runoff from storm sewers, that discharges to watercourses from the Lower Des Plaines watershed, and the Summit Conduit area, and

4. The runoff portion of the O'Hare flow transfer.

Column 7: Lake Michigan Pumpage by Federal Facilities Which Discharge to the CSSC

Column 7 represents Lake Michigan diversion by federal facilities not chargeable to the State of Illinois allocation. Federal facilities represented by the column are as follows:
Hines VA Hospital
Fort Sheridan
Glenview Naval Air Station (removed WY2000)
USACE emergency navigation makeup water

Column 8: Total Deduction from the CSSC at Romeoville

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

Column 9: Lake Michigan pumpage not discharged to the CSSC

Column 9 is the water supply pumpage from Lake Michigan that is not discharged to the CSSC. The water supply pumpage not discharged to the CSSC has two components:

1. Water supply used by communities whose sewage effluent is not discharged into the CSSC, and

2. The sanitary portion of combined sewer overflows that are not discharged to the CSSC, from Lake Michigan water supply, originating from communities whose sewage effluent is tributary to CSSC.

The value in Column 9 for Lake Michigan Pumpage not discharged to the Canal is based on water-supply pumpage records and beginning in WY 1997 these records were reduced by 10 percent to account for consumptive use.

Column 10: Total Diversion

Column 10 is the total Lake Michigan diversion that is accountable to the State of Illinois. Column 10 is equal to column 3 minus column 8 and plus column 9.

Column 11: Lake Michigan pumpage

Column 11 is the total Lake Michigan pumpage for which Illinois is accountable. The Lake Michigan pumpage is from water pumpage records of primary diverters of Lake Michigan water. They are measured at water-treatment plants or pumping stations, and beginning in WY 1997 these records were reduced by 10 percent to account for consumptive use.

Column 12: Runoff from the diverted Lake Michigan watershed

Column 12 is composed of runoff determined by removing wastewater flows for the measured flows on the North Branch Chicago River at Niles and the Little Calumet River at South Holland, and the simulated runoff from the other parts of the diverted Lake Michigan Watershed including infiltration and inflow entering the storm sewer system. This runoff is estimated using the computer programs Hydrological Simulation Program – Fortran (HSPF), Special Contributing Area Loading Program (SCALP), and Tunnel NETwork (TNET) models, and streamflow-separation techniques.

Column 13: Total direct diversion from Lake Michigan

Column 13 represents the total direct diversion of Lake Michigan water into the diverted river systems through the controlling structures at Wilmette, the CRCW, and the O'Brien Lock and Dam. Prior to WY 1998 the values were reported by MWRDGC on their LMO-6 reports. Beginning in WY 1998 the direct diversions were estimated on the basis of the measurements at the USGS gages at Columbus Drive on the Chicago River, Maple Avenue on the North Shore Channel at Wilmette, and O'Brien Lock and Dam on the Calumet River.

3.2 DESCRIPTION OF COMPUTATIONAL WATER BUDGETS

Fourteen computational budgets compile input for the diversion calculation and estimate flows that cannot be measured. A summary of these budgets is presented in Table 3.2-a, Budgets 1 and 2 are summations of water-supply pumpage data. Budgets 3 through 6 partition stream-gage records into runoff and sanitary/industrial discharge components to estimate a portion of the runoff from the diverted watershed that is used as input to column 12 (Runoff from the diverted Lake Michigan watershed). Budgets 7 through 13 compare simulated to measured flows at MWRDGC facilities. These budgets are for verification of the diversion-accounting procedures and give an indication of the accuracy of the diversion accounting. Budget 14 compares canal system inflows and outflows.

Table 3.2-a: Description of the diversion accounting computational water budgets

Budget Number	Title	Description
1	Diverted Lake Michigan Pumpage	This budget sums the Lake Michigan water diverted by the State of Illinois in the form of industrial and municipal water supply. The results of this budget are used in Column 11.
2	Groundwater Discharged to the CSSC	This budget sums groundwater pumpages that are discharged to the CSSC. The results of this budget are used in Column 4.
3	North Branch Chicago River at Niles, IL	This budget performs a simple separation of stream flow into sanitary and runoff portions. The results of this budget are used in Budget 14 and Column 12.
4	Little Calumet River at the IL-IN State Line	This budget performs a simple separation of stream flow into sanitary and runoff portions. The results of this budget are used in Budget 14 and Column 12.
5	Thorn Creek at Thornton, IL	This budget performs a simple separation of stream flow into sanitary and runoff portions. The results of this budget are used in Budget 14 and Column 12.
6	Little Calumet River at South Holland, IL	This budget performs a simple separation of stream flow into sanitary and runoff portions. The results of this budget are used in Budget 14 and Column 12.
7	MWRDGC North Side Water Reclamation Plant	This budget performs hydrologic and hydraulic simulation of the service basin tributary to the MWRDGC North Side Water Reclamation Plant. The simulation estimates the runoff from portions of the Lake Michigan and Des Plaines River watershed within the North Side service basin that is diverted to the CSSC in the form of inflow-infiltration. The budget provides an internal verification of the accounting procedures. The results of this budget are used in Budget 14 and Columns 6 and 12.
8	Upper Des Plaines Pumping Station	This budget performs hydrologic and hydraulic simulation of the MWRDGC Upper Des Plaines Pumping Station. This budget provides a calibration point to verify models of the Des Plaines River watershed.
9	MWRDGC Mainstream TARP Pumping Station	This budget performs hydrologic and hydraulic simulation of the MWRDGC Mainstream TARP Pumping Station including flow from the Des Plaines TARP tunnels. The results of this simulation are used in Budgets 10 and 14 and Columns 4, 6, and 12. The budget also provides internal verification of the accounting procedures.
10	MWRDGC Stickney Water Reclamation Plant	This budget performs hydrologic and hydraulic simulation of the service basin tributary to the MWRDGC Stickney Water Reclamation Plant. The simulation estimates the runoff from portions of the Lake Michigan and Des Plaines River watersheds within the Stickney service basin that is diverted to the CSSC in the form of inflow-infiltration. The budget provides an internal verification of the accounting procedures. The results of this budget are used in Budget 14 and Columns 6 and 12.
11	MWRDGC Calumet TARP Pumping Station	This budget performs hydrologic and hydraulic simulations of the MWRDGC Calumet TARP Pumping Station. The results of this simulation are used in Budgets 12 and 14 and Columns 4, 6, and 12. The budget also provides internal verification of the accounting procedures.

12	MWRDGC Calumet Water Reclamation Plant	This budget performs hydrologic and hydraulic simulation of the service basin tributary to the MWRDGC Calumet Water Reclamation Plant. The simulation estimates the runoff from portions of the Lake Michigan and Des Plaines River watersheds within the Calumet service basin that is diverted to the CSSC in the form of inflow infiltration. The budget provides an internal verification of the accounting procedures. The results of this budget are used in Budget 14 and Columns 6 and 12.
13	MWRDGC Lemont Water Reclamation Plant	This budget performs hydrologic and hydraulic simulation of the service basin tributary to the MWRDGC Lemont Water Reclamation Plant. The simulation estimates the runoff from portions of the Des Plaines River watershed within the Lemont service basin that is diverted to the CSSC in the form of inflow-infiltration. The budget provides an internal verification of the accounting procedures. The results of this budget are used in Budget 14 and Column 6.
14	Chicago Canal System	This budget performs a water balance of the Chicago Waterway System which includes the CSSC and adjoining channels. This budget provides a verification point for the accounting procedures.

4.0 HYDROLOGIC AND HYDRAULIC MODELS APPLIED TO DIVERSION ACCOUNTING

The use of hydrologic and hydraulic (H&H) models for the Lake Michigan Diversion Accounting varies in importance depending on whether Romeoville Accounting is used or if a switch is made to Lakefront Accounting. In Romeoville Accounting, the H&H models are directly used to compute the runoff from the Des Plaines River watershed reaching the CSSC that must be deducted from the measured flow at Romeoville (Column 6 of the Diversion Accounting Table). The H&H models also are directly used to compute the groundwater infiltration into the TARP tunnels that must be deducted from the measured flow at Romeoville (part of Column 4 of the Diversion Accounting Table). Beginning in WY 1993, a hydraulic model was used to determine the relation between Lake Michigan water level and Indiana water supply pumpage from Lake Michigan reaching Illinois through the Grand Calumet River (part of Column 5 of the Diversion Accounting Table). Finally, the H&H models are used to compute runoff from the diverted Lake Michigan watershed (Column 12 of the Diversion Accounting Table) and from the "ungaged" Calumet Watershed, lower Des Plaines River Watershed, and combined sewer overflows reaching the CSSC (Budget 14) as checks of the overall Romeoville Accounting procedure.

The average values of simulated Des Plaines River watershed runoff (from 1983-1999) and TARP groundwater inflow (from 1986-1999) are 183.4 and 64.0 cfs, respectively, which together compose 7.3 percent of the total diversion of 3,387 cfs or 6.9 percent of the total flow measured at Romeoville of 3,589 cfs (both averages for 1983-1999). At first glance, this might seem to be a fairly small portion of the diversion accounting. However, it should be noted that the combined 2000 water supply withdrawals of Arlington Heights, Bedford Park, Des Plaines, Evanston, Glenview, Naperville, Schaumburg, Skokie, and Waukegan was less than the average annual Des Plaines River watershed runoff (142.7 cfs vs. 183.4 cfs), and that the 2000 water supply withdrawal for Evanston was 14.9 cfs. Thus, errors in the H&H models easily could be of the magnitude of the water supply for a city of 70,000 people. Thus, the model-estimated portion of the Romeoville Accounting may be relatively small, but it still is important.

In Lakefront Accounting, the H&H models are used to estimate the long-term average annual runoff for the diverted Lake Michigan watershed, which then is subtracted from the allowable average annual diversion of 3,200 cfs. The long-term average annual runoff has been estimated to be 800 cfs in the Lakefront Accounting. This comprises 25 percent of the allowable diversion. Thus, the accuracy of the H&H models plays an even more important role for the Lakefront Accounting than it does for the Romeoville Accounting.

In the following sections the basic features of the modeling are described, whether the models are state of the art and properly applied is evaluated, suggestions are made for the improved application of the models, and issues needing further study are identified.

4.1 MODEL BACKGROUND

The USACE, Chicago District, has developed a sophisticated, system of three hydrologic and hydraulic models for direct computation of portions of the diverted flow and for indirect checking of the diversion accounting procedures. These models are the Hydrological Simulation Program-Fortran (HSPF), which is used to compute the surface and subsurface runoff from the watersheds on a continuous basis, Special Contributing Area Loading Program (SCALP), which is used to route combined sewer flows to the Water Reclamation Plants (WRPs) and to determine flows to the TARP tunnels and overflows to the rivers and canals, and Tunnel NETwork (TNET) model, which is used to model the flow through the TARP tunnels, and, thus, also affects the amount of combined sewer overflows.

The HSPF and SCALP models have their roots in models (Hydrocomp Simulation Program, HSP, and SCALP) developed by Hydrocomp, Inc. for the Northeastern Illinois Planning Commission (NIPC) for use in the Areawide Clean Water Planning program under Section 208 of the Federal Water Pollution Control Act Amendments of 1972. These models were subsequently revised by NIPC for use in diversion accounting, and the diversion accounting models have been revised and improved by the USACE and its contractors in response to changes and improvements in the available data and changes to the physical drainage system.

The most significant changes to the physical drainage system have been the addition of the Mainstream TARP tunnels in 1985, the Calumet TARP tunnels in 1986, and the Des Plaines TARP tunnels in 1993. Each of these systems has expanded since the tunnels first became operational, and the Mainstream and Des Plaines tunnels are now complete. Portions of the Calumet tunnel system still are under construction. To simulate the flow into and through the tunnel system the USACE developed the TNET model for the design and operational planning of the tunnel and reservoir system.

Among the three models—HSPF, SCALP, and TNET—the accuracy of the HSPF model is much more important to the diversion computations than the other two models. HSPF determines the amount of total runoff resulting from rainfall, whereas SCALP and TNET determine the amount of this total runoff and sewage flow that directly reach the Chicago Waterway System[1] (CWS) or the Des Plaines River as combined sewer overflows (CSOs). Since overflows to the CWS are measured at Romeoville the only components of the diversion computation affected by SCALP and TNET are the amount of CSOs from the Des Plaines River watershed draining to the CWS, and distribution of interceptor versus CSO flows in the Des Plaines River watershed draining the WRPs in the CWS drainage area. TNET computations also determine the groundwater infiltration to the TARP tunnels. Thus, the modeling discussion will focus on the accuracy and proper application of HSPF.

4.2 ASSESSMENT OF BEST CURRENT ENGINEERING PRACTICE AND SCIENTIFIC KNOWLEDGE

4.2.1 Hydrological Simulation Program-Fortran (HSPF)

The HSPF model (Bicknell et al., 1997) is supported by the U.S. Environmental Protection Agency and the U.S. Geological Survey (USGS). It has been applied for the solution of many hydrologic and water-quality problems across the U.S. including urban stormwater and floodplain management. Many of its applications are cited in the discussion of HSPF in the following sections. Its status as a “state of the art” model for the continuous simulation of the rainfall-runoff process is evidenced by its support by two Federal agencies and its many applications nationwide. **Proper application of HSPF in the diversion accounting would meet the Supreme Court’s requirement that the diversion accounting be done according to the “best current engineering practice and scientific knowledge.”**

[1]The Chicago Waterway System is the combination of streams and canals draining to and including the CSSC whose flow is measured at Romeoville, Ill.

4.2.2 Special Contributing Area Loading Program (SCALP)

The SCALP model is a specialty model primarily developed for use in the Chicago area. SCALP applies the linear reservoir concept to represent storage in each of the aggregated lateral, submain, and main pipe networks of the combined (or separate sanitary) sewer system in a designated area draining to the CWS, known as a special contributing area (SCA). A storage is defined for each of the three types of pipe, and flow is routed through each of the storages consecutively.

The sanitary flow from an SCA is computed on the basis of the population in the SCA and is distributed in time on the basis of monthly, daily (Sunday-Saturday), and hourly coefficients that were set by examination of the recorded flow to the WRPs over the year and week (Hydrocomp, 1979, U.S. Army Corps of Engineers, 2001b). Subsurface flow generated by HSPF enters the pipe system as infiltration if sufficient capacity is available. Surface flow generated by HSPF enters the pipe system as inflow if sufficient capacity is available. If sufficient capacity is not available, excess inflow and infiltration are "stored" at the entrance to the pipe (lateral, submain, or main) until capacity is available. The capacity (Q_{MAX}) for each aggregated pipe system represents the maximum outflow under surcharged conditions. SCALP keeps track of the relative percentages of sanitary, infiltration, and surface flows reaching treatment plants and in CSOs, which is important for the Diversion Accounting, e.g., CSOs to the Des Plaines River may include Lake Michigan water supply pumpage return flow (wastewater).

A simple cutoff rule is used to approximate the operation of hydraulic devices used to divert flow out of a combined sewer. Any flow up to the cutoff level, SPLIT, is routed to the interceptor and treatment plant, while any excess over the cutoff is diverted toward the stream. Values for SPLIT were based on calibration of interceptor flows to the WRPs, particularly when matching peak flows at the WRPs (Hydrocomp, 1979; Hey et al., 1980). Whether this excess flow becomes an overflow to the CWS depends on the operation of TARP as simulated with TNET.

From a hydraulic standpoint, SCALP is not a "state of the art" model for a sewer system. Models such as Modeling of Urban Sewers (MOUSE) developed by the Danish Hydraulic Institute (http://www.dhisoftware.com/mouse/) can provide more accurate and detailed simulation of the combined sewer and separate sewer systems. The dynamic wave routing option in MOUSE, MOUSE HD, is founded on an implicit, finite difference numerical solution of the full dynamic wave equations (also known as the de Saint Venant equations) for momentum and flow conservation in open channels and closed conduits (approximated as open channel flow using the Preissman slot technique). Application of dynamic wave modeling to individual pipes is far more accurate than the linear reservoir routing through aggregated pipe systems done with SCALP. MOUSE has been applied to a number of large wastewater systems in the U.S. (e.g., it is used by the Milwaukee Metropolitan Sewerage District).

Even though SCALP is not a "state of the art" model of sewer system hydraulics, it is adequate for the purpose of diversion accounting. That is, complete hydraulic modeling is necessary for operation of a sewer system, for example, using real time control. However, simplified models similar to SCALP frequently are used for design and planning of sewer systems and treatment plants. For example, the KOSIM model (Harms and Kenter, 1987) developed by the Institut fur Technisch-Wissenschaftliche Hydrologie in Hanover, Germany, is similar to SCALP. Dry weather flows (wastewater flows) are determined on a per capita basis and distributed in time by coefficients. Infiltration is taken as a ratio to the dry weather flow determined from field measurements. Inflow is computed by a rainfall-runoff model that routes the inflow using a cascade of three identical linear reservoirs, and the flow is then routed through the sewer system using a hydrograph translation technique. Overflows are determined using the same approach as in SCALP. The KOSIM model has been frequently applied for sewer design and management in Europe. For example, it was applied to the modeling of the combined sewer system for the City of Brussels, Belgium, to aid in the design of two new wastewater treatment plants and the adjustment of CSOs (Demuynck and Bauwens, 1996).

4.2.3 Tunnel Network (TNET) Model

The TNET model solves the full dynamic wave equations for momentum and flow conservation (also known as the de Saint Venant equations) in open channels and closed conduits (approximated as open channels using the Preissman slot technique), to simulate the movement of flow in the TARP tunnels. Because TNET solves the full dynamic equations of motion it is a sophisticated hydraulic model. The full dynamic equations of motion are based on the assumption of gradually varied flow for which use of a hydrostatic pressure distribution is valid. However, flows in the TARP tunnels are not always gradually varied. For example, water-hammer type pressure waves resulting from the rapid closure of gates or switching off pumps in the TARP system yield rapidly varied flow for which use of a hydrostatic pressure distribution is not valid. However, it should be noted that water hammer is rare because the TARP tunnels are seldom pressurized as the MWRDGC closes the drop shaft sluice gates (except the uncontrolled drop shaft sluice gates (except the uncontrolled drop shafts) much earlier than when the tunnels are at full capacity. Further, the sudden influx of flow from the drop shafts also results in rapidly varied flow. This rapid influx has made it necessary to restrict the simulated drop shaft inflow to prevent the tunnel from pressurizing too rapidly such that mathematical instability would result (Mead and Hunt, 2002). The restriction on simulated inflows to the TARP tunnels is used to avoid computational "break downs" of the TNET model. TNET also experiences computational instability at various times in the simulation and some of these can be solved by shortening the computational time step from 0.25 hr to 0.2, 0.1, or 0.05 hr (Mead and Hunt, 2002). These instabilities also may result from rapidly varied flow in the TARP tunnels that is more easily approximated as gradually varied flow at short time steps.

TNET primarily was developed for the design of the TARP reservoirs, and, thus, it has hypothetical pump operation rules coded into it. In the TNET model, the TARP pump station is modeled as a pumped diversion with 2 pumping levels from a small storage area that represents the wet shaft of the pump station (Burke, 1999). TNET cannot simulate variable head pumps, therefore, constant nominal pump capacities are incorporated in the model and all units are switched on whenever the water level in the tunnels exceeds designated levels. The simulated TARP pumpage is sometimes out of phase with the observed record. This could be the result of simulated pumpage occurring sooner and more frequently than actual pumpages in order to maintain computational stability during simulation (U.S. Army Corps of Engineers, 2004). Whereas hypothetical operation rules are necessary for system design, it seems that simulating the actual observed pump operation would more reliably evaluate TARP flows for determination of overflows. A suggested approach to use actual operation in simulation is discussed in detail in Section 4.4.5.

At the present time, the MWRDGC has entered into an agreement with the University of Illinois at Urbana-Champaign to develop new operational models for the TARP tunnels. These new models will be suitable for rapidly varied transient flow in the tunnels. However, this project, which began late in 2003, has a total duration of 7 years, thus, a test version of the new model probably will not be available for several more years. At that time, a future Sixth Technical Committee for Review of Diversion Flow Measurements and Accounting Procedures could consider whether the new model would be appropriate for inclusion in the diversion accounting. **At present, whereas TNET is not "state of the art" and it has computational difficulties**

during rapidly varied flow, it probably is sufficient for its current use in the diversion accounting, particularly if its application is modified as discussed in Section 4.4.5.

4.2.4 Summary

HSPF is a "state of the art" model for continuous simulation of the rainfall-runoff process. SCALP is not a "state of the art" model for hydraulic modeling of flow through the combined and separate sanitary sewer systems. However, SCALP is consistent with models commonly used in design and evaluation of sewer systems and treatment plants. TNET is a sophisticated hydraulic model of the TARP tunnels, but it assumes gradually varied flow, which is not always present in the tunnels leading to numerical instability and possible computational shut down. Despite its limitations TNET still is adequate for use in diversion accounting particularly if its use is modified as described in Section 4.4.5. **Thus, the models used to compute aspects of the diversion accounting meet the Supreme Court's requirement that the diversion accounting be done according to the "best current engineering practice and scientific knowledge" if these models are properly applied to the Lake Michigan and Des Plaines River watersheds**. As noted previously, HSPF is the most important model in the computation of diversion components. Thus, the following section will carefully review the application of HSPF for use in the diversion accounting.

4.3 EVALUATION OF THE HYDROLOGICAL SIMULATION PROGRAM-FORTRAN (HSPF) APPLICATION TO DIVERSION ACCOUNTING

HSPF is a conceptual model that approximates the land-surface portion of the hydrologic cycle by a series of interconnected water storages: an upper zone, a lower zone, and a ground-water zone. The amounts of water in these storages and the flux of water between the storages and the stream or atmosphere are simulated on a continuous basis for a subarea of a given land cover and meteorological input (precipitation, potential evapotranspiration, temperature, solar radiation, cloud cover, wind speed, and dew point). The fluxes of water between storages and to the stream or atmosphere are controlled by model parameters. The model parameters have physical meaning conceptually, some are physically measurable, but most must be determined by calibration. The model parameters include threshold values, partition coefficients, and linear reservoir-release coefficients. The conceptual storages, their interactions, and the model parameters that affect the storages and their outflows are shown schematically in Figure 4.3-a. The definitions of the key rainfall-runoff and snowmelt parameters are listed in Tables 4.3-a and 4.3-b, respectively.

A distinction should be clearly drawn between the model parameters listed in Tables 4.3-a and 4.3-b and watershed characteristics such as drainage area and percentages of the various land covers (directly connected impervious surfaces, grassland, and forest in the diversion accounting H&H models). In a number of reports related to diversion accounting the adjustment or correction of the watershed characteristics has been referred to as "calibration." However, in this "calibration" the rainfall-runoff and snowmelt parameters were not adjusted or changed at all. Calibration normally is defined as the process of systematically adjusting the model parameters (Tables 4.3-a and 4.3-b) within physically reasonable ranges (if available) to reduce the difference between calculated and measured discharge. As described in Section 4.3.2 a number of different measures are commonly used to characterize the difference between calculated and measured discharge when HSPF is calibrated.

Figure 4.3-a: Schematic diagram of the Hydrological Simulation Program—Fortran model.

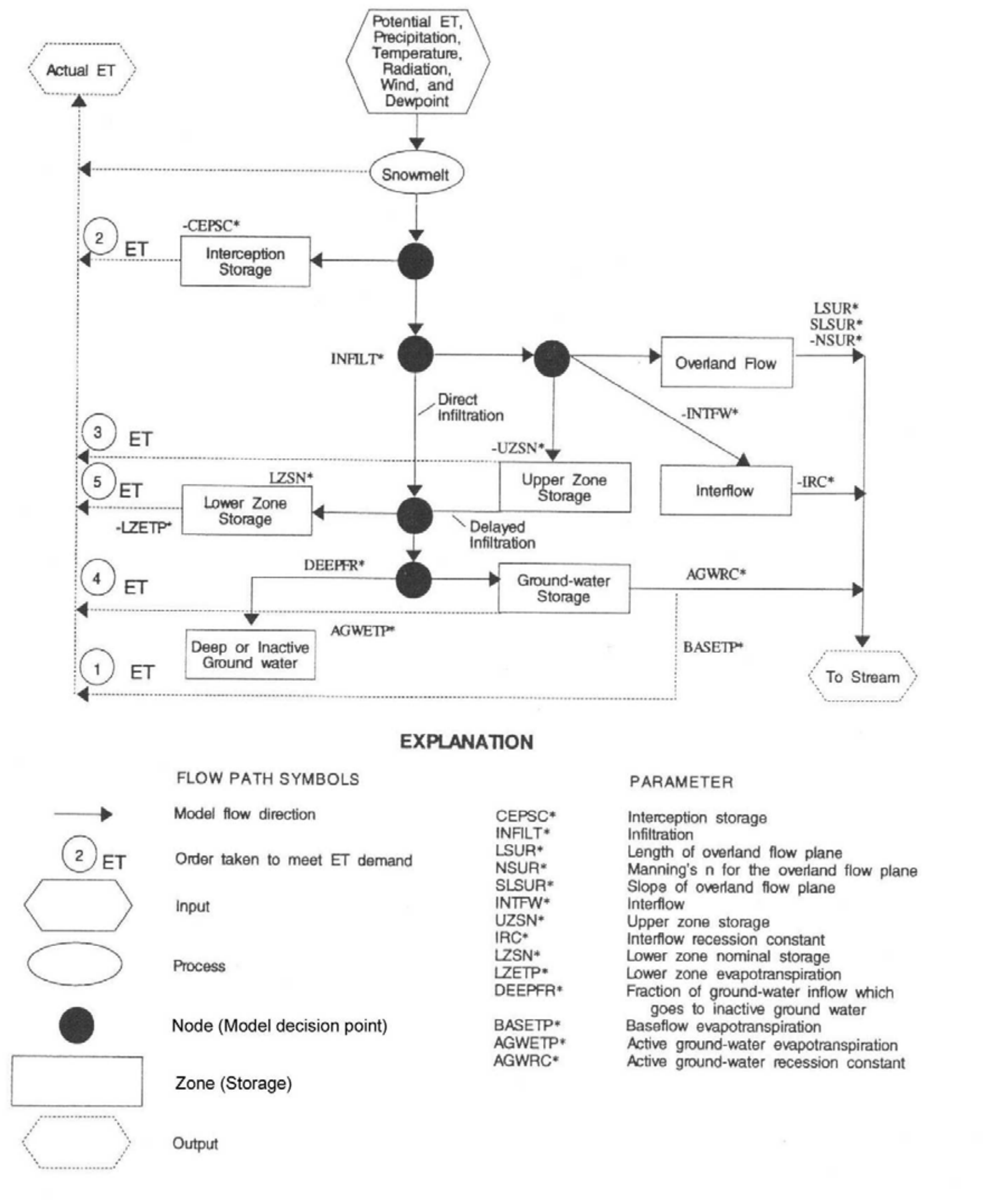


Table 4.3-a: Hydrological Simulation Program-Fortran (HSPF) parameters used to simulate hydrology for pervious land segments (PERLND) and impervious land segments (IMPLND).

Parameter	Explanation	Function
LZETP	Lower zone evaporation. An index value (ranging from 0 to 0.99) representing the density of deep rooted vegetation that can remove water from the lower zone.	PERLND
INFILT	Infiltration capacity. An index to the infiltration capacity of soils. This parameter also affects percolation to the ground-water zone.	PERLND
INFEXP	Exponent for the infiltration equation. Controls the rate of infiltration decrease as a function of increasing soil moisture. Default value of 2 used.	PERLND
INFILD	Ratio of maximum to mean infiltration rate. Default value of 2 used.	PERLND
INTFW	Interflow index. An index that controls the amount of infiltrated water that flows as shallow subsurface runoff.	PERLND
IRC	Interflow recession coefficient. An index for the rate of shallow subsurface flow.	PERLND
CEPSC	Interception storage capacity	PERLND
RETSC	Retention storage capacity	IMPLND
LZSN	Lower zone nominal storage. The lower zone storage level at which half of the incoming infiltration enters the lower zone and half moves to groundwater. The lower zone may be viewed as the entire soil from just below the surface down to the capillary fringe above the water table. In practice the focus is on the transient portion of this storage, i.e. the volume which is emptied by evapotranspiration and refilled by infiltration. Thus, values of LZSN do not necessarily reflect the total moisture storage capacity of the lower zone.	PERLND
UZSN	Upper zone nominal storage. An index to the amount of surface storage in depressions and the upper few inches of soil.	PERLND
BASETP	Fraction of available potential-evapotranspiration demand that can be met from ground-water outflow. Simulates evapotranspiration from riparian vegetation. Added in the 1980s to simulate the effects of phreatophytes on the water balance. Default value of 0 used.	PERLND
AGWETP	Fraction of available potential-evapotranspiration demand that can be met from stored groundwater.	PERLND
AGWRC	Ground-water recession parameter. An index of the rate at which groundwater drains from the land.	PERLND
KVARY	Ground-water outflow modifier. An index of how much effect recent recharge has on ground-water outflow.	PERLND
DEEPFR	Fraction of groundwater that does not discharge to the surface water bodies within the boundaries of the modeled area.	PERLND
LSUR	Average length of the overland flow plane	PERLND/ IMPLND
SLSUR	Average slope of the overland flow plane	PERLND/ IMPLND
NSUR	Average roughness of the overland flow plane	PERLND/ IMPLND

Table 4.3-b: Hydrological Simulation Program-Fortran (HSPF) parameters used to simulate snowmelt.

Parameter	Description
CCFACT	A parameter that adapts the snow condensation/convection melt equation to field conditions.
SNOWCF	The factor by which the input precipitation data will be multiplied, if the simulation indicates it is snowfall, to account for the poor catch efficiency of the gage under snow conditions.
RDCSN	The density of cold, new snow relative to water. This value applies to snow falling at air temperatures lower than or equal to 0° F. At higher temperatures the density of snow is adjusted.
SHADE	The fraction of the pervious or impervious land segment that is shaded from solar radiation, e.g., by trees.
MGMELT	The maximum rate of snowmelt by ground heat, in depth of water per day. This is the value that applies when the pack temperature is at the freezing point.
MWATER	The maximum content of the snow pack, in depth of water per depth of water.
COVIND	The maximum snowpack (water equivalent) at which the pervious or impervious land segment will be covered with snow.
SNOEVP	A parameter that adapts the snow evaporation (sublimation) equation to field conditions.
TSNOW	The air temperature below which precipitation will be snow under saturated conditions. Under non-saturated conditions the temperature is adjusted slightly.

The HSPF model parameters HAVE NEVER BEEN CALIBRATED FOR THE AREAS TO WHICH HSPF IS APPLIED FOR DIVERSION ACCOUNTING. Emphasis is added to the foregoing statement because many reviewers of the diversion accounting procedures assume the models have been calibrated for the areas to which HSPF is applied for diversion accounting. For example, see the comments of the State of Illinois, State of New York, and the Hydrologic Engineering Center on the Lake Michigan Diversion Accounting Lakefront Accounting Technical Analysis (U.S. Army Corps of Engineers, 1996). There are two reasons why HSPF was never calibrated for the watersheds whose flow is simulated for diversion accounting. First, many of the areas simulated with HSPF for the diversion accounting are ungaged or poorly gaged, such as the “ungaged” Calumet River watershed, the Des Plaines River watershed, and combined sewer overflows in the Lake Michigan watershed. Calibration cannot be done without gaged flows. Second, whereas gaged flows are available for the drainage basins for the WRPs, flow source uncertainties make calibration difficult. In their review of the original diversion accounting models, the U.S. Army Corps of Engineers Hydrologic Engineering Center (1986, p. 5-1) stated the following with regard to the Stickney WRP, but the statement also is true for the other WRPs:

> “approximately 80 percent of the influent to the plant is sanitary flow. The component of flow at the plant that is derived from storm runoff cannot be determined accurately because the sanitary portion of the flow is not precisely known, but must be based on assumptions regarding the proportion of water supply that is returned as wastewater. Hence, the basis for calibration, the “measured” storm runoff, is itself subject to substantial uncertainty. For these reasons, the LANDS parameters for the contributing drainage areas at treatment plants are based primarily on adopting values that were previously calibrated for the stream gages in the North Branch and Little Calumet basins.”

The Second Technical Committee (Espey et al., 1987) described this issue even more clearly (statement in italics added):

> “Since more than 80 percent of the total simulated flow to the treatment plants is sanitary flow, the estimation of influent is highly sensitive to return flow

(consumptive use) assumptions and relatively insensitive to the infiltration and inflow parameters."

The return flow/consumptive use assumption is that 90 percent of the water supply for the WRP drainage basin returns to the WRP as wastewater flow. This flow then is divided by the population of the drainage basin to determine the per capita wastewater flow used in SCALP.

Since, in general, the HSPF model parameters need to be calibrated before HSPF can be effectively used, the first question that must be answered is 'is transfer of HSPF model parameters from nearby calibrated watersheds consistent with the "best current engineering practice and scientific knowledge"?' If so, has the transfer been properly done? These questions will be addressed in the following subsections.

4.3.1 Validity of Model Parameter Transfer

In order to develop a method to apply the Stanford Watershed Model (a predecessor of HSPF) to ungaged watersheds several early studies with the Kentucky version of the Stanford Watershed Model attempted to relate model parameters to soil properties. These studies attained mixed results with some model parameters (e.g., the Lower Zone Nominal Storage) strongly related to soil properties and others weakly related to soil properties (e.g., Infiltration Capacity Index). James (1972) presented graphical relations between lower-zone nominal storage and available moisture capacity, and the infiltration index and soil permeability. Magette et al. (1976) developed linear-regression relations between model parameters and watershed and soil characteristics.

Because past research found that relations between measurable soil properties and HSPF parameters are difficult to develop and apply, an alternative approach for simulation of runoff for ungaged watersheds was sought. The concept that has been used successfully in many places is that of regional parameter sets. Regional parameter sets are obtained by calibrating and verifying HSPF rainfall-runoff parameters to runoff data in a given region (e.g., a county). These parameters then are assumed to apply for all similar pervious land segments, PERLNDs, which are defined by the land cover/soil type combination, in all hydrologically similar watersheds within that region. For countywide stormwater management, Lumb and James (1976) first proposed this approach for DeKalb County, Georgia. Lumb and James (1976) jointly calibrated the Stanford Watershed Model for rainfall and runoff data for 4 watersheds in or near DeKalb County, and reasoned that these parameters could be applied to any watershed in the county with similar soil types. The optimal parameters for the primary soil type in DeKalb County represented by these four watersheds then were slightly adjusted to account for higher and lower permeability soils.

The use of regional parameter sets for stormwater management has a nearly 30-year history. The transferability of regional HSPF parameter sets to other watersheds in a region has been successfully tested in numerous regions around the country including: Dupage County, Ill. (Price, 1994; Duncker and Melching, 1998); Lake County, Ill. (Duncker et al., 1995); Jefferson County, Kent. (Jarrett et al., 1998); Heron Lake Basin, Minn. (Jones and Winterstein, 2000); the Walt Disney World property in Florida (Wicklein and Schiffer, 2002), and the watersheds in the vicinity of the proposed Crandon Mine in northern Wisconsin (Chruscicki et al., 2003). Regional parameter sets also have been developed for southeastern Wisconsin by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) and are frequently used for hydrologic simulation on ungaged watersheds.

In summary, "regional" calibration of HSPF parameter sets and their application to nearby hydrologically similar watersheds is consistent with the "best current engineering practice and scientific knowledge." To evaluate whether this approach has been appropriately applied for the Diversion Accounting H&H Models three questions must be considered:

1. Was the original calibration done adequately resulting in accurate models?

2. Are the watersheds (diversion accounting watersheds) to which the regionally determined parameters are applied hydrologically similar to the original calibration watersheds?

3. Was the parameter transfer done properly?

These questions are evaluated in the following subsections.

4.3.2 Assessment of the Original Calibration

Criteria for Evaluating the Quality of the Calibration

The main premise for using continuous simulation models for planning and design is that accounting for water stored in the watershed throughout time more realistically considers antecedent conditions and estimates flood sequences than do event based models using assumed antecedent conditions. Annual and monthly water balances must be accurately simulated for this to be correct. Thus, HSPF calibration typically is performed in a stepwise manner using data available at streamflow gages and matching the overall water budget, the annual water budgets, the monthly and seasonal water budgets, and finally, considering storm-runoff volumes and frequencies. In evaluating the monthly and seasonal water budgets and storm-runoff volumes, the relative proportions of high flows and low flows are considered. Several criteria are utilized to determine if the quality of the fit between the simulated and observed runoff is acceptable. James and Burges (1982) recommend that graphical and statistical means be used to assess the quality of fit because trends and biases can be easily detected on graphs, and statistics provide an objective measure of whether one simulation is an improvement over another.

For the overall and annual water budgets only the percent error typically is considered. Donigian et al. (1984, p. 114) state that for HSPF simulation the annual or monthly fit is very good when the error is less than 10 percent, good when the error is between 10 and 15 percent, and fair when the fit is between 15 and 25 percent.

Plots of observed and simulated runoff typically are prepared for the monthly water budget and checked for periods of consistent oversimulation or undersimulation of runoff. The quality of fit for monthly values also typically is evaluated using three statistics: (1) the correlation coefficient between simulated and observed flows, (2) the coefficient of model-fit efficiency (Nash and Sutcliffe, 1970) between simulated and observed flows, and (3) the number of months for which the percentage error is less than a specified percentage (10 and 25 percent are typically selected as per Donigian et al. (1984)). The average relative percentage error in monthly flows over the calibration period also is considered, but relatively small overestimates in months with very low flows may make this statistic a poor indicator of the overall quality of the fit. The correlation coefficient and coefficient of model-fit efficiency often are used to evaluate simulated daily flows as well as monthly flows. The correlation coefficient, C, is calculated as

$$C = [\Sigma (Qm_i - Qm)(Qs_i - Qs)/[\Sigma (Qm_i - Qm)^2] \Sigma (Qs_i - Qs)^2]^{1/2}$$

where Qm_i is the measured runoff volume for time period (day, month) i, Qs_i is the simulated runoff volume for time period i, Qm is the average measured runoff volume, Qs is the average simulated runoff volume, and i = 1,..., N, where N is the number of time periods in the calibration period. The coefficient of model-fit efficiency, E, is calculated as

$$E = [\Sigma (Qm_i - Qm)^2 - \Sigma (Qm_i - Qs_i)^2]/\Sigma (Qm_i - Qm)^2$$

James and Burges (1982) suggest that an excellent calibration is obtained if the E exceeds 0.97, and present an example of an HSPF application where both the C and E values for daily flows exceed 0.98. For the Stanford Watershed Model, Crawford and Linsley (1966) reported C values for daily flows between 0.94 and 0.98 for seven watersheds ranging in size from 18 to 1,342 mi^2 and with 4 to 8 years of data. Other researchers studying monthly and daily flows have determined best model fits with lower correlation coefficient values. Ligon and Law (1973) applied the Stanford Watershed Model to a 561-acre experimental agricultural watershed in South Carolina and obtained C and E values for monthly flows of 0.966 and 0.931, respectively, for a 60-month calibration period. Chiew et al. (1991) applied HSPF to a 56.4 mi^2 agricultural watershed in west Tennessee and obtained a C value for monthly flows of 0.8 for a 54-month calibration period. Duncker et al. (1995) applied HSPF to five watersheds in Lake County, Ill., ranging in size between 6.3 and 59.9 mi^2. For a 43-month calibration period, the C values for monthly flows ranged between 0.93 and 0.97 and the E values for monthly flows ranged between 0.86 and 0.92 for best-fit calibrations, whereas for regional calibrations (in which 3 of the watersheds were calibrated jointly) and verification (on 2 watersheds) the C values ranged between 0.93 and 0.95 and the E values ranged between 0.86 and 0.91. Duncker and Melching (1998) applied HSPF to three watersheds in Du Page County, Ill., ranging in size between 11.1 and 18.0 mi^2. For a 45-month calibration period the C values for monthly flows ranged between 0.92 and 0.94 and the E values for monthly flows ranged between 0.83 and 0.86 for regional calibrations, for a 39-month verification period the C values ranged between 0.78 and 0.93 and the E values ranged between 0.34 and 0.82 (one watershed had markedly poorer results than the other two). Jarrett et al. (1998) applied HSPF to two watersheds in Jefferson County, Ky., ranging in size between 17.2 and 18.9 mi^2. For a 3-year calibration period the C and E values for daily flows were 0.91 and 0.82, respectively, for the calibration watershed. For the same three years, on the confirmation watershed (i.e. a test of the spatial transfer of parameters) the C and E values were 0.88 and 0.77, respectively. Zarriello and Reis (2000) applied HSPF to two watersheds (areas of 44.5 and 125 mi^2) in the Ipswich River watershed in Massachusetts. For a 5-year calibration period E values for daily flows ranged between 0.85 and 0.88. Finally, Wicklein and Schiffer (2002) applied HSPF to five watersheds in the Reedy Creek watershed in Florida ranging in size from 12.4 to 177 mi^2. For a 6-year calibration period the C and E values for monthly flows ranged from 0.85 to 0.88 and from 0.72 to 0.75, respectively, for the two calibration watersheds. For the same six years, on three confirmation watersheds (i.e. a test of the spatial transfer of parameters) the C and E values ranged from 0.88 to 0.91 and 0.68 to 0.78, respectively. In summary, it appears that very good calibrations have C and E values for monthly or daily flows greater than 0.9 and acceptable calibrations have C values greater than 0.8 and E values greater than 0.7.

The daily flows typically are checked graphically by comparing the observed and simulated flow-duration curves and time series. General agreement between the observed and simulated runoff-duration curves indicate adequate simulation over the range of the simulated flow conditions. Substantial or consistent departures between the observed and simulated runoff-duration curves indicate inadequate calibration. Three statistics are utilized in the expert system for calibration of HSPF, HSPEXP (Lumb et al., 1994), to numerically evaluate the high-flow/low-flow distribution indicated in a flow-duration curve. These statistics and the HSPEXP default criteria are given in the following list.

1. The error in the mean low-flow-recession rates based on the computed ratios of daily mean flow today divided by the daily mean flow yesterday for each day for the highest 30 percent (or other user-selected value) of the ratios less than 1 (i.e. during flow recession). The default allowable difference in the mean low-flow-recession rate is ≤ 0.03 (3 percent).

2. The error in the mean of the lowest 50 percent of the daily mean flows. The default allowable error is ≤ 10 percent.

3. The error in the mean of the highest 10 percent of the daily mean flows. The default allowable error is ≤ 15 percent.

The quality of fit for the larger storms typically is done graphically by evaluating the agreement between the simulated and observed partial-duration series of runoff volumes or flood discharges. Also, the following criteria are utilized in the HSPEXP (Lumb et al., 1994) for storm volumes: (1) the error in total flow volumes for the sum of up to 36 selected storms must be less than 20 percent, and (2) the error in total flow volumes for the sum of selected summer storms must be less than 50 percent. In the course of normal calibration, the default criteria in HSPEXP typically are progressively tightened until an improvement in one criterion cannot be achieved without harming the other criteria.

4.3.3 Quality of the Original Calibration

Most of the typical HSPF calibration criteria previously discussed have been developed after the original calibration was done for the watersheds adjacent to the diverted Lake Michigan watershed. However, the original calibration and subsequent application of HSPF in the diversion accounting will be compared to the previously discussed criteria where possible to evaluate the quality of the models.

In the original calibration, the following fit criteria were considered. The errors in the overall and annual flow volumes were considered. For monthly flows scattergrams were prepared comparing measured and simulated monthly flows. For daily flows time series plots and flow-duration curves were prepared comparing simulated and measured flows. The flow-duration curves allow the HSPEXP criteria on the highest 10 percent and lowest 50 percent of flows to be evaluated by assuming the 5 percent exceeded flow represents the mean of the highest 10 percent of daily mean flows and the 75 percent exceedance flow represents the mean of the lowest 50 percent of daily mean flows. Finally, for daily flows a flow variance analysis was done. The flow variance analysis is based on the criterion that, for any flow interval, the mean number of days simulated flows remain in the interval should be within plus or minus two standard deviations of the mean number of days measured flows are in the interval (Hydrocomp, 1977a). If the simulated flows meet this criterion for an interval, they are accepted as representative of the recorded flows for the interval.

As noted previously, the source areas for the calibrated model parameters applied in the diversion accounting H&H models include the North Branch Chicago River watershed upstream of Touhy Avenue in Niles, Ill.(Hydrocomp, 1977d) and the Little Calumet River watershed upstream of Cottage Grove Avenue in South Holland, Ill. (Hydrocomp, 1977c). Hydrocomp (1979) also stated that parameters for the ungaged Calumet and lower Des Plaines River watersheds were in part based on the hydrologic calibration for the Hickory Creek watershed (Hydrocomp, 1977b). Finally, whereas the calibration experience on the Des Plaines River watershed (Hydrocomp, 1977a) is not specifically mentioned as a source for the HSPF parameters applied in the diversion accounting, it is part of the "regional experience" with HSPF and will be included in the discussion here. For nearly all of these watersheds the calibration period was WYs 1965-1969 and the verification period was WYs 1970-1974. Among these 4 watersheds, the calibration and verification were checked at 14 sites:

- Des Plaines River at Gurnee (230 mi^2),
- Des Plaines River at Des Plaines (359 mi^2),
- Des Plaines River at Riverside (635 mi^2),
- Buffalo Creek (19.4 mi^2) – Des Plaines Basin,
- McDonald Creek (7.52 mi^2) – Des Plaines Basin,
- Long Run (20.8 mi^2) – Des Plaines Basin,
- Hickory Creek at Joliet (107 mi^2),
- Thorn Creek at Thornton (104 mi^2) – Little Calumet Basin,
- Little Calumet at South Holland (208 mi^2),
- West Fork North Branch Chicago River at Northbrook (11.5 mi^2),
- Skokie River at Lake Forest (13.0 mi^2) – North Branch Chicago River Basin,
- Skokie River near Highland Park (21.1 mi^2) – North Branch Chicago River Basin,
- North Branch Chicago River at Niles (100 mi^2), and
- North Branch Chicago River at Deerfield (19.7 mi^2).

The annual and total simulation errors for each of these 14 watersheds are listed in Table 4.3-c. For all the watersheds the total simulation error was less than 10 percent indicating a very good calibration. Nine of 14 total simulation errors were less than 5 percent, the largest total simulation error was 6.1 percent, and the model resulted in oversimulations for 7 watersheds and undersimulations for 7 watersheds.

Table 4.3-c: Annual and total simulation percentage errors for the watersheds in the metropolitan Chicago region used to derive Hydrological Simulation Program-Fortran parameters applied in diversion accounting.

Watershed	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	Total
Des Plaines River at Gurnee					-3.4	45.7	-0.9	9.7	-3.8	1.5	5.3
Des Plaines River at Des Plaines				63.4	-13.3	20.5	-4.3	12.5	1.9	-1.6	5.2
Des Plaines River at Riverside				-11.8	1.7	-5.4	-2.5	0.6	2.7	0.1	-0.9
Buffalo Creek	-18.3	-7.9	21.5	52.4	-20.9	-22.6	-17.2	3.9	7.5	-5.4	-3.5
McDonald Creek	24.7	-5.2	14.3	15.4	0.8	-18.6	-1.0	-20.7	6.9	-3.5	-1.8
Long Run	-22.1	-0.3	-12.6	8.8	11.5	-10.9	0.5	2.1	20.6	22.0	3.0
Hickory Creek	-1.0	-15.2	21.7	-0.5	17.1	16.1	-8.5	45.0	-16.5	-11.4	0.5
Thorn Creek at Thornton	-0.8	-11.7	6.8	3.3	-7.5	2.0	18.4	26.1	2.5	21.1	5.7
Little Calumet River at South Holland	10.7	-1.0	17.5	8.1	-6.4	-0.5	2.4	2.5	-3.7	5.2	2.9
West Fork North Branch Chicago River at Northbrook	-2.1	-0.1	12.1	4.2	-15.3	1.1	-8.9	-14.0	-4.3	-16.7	-6.1
Skokie River at Lake Forest	8.3	-3.7	20.6	6.8	-18.7	13.9	-7.7	-3.8	-1.6	-6.8	-0.7
Skokie River near Highland Park				5.1	-20.4	9.6	-3.5	-6.8	-2.8	-0.9	-6.0
North Branch Chicago River at Niles	13.3	-4.6	18.0	26.2	-13.0	5.8	-14.8	-1.5	-2.0	-8.2	0.1
North Branch Chicago River at Deerfield	12.3	-0.9	21.4	19.3	-26.0	2.0	-8.2	-1.3	-2.9	-8.0	-1.8

For the 14 watersheds a total of 127 years of flow was simulated. Among these 58 percent of the years had simulation errors less than 10 percent indicating a very good calibration, 13 percent had simulation errors between 10 and 15 percent indicating a good calibration, and 23 percent had simulation errors between 15 and 25 percent indicating a fair fit. Only 7 of the 127 years had simulation errors greater than 25 percent. Further, 67 of the years were undersimulated and 60 of the years were oversimulated. The average annual error was 2.0 percent and the average absolute annual error was 10.6 percent. **These results clearly show that the HSPF model was well calibrated to these watersheds on annual and overall bases, which is very important for diversion accounting purposes.**

The quality of the simulation results was substantially poorer on a monthly basis. The scattergrams indicated the simulated values followed the general trend of the measured values, but wide scatter relative to the line of perfect agreement (1:1 line) was found. The deviations from the line of perfect agreement primarily were attributed to the sparse precipitation coverage which, in particular, poorly represented thunderstorms. The high scatter in the monthly simulation results also may indicate that monthly values for model parameters may be appropriate. In the 1980s (after the original calibration was completed), HSPF was modified to utilize monthly variable values of CEPSC, LZETP, UZSN, INTFW, and IRC. Such monthly variable values of CEPSC, LZETP, and UZSN were applied by Burke (1999) in the HSPF model used in the design of the Calumet TARP system and the Thornton Reservoir. When the model parameters were applied to the WRP drainage basins the scatter in the monthly values was greatly reduced (Hydrocomp, 1979) indicating the dominant role of wastewater flows on the flow to the WRPs.

The daily flows were evaluated in time series plots, flow-duration curves, and a flow variance analysis. Table 4.3-d lists a comparison of the information in the flow-duration curves with the calibration statistic applied in HSPEXP (Lumb et al., 1994) for the highest 10 percent of flows and the lowest 50 percent of flows. For the highest 10 percent of flows the default acceptable criterion is that the absolute error should be less than or equal to 15 percent. This criterion was met for all watersheds except Buffalo Creek, Hickory Creek, West Fork North Branch Chicago River, Skokie River at Lake Forest, and North Branch Chicago River at Deerfield and Niles. If the criterion were relaxed to 20 percent only Buffalo Creek, Hickory Creek, and the North Branch Chicago River at Deerfield would not meet the criterion. The poor results at Buffalo Creek were attributed to urbanization during the 10-year simulation period, which was represented with a single land cover distribution (Hydrocomp, 1977a). Fleming and Franz (1971) presented a comparison of the measured flood frequency for the West Fork North Branch Chicago River at Northbrook and the simulated flood frequency using an early calibration of the HSP model. The comparison indicated good agreement between the measured and simulated flood frequency. This suggests that the final calibration for this watershed (Hydrocomp, 1977d), also reliably simulated flood events.

Table 4.3-d: Comparison of original Hydrological Simulation Program-Fortran (HSPF) model calibration for northeastern Illinois watersheds with high flow and low flow criteria applied in the expert system for the calibration of HSPF (HSPEXP)

Watershed	Error in Highest 10% of flows (percent)	Error in Lowest 50% of flows (percent)
Des Plaines River at Gurnee	15.3	78.6
Des Plaines River at Des Plaines	13.5	62.5
Des Plaines River at Riverside	off chart	24.0
Buffalo Creek	-42.0	46.7
McDonald Creek	4.0	-33.3
Hickory Creek	-34.2	20.0
Thorn Creek at Thornton	2.9	20.0
Little Calumet River at South Holland	near 0	33.3
West Fork North Branch Chicago River at Northbrook	-16.0	near 0
Skokie River at Lake Forest	-19.4	near 0
Skokie River near Highland Park	near 0	20.0
North Branch Chicago River at Niles	-17.1	77.8
North Branch Chicago River at Deerfield	-25.3	110.5

For the lowest 50 percent of flows the default acceptable criterion is that the absolute error should be less than or equal to 10 percent. This criterion was only met for the Skokie River at Lake Forest and the West Fork North Branch Chicago River at Northbrook. For nearly all the other watersheds the low flows appear to be substantially overestimated.

The poor results for low flows relative to the HSPEXP criterion is mitigated by the results of the flow variance analysis. The results of the flow variance analysis were not reported for all watersheds, but those reported generally are positive. The flow variance analysis indicated acceptable results for all but one interval (100-150 cfs) at Gurnee for the 3 stations on the Des Plaines River mainstem. For Hickory Creek the simulated number of days falls within the acceptable range except for two intervals. More simulated days than expected fall into the intervals 40-80 cfs and 80-120 cfs. For the Little Calumet River watershed, the number of simulated days falls within the acceptable range for all intervals for the Little Calumet River at South Holland, and for one interval, 75-100 cfs, the number of simulated days is outside the expected interval for Thorn Creek at Thornton. For the North Branch Chicago River watershed, the simulated number of days falls within the acceptable range for all intervals for the West Fork North Branch Chicago River at Northbrook. For the North Branch Chicago River at Niles, there were three ranges for which the number of simulated days were outside the expected range. For the flow range of 50-125 cfs, a greater number of simulated values than expected fell in this range, and a lesser number in the range 10-25 cfs. Thus, the flow variance analysis generally found acceptable results at most sites with medium flows more likely to be outside the expected range than low flows whereas the HSPEXP criterion indicated poor results for low flows.

In summary, the original calibration accurately estimated overall and annual flows which are very important to diversion accounting. The original calibration also reliably estimated high flows, indicating that estimated CSO volumes might be accurately estimated. Thus, the original model was suitably calibrated for the purposes of the diversion accounting.

4.3.4 Hydrologic Similarity of Watersheds

A key assumption of the transfer of calibrated HSPF parameters to "ungaged" watersheds is that the "ungaged" watersheds are hydrologically similar to the "calibration" watersheds. This assumption is reasonable for the transfer of the calibrated model parameters to the ungaged lower Des Plaines River and "ungaged" Calumet watersheds. However, it is questionable for the drainage basins of the WRPs.

The WRP drainage basins are substantially more impervious than the "calibration" watersheds, but this can be reasonably accounted for by varying the proportions of pervious and impervious areas (discussed in detail in the next subsection). The bigger issue is the proportion of areas drained by combined sewers in the WRP drainage basins relative to the calibration watersheds. Hydrocomp (1979) reported that the percentages of the WRP drainage areas with combined sewers were 62, 73, and 29 percent for the North Side, Stickney, and Calumet WRPs, respectively. Whereas areas drained by combined sewers make up 6 percent of the North Branch of the Chicago River at Niles and 3 percent of the Little Calumet River at South Holland (the "calibration") watersheds. The primary issue is that the combined sewers create a much more efficient drainage network than a natural river system such as found in the Little Calumet River watershed upstream of the South Holland gage and the North Branch Chicago River watershed upstream of the Niles gage. This issue has been recognized, but not emphasized since the early development of the diversion accounting models. Hydrocomp (1979, p. 29) noted (italics added):

> "In the Chicago area, the combined sewer system forms a dense network of underground pipes. The system is old and some sections are constructed of brick. Infiltration of groundwater into this system is considerable. Therefore, it was assumed that 100 percent of the subsurface flow computed by LANDS *(the pervious land portion of HSP)* eventually entered the system."

Initially this 100 percent of subsurface flow was only for SCAs drained by combined sewers, but later Burke (1990) expanded this to 100 percent of pervious areas in separately sewered areas. Later the Third Technical Committee (Espey et al., 1994, p. 60) more directly addressed this issue:

> "The subsurface component of HSPF was designed to simulate the flow of water from soil storage into stream channels—thus creating baseflow. This concept is similar but different from the infiltration into the sewers."

This difference may soon need to be emphasized. The current procedure for computing infiltration into the sewer system is added to 90 percent of the water supply (return/wastewater flow) in the WRP drainage basin to yield a reasonable estimate of dry weather flows to the WRPs. However, review of water withdrawal and delivery data in Section 4.6 indicates that a 10 percent consumptive use factor is substantially smaller than the losses from the withdrawal point to households. Thus, as consumptive use increases in future modeling, infiltration must increase to maintain a good flow balance during dry weather flow. Thus, the ground-water flow and interflow portions of HSPF may need to be adjusted in future modeling. The porous nature of the sewer systems and the efficiency and density of the drainage networks make such an increase in sewer system infiltration reasonable.

4.3.5 Evaluation of Appropriate Parameter Transfer

Drainage Area Determination and Composition

Time series of surface runoff per unit area from both pervious and impervious areas and subsurface runoff per unit area from pervious areas are computed with HSPF for precipitation input from each of the 25 precipitation gages and associated other meteorological data (potential evapotranspiration, temperature, solar radiation, cloud cover, wind speed, and dew point) for each appropriate land cover: grassland, forest, and impervious. The total inflow to the sewer system from an SCA is equal to

$$\text{Inflow }(SCA_i) = LSRO_G \text{ x } Area_{Gi} + LSRO_F \text{ x } Area_{Fi} + IMPRO \text{ x } Area_{Ii}$$

where $LSRO_G$ is the surface runoff per unit area for grassland, $LSRO_F$ is the surface runoff per unit area for forest, IMPRO is the surface runoff per unit area for impervious areas, $Area_{Gi}$ is the grassland area in SCA i, $Area_{Fi}$ is the forest area in SCA i, and $Area_{Ii}$ is the impervious area in SCA i. Similarly, the total infiltration to the sewer system from an SCA is equal to

$$\text{Infiltration }(SCA_i) = SSRO_G \text{ x } Area_{Gi} + SSRO_F \text{ x } Area_{Fi}$$

where $SSRO_G$ is the subsurface runoff per unit area for grassland, and $SSRO_F$ is the subsurface runoff per unit area for forest land. The inflow and infiltration computations for an SCA may need to be further subdivided by precipitation gage if the drainage area of an SCA is represented by more than one gage. For separately sewered areas in the ungaged Calumet and lower Des Plaines River watersheds the summation of Inflow and Infiltration is the total streamflow. If the meteorological data have been accurately measured and/or estimated and the model parameters have been reliably determined through calibration and/or transfer from hydrologically similar watersheds, then proper determination of the drainage areas of the different land covers is the key to accurate simulation of flows from an SCA. Further, given that the model parameters for the majority of the modeled watersheds have had the same values throughout the entire period of model use (explained in the next subsection), the adjustment of drainage areas and land covers has been the primary means of fitting/adjusting the model. Thus, it is useful to review the various changes in drainage area throughout the period of model use.

The Second Technical Committee (Espey et al., 1987) found substantial problems with the drainage area and land cover delineation used by NIPC in establishing the original diversion accounting models. They wrote (Espey et al., 1987, p. 3-15 & 3-16), statements in italics added:

> "Much of the input data utilized in the simulation of runoff from the combined sewer areas is more than 20 years old. It was originally obtained as part of the data collection phase for the Development of a Flood and Pollution Control Plan for the Chicagoland Area (Warren and Van Praag, 1971), the predecessor of TARP. The original data takeoff was performed during the years 1970 to 1971. However, some of the data relating to sewer sizes, service areas, imperviousness, etc. was incomplete and out dated even for 1970."

> "The combined sewer drainage area data for the Des Plaines River area (used in calculating deductions in Column 8 *[now Column 6]*) and the Calumet area (used in simulating runoff for the entire watershed, Column 14 *[now Column 12]*) were found to contain significant errors. These errors in the Warren and Van Praag data were corrected and refined as part of the TARP modeling for final design of

> that project (Knoerle, Bender and Stone, Dec. 1976 and Keifer and Associates, Inc., Dec. 1976). The Chicago District's work in conjunction with the Chicagoland Underflow Plan (CUP) recognized and utilized the updated 1976 data in the NIPC simulation model. However, on the basis of a cursory review of the input data for the NIPC Simulation Model used for diversion, the revised 1976 data was not used."

Espey et al. (1987) also found that the combined sewer area was overestimated by 17.7 mi^2 in the Des Plaines River watershed and by 16.8 mi^2 in the Calumet watershed. Finally, Espey et al. (1987) found that the NIPC simulated watershed still included about 17 mi^2 of drainage area that is largely unsewered and still tributary to Lake Michigan along the lakeshore primarily in the City of Chicago.

In response to these comments the USACE and its contractor Christopher B. Burke Engineering Limited did a detailed review of the drainage areas for the diversion accounting H&H models (Burke, 1990). The updated drainage area boundaries for the Des Plaines River watershed were based on the 1975 TARP design study done by Knoerle, Bender and Stone (1976). The various communities within the Des Plaines basin were contacted to determine major revisions in their sewer systems since 1975 and if land use in their corporate boundaries had been significantly altered (Burke, 1990). Since the study area was substantially fully developed prior to the 1975 data collection, none of the communities reported any land use changes. In the Des Plaines River watershed, 14.9 mi^2 of area previously identified as having combined sewers were found to contain separate sewers (Burke, 1990). In the NIPC SCALP models, 100 percent of the subsurface flow from HSPF was assumed to enter combined sewers as infiltration and 45 percent of the subsurface flow from HSPF was assumed to enter the sanitary sewers as infiltration. The Burke (1990) study confirmed that 100 percent of subsurface flow enters combined sewers as infiltration, however, they also found it necessary to assume that 100 percent of subsurface flow from HSPF enters sanitary sewers as infiltration. The Burke (1990) study also found it necessary to increase the surface runoff inflow to sanitary sewers from 2.5 percent in the NIPC model to 5 percent. The net effect of these offsetting revisions was to increase the WYs 1984 and 1985 Des Plaines River watershed runoff deduction by 18 and 19 cfs, respectively, compared to the NIPC H&H models (U.S. Army Corps of Engineers, 1990).

In the USACE review of the WY 1984 accounting (U.S. Army Corps of Engineers, 1990) it was discovered that 28 mi^2 of drainage area in the western portion of the Lake Michigan watershed was included in the calculation of the Des Plaines River watershed deduction. Excluding this area from the calculation decreased the WY 1984 and 1985 deductions by 28 cfs compared to the NIPC H&H models.

For the computation of the WY 1990 diversion the drainage areas and their composition again were modified as a result of the establishment of the 25 gage precipitation network. Rust Environment and Infrastructure (1993a) revised the HSPF and SCALP models to compute runoff using precipitation data from the new 25-gage precipitation network. Percentages of grassland, impervious area, and forest also were re-evaluated on the basis of 1990 aerial photographs. The drainage area for the combined sewer drainage area for Mainstream TARP and Mainstream TARP-North Leg increased 9.6 and 0.7 mi^2, respectively, whereas that for the Calumet WRP and Des Plaines River watershed decreased 2.4 and 0.1 mi^2, respectively (Table 4.3-e).

Table 4.3-e: Drainage areas (in square miles) and percentages of grassland and impervious area in the hydrologic models used in the computation of the Lake Michigan Diversion Accounting

	Ungaged Calumet[1]	Ungaged Lower Des Plaines[1]	Calumet WRP Combined Sewer Area	Mainstream TARP Combined Sewer Area	Mainstream-North Leg Combined Sewer Area	Des Plaines Combined Sewer Area
Basin Area						
1984-1989	80.2	unknown	90.4	200.0	14.5	32.4
1990-1990	84.2	57.9	88.0	209.6	15.2	32.3
Grassland						
1984-1989	84.5	unknown	66.0	55.3	65.6	54.5
1990-1996	54.3	37.0	45.8	39.3	45.3	44.3
1997-1999	58.7	40.3	49.6	43.6	51.3	51.4
Impervious						
1984-1989	10.0	unknown	34.0	44.7	34.4	45.5
1990-1996	40.2	33.3	54.2	60.7	54.7	55.7
1997-1999	35.8	30.1	50.4	56.4	48.7	48.6

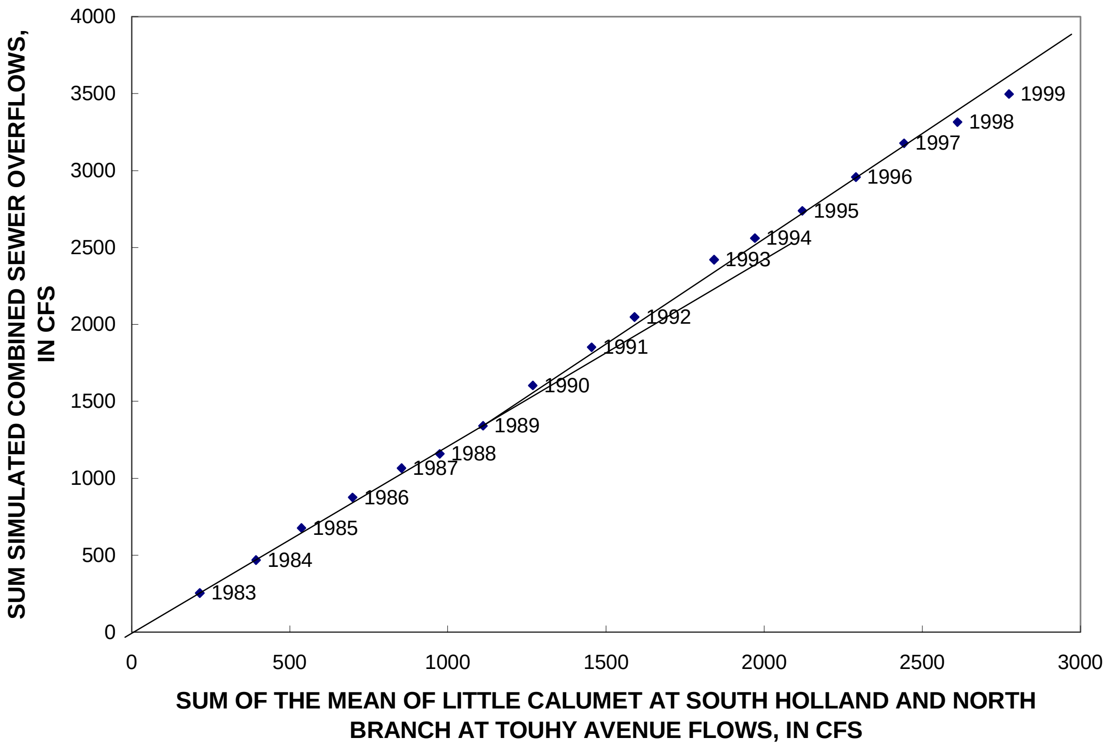
[1]The ungaged Calumet and the ungaged Lower Des Plaines watersheds also have forest area composing 5.5 and 29.7 percent, respectively, of their areas.

Substantial increases in the percentage of impervious area resulted for the WY 1990 revision (Table 4.3-e). These large increases in the percentage of impervious area cannot be solely attributed to changes in urbanization between 1975 and 1990. As noted previously with respect to the Des Plaines River watershed, Burke (1990) reported that "Since the study area was substantially fully developed prior to the 1975 data collection, none of the communities reported any land use changes." Therefore, the means to determine the percentage of impervious area requires review. Beginning with the WY 1993 diversion accounting report (U.S. Army Corps of Engineers, 1997b) the USACE noticed that the impervious percentages revised in 1990 seemed to result in overestimated runoff that was not apparent in the WRP balances but only in the CSO flows. In the Lakefront Accounting Technical Analysis (U.S. Army Corps of Engineers, 1996) the USACE realized that the increase of impervious area for the "ungaged" Calumet watershed from 10 percent in 1975 to 40 percent in 1990 probably was too great, and, thus, an impervious percentage of 25 percent was applied in the period of record simulation analysis. Finally, in the WY 1997 diversion accounting (U.S. Army Corps of Engineers, 2001b) the percentages were recomputed. Figure 4.3-b shows the double mass plot of simulated annual CSO flows versus the mean of the measured flows at the North Branch Chicago River at Niles and the Little Calumet River at South Holland gages. The mean of the North Branch and Little Calumet flows was used in the comparison with the simulated annual CSO flows to try to provide a consistent reference for the runoff originating geographically between these two gages. This figure 4.3b clearly shows that the runoff for the computed CSOs substantially increased relative to the 1983-1989 period in the 1990-1996 period and decreased again in the 1997-1999 period. To make the 1990-1996 values consistent with the 1983-1989 values they would have to decrease 11.9 percent on average, and to make the 1990-1996 values consistent with the 1997-1999 values they would have to decrease 18.7 percent on average. Conversely, the average simulated to recorded ratio for WRP flows show little change among the 3 periods in Table 4.3-f:

Table 4.3-f: Average Simulated to Recorded Ratio for Water Reclamation Plant Flows

	1983-1989	1990-1996	1997-1999
North Side WRP	0.966	0.946	0.961
Stickney WRP	1.015	1.038	1.034
Calumet WRP	0.881	1.029	1.021

Figure 4.3-b: Double mass plot comparing the sum of the simulated annual combined sewer overflows with the sum of the mean of the annual mean flows for the North Branch Chicago River at Niles and the Little Calumet River at South Holland. Trend lines show the relation between the two sums for 1983-1989 and 1990-1996.



The low value for the Calumet WRP for 1983-1989 resulted because of errors in the simulation of Calumet drainage area and in the per capita sanitary loading that were corrected for the WY 1989 diversion accounting (U.S. Army Corps of Engineers, 1994).

The adjustments to the percentage of impervious area made for the WY 1997 diversion accounting appear to have improved the simulated CSO flows relative to the USACE conclusion that CSO flows might be overestimated (U.S. Army Corps of Engineers, 1997b). However, it still is worthwhile to review the delineation of watersheds into impervious and pervious areas. The aerial photographs were delineated into subareas falling into 11 land use categories. For each of these land uses a representative percentage of impervious cover was determined by Rust Environment and Infrastructure (1993a) and division of an SCA into pervious (grassland) and impervious areas was determined as the product of the land use in acres and the percentage impervious (Table 4.3-g) divided by 100. The percentages of directly connected impervious area determined by Rust for residential areas appeared to be too high relative to other information in the literature. Therefore, the U.S. Army Corps of Engineers (2001b) adjusted the impervious percentages for residential areas on the basis of information provided by the Soil Conservation Service (1986) in Technical Release 55 (also listed in Table 4.3-g). However, information in the literature indicates that impervious percentages could be even lower for residential areas. Also listed in Table 4.3-g are percentages of impervious area used in Du Page County, Ill., for HSPF modeling in 1993[2]. Antonie (1964) found that for lots with areas between 6,000 and 15,000 ft^2 the impervious area typically comprises 40 percent of the total area. Thus, the Du Page County (1993) value for ¼ acre lots probably is too low for use for high-density residential development, but the values for medium and low density residential development may merit consideration in the watersheds whose runoff affects the diversion accounting.

Table 4.3-g: Percentage of impervious area for various land uses.

Land Use	Rust (1993a)	TR-55[1]	Du Page (1993)[2]
Forest	0		
Open Space/Park	5		determined case by case
Low Density Residential: (1.1 acre median lot)	19	20	10
Medium Density Residential: (1/2 acre median lot)	40	25	15
High Density Residential: (1/5 acre median lot)	56	38[3]	28[3]
Multifamily and High Rise	70	65	50
Commercial	85	85	85
Industrial	72	72	85
Highway Corridor:			
With Grassed Median	50		50
No Median	80		100
Open Water	100		100

[1]The Soil Conservation Service (1986) only listed average percentage impervious values for the land uses for which numbers are included in this table. Multifamily and high rise is taken as equivalent to the 1/8 acre or less (town houses) land use in TR-55.

[2]The Du Page County (1993) guidelines included percentages for hydraulically connected and non-hydraulically connected residential lots, the percentages for hydraulically connected lots are considered more representative of the watersheds simulated in diversion accounting and are included here.

[3]For both TR-55 and Du Page (1993) values for ¼ acre lots are entered here.

At present it appears the drainage areas simulated with HSPF and SCALP have been properly delineated, and their division into grassland, forest, and impervious area also appears to be acceptable. The performance of the 1997 modifications to land use should be monitored as additional years of diversion calculations are completed. If the CSO flows still seem to be overestimated, the Du Page County (1993) values for medium and low density residential development should be applied for the H&H modeling in the diversion accounting.

[2]The Du Page County Department of Environmental Concerns substantially lowered the percentage of directly connected impervious area for residential areas used in HSPF modeling in a March 11, 1994, memorandum by Jon Steffen, Principal Engineer, on "Hydrologic and Hydraulic Methods Used for Flood Plain Mapping of Du Page County Watersheds." The Committee felt these percentages were too low for use in the watersheds whose runoff affects the diversion accounting.

4.3.6 Regional Parameters and Their Transfer

Tables 4.3-h and 4.3-i list the HSPF rainfall-runoff parameters for grassland and forest areas, respectively, determined by the original calibrations on the North Branch Chicago River, Little Calumet River, Des Plaines River, and Hickory Creek watersheds. For some watersheds slightly different values of a parameter may have been used for the different raingage inputs resulting in the ranges in parameter values for some watershed in Tables 4.3-h and 4.3-i. Also listed in Table 4.3-h are the HSPF parameter values used in the original HSPF model of the watersheds draining to the CSSC (Hydrocomp, 1979). It is clear that the original CSSC model directly applied the parameter transfer concept.

Table 4.3-h also lists the parameter values applied to 10 of 13 raingages used in the WY 1989 diversion accounting (Rust Environment and Infrastructure, 1993b). Table 4.3-i also lists the parameter values applied in the WY 1989 diversion accounting (Rust Environment and Infrastructure, 1993b). It is assumed that these parameter values are those originally used by NIPC in the first diversion accounting models because none of the diversion accounting reports for WYs 1984-1989 mention any adjustment of the HSPF model parameters. For grassland the currently used HSPF parameters are identical to those used in WY 1989, and for forest the currently used HSPF parameters are identical to those used in WY 1989 except for LZSN which decreased from 10 to 9.5 and LSUR which increased from 300 to 400 ft. The rainfall-runoff parameters for impervious areas and the snowmelt parameters also have changed slightly from the original calibration to current application. They are summarized in Appendix A. In summary, it appears that the HSPF rainfall-runoff parameters for pervious areas have remained nearly constant over the duration of the application of modeling to the diversion accounting.

As indicated by the use of bold numbers in Tables 4.3-h and 4.3-i, the values of CEPSC, UZSN, LZSN, LZETP, INTFW, LSUR, and KVARY for grassland, and UZSN, LZSN, INTFW, and KVARY for forest currently are outside of the range of calibrated values obtained on nearby watersheds. Thus, HSPF parameter transfer on the basis of regional model parameters really has not been applied in the HSPF models applied since at least WY 1989, and probably throughout the entire period of using models in the diversion accounting. Further, this implies that the ±10 percent accuracy in the annual flow estimate achieved in the original calibration may not be valid for the HSPF model currently applied in the diversion accounting. The expert system for the calibration of HSPF, HSPEXP (Lumb et al., 1994), provides guidance on the calibration process based on the assessment of a number of fit criteria and rules for adjusting parameter values based on the fit criteria. Table 4.3-j lists the HSPF model parameters for which HSPEXP provides guidance, the runoff features these parameters primarily affect, and the number of calibration rules related to each parameter. If the number of rules related to a parameter is a measure of the sensitivity of the output to a parameter, it can be seen that LZETP, LZSN, and INTFW are among the most important parameters and these are among the parameters whose current values are significantly different from the original calibrations.

Table 4.3-h: Rainfall-runoff parameters for grassland in the Hydrological Simulation Program-Fortran model used in the current diversion accounting, found by calibration in neighboring watersheds, applied in the original model of the Chicago Sanitary and Ship Canal (CSSC), and applied for 10 of 13 raingages in the diversion accounting models developed by the Northeastern Illinois Planning Commission (NIPC) for Water Year 1989.

Parameter	North Branch	Little Calumet	Des Plaines	Hickory Creek	CSSC	NIPC	Current
CEPSC	0.12	0.1-0.2	0.12-0.15	0.15	0.1-0.12	0.25	**0.25**
UZSN	1.1	0.75-0.8	0.75-2.2	1.5	0.75-1.1	1.8	**1.8**
LZSN	7.5	8.5	7.5-8.0	8.0	7.5-8.5	9.5	**9.5**
LZETP	0.25	0.1-0.25	0.25-0.35	0.25	0.1-0.25	0.38	**0.38**
AGWETP	0.08	0.02-0.05	0.05-0.30	0.05	0.00-0.08	0.05	0.05
INFILT	0.015	0.02-0.022	0.015-0.045	0.02-0.03	0.015-0.02	0.015	0.015
DEEPFR	0.08	0.05-0.10	0.05-0.30	0.05	0.00-0.08	0.05	0.05
INTFW	3.5	2.7-3.2	2.5-5.0	3.5	3.2-3.5	15.0	**15.0**
LSUR	250	400	250-500	400	250-400	50	**50**
SLSUR	0.01	0.002	0.01-0.05	0.05	0.002-0.01	0.01	0.01
NSUR	0.25	0.35	0.2-0.35	0.35	0.25-0.35	0.2	0.2
IRC	0.5	0.5	0.5-0.6	0.5	0.5	0.5	0.5
KVARY	1.0	1.5	1.0-1.5	1	1.0-1.5	1.7	**1.7**
AGWRC	0.98	0.99	0.97-0.99	0.97	0.98-0.99	0.98	0.98

References: North Branch = Hydrocomp (1977d)
Little Calumet = Hydrocomp (1977c)
Des Plaines = Hydrocomp (1977a)
Hickory Creek = Hydrocomp (1977b)
CSSC = Hydrocomp (1979)
NIPC = Rust Environment and Infrastructure (1993b)

Table 4.3-i: Rainfall-runoff parameters for forest in the Hydrological Simulation Program-Fortran model used in the current diversion accounting, found by calibration in neighboring watersheds, and applied in the diversion accounting models developed by the Northeastern Illinois Planning Commission (NIPC) for Water Year 1989.

Parameter	North Branch	Little Calumet	Des Plaines	Hickory Creek	NIPC	Current
CEPSC	0.2	0.25-0.4	0.18-0.20	0.2	0.2	0.2
UZSN	6.0	6.0	5.0-6.0	6.0	3.0	**3.0**
LZSN	7.5	8.0	7.5-8.0	8.0	10.0	**9.5**
LZETP	0.9	0.8-0.9	0.85-0.90	0.9	0.9	0.9
AGWETP	0.15	0.10-0.26	0.05-0.15	0.05	0.15	0.15
INFILT	0.007	0.01-0.025	0.005-0.015	0.005	0.01	0.01
DEEPFR	0.15	0.15-0.20	0.05-0.20	0.05	0.05	0.05
INTFW	3.5	2.5-5.0	3.0-5.0	3.5	7.5	**7.5**
LSUR	1000	1000	100-1000	1000	300	400
SLSUR	0.001	0.002	0.00-0.01	0.0	0.01	0.01
NSUR	0.35	0.35	0.25-0.35	0.35	0.25	0.25
IRC	0.5	0.5	0.5-0.6	0.5	0.5	0.5
KVARY	1.0	1.5	1.0-1.5	1	1.7	**1.7**
AGWRC	0.99	0.99	0.97-0.99	0.97	0.98	0.98

References: North Branch = Hydrocomp (1977d)
Little Calumet = Hydrocomp (1977c)
Des Plaines = Hydrocomp (1977a)
Hickory Creek = Hydrocomp (1977b)
NIPC = Rust Environment and Infrastructure (1993b)

Table 4.3-j: Runoff features affected by the model parameters in the Hydrological Simulation Program-Fortran (HSPF) and the number of rules in the expert system for calibration of HSPF related to each parameter and runoff feature.

Parameter	Runoff Features Affected	Number of Rules
LZETP	Overall water balance	12
	Seasonal runoff distribution	2
INFILT	Overall water balance	6
	High flow-low flow distribution	6
	Stormflow	2
LZSN	Overall water balance	4
	High flow-low flow distribution	6
INTFW	Stormflow	10
IRC	Stormflow	8
DEEPFR	Overall water balance	3
	High flow-low flow distribution	1
AGWRC	High flow-low flow distribution	4
UZSN	Seasonal runoff distribution	4
PRIMP[1]	Seasonal runoff distribution	4
BASETP	High flow-low flow distribution	1
	Seasonal runoff distribution	2
KVARY	Seasonal runoff distribution	3
CEPSC	Seasonal runoff distribution	2

[1]PRIMP is not a defined model parameter, it is the percent impervious for the entire watershed.

The changes in the parameter values from the originally calibrated values to the current values probably resulted during a hydrologic recalibration for the North Branch Chicago River and Little Calumet River and a hydrologic testing for the CSSC done by Hey et al. (1980). For the North Branch Chicago River above Touhy Avenue in Niles, Hey et al. (1980) noted the following changes to the modeling:

1. Some minor adjustments were made to the boundaries and land use categories (i.e. impervious, grassland, agricultural, and lowland).

2. The most significant change to the water budget was adjustment in seasonal runoff. The simulated to recorded (S/R) ratio was low for the months of November to May and high for the months of June to October. The major causes of this bias were found to be inadequate control of infiltration during winter months when water in the higher soil horizons was frozen, too little interception storage (*corrected by increasing CEPSC as shown in Table 4.3-h*), and too much directly connected imperviousness (corrected by the minor adjustments in item 1 above). To allow better adjustment of the infiltration rate under frozen ground conditions, a code change was made in the LANDS program (an ancestor of HSPF). Two parameters, previously non-adjustable, were added FZG and FZGL. FZGL is the lower limit for infiltration (originally 0.1 changed to 0.01) and FZG is a multiplier used to adjust the impact of frozen ground on infiltration (originally 1.0 changed to 20.0).

After these changes were made the overall S/R ratio became 1.03 (1.00 in original calibration) and the monthly scatter greatly decreased (Hey et al., 1980). The same type of adjustments were applied in the recalibration of the Little Calumet River above South Holland. Hey et al. (1980) also noted that several other refinements were made in the LANDS parameters to improve seasonal runoff for the Little Calumet River, but details were not given. The recalibration resulted in an overall S/R ratio of 0.99 (1.03 in original calibration) and the monthly scatter greatly decreased (Hey et al., 1980). These adjustments also were applied to the simulation of the WRP drainage areas. Hey et al. (1980) reported the overall S/R ratio for the re-calibrated North Side and Calumet WRP flows as 1.0 (same as original calibration) and 1.03 (1.08 original), respectively, for the 6-year (1969-1974) calibration period. They also included flow duration curves for these two WRPs and the comparison between the re-calibration results and the HSPEXP fit-quality measures given in Table 4.3-k.

Table 4.3-k: Comparison Between the Re-calibration Results and the HSPEXP Criteria for Water Reclamation Plants

Drainage Area	Error in Highest 10% of Flows (percent)	Error in Lowest 50% of Flows (percent)
North Side Water Reclamation Plant	7.3	Nearly identical
Calumet Water Reclamation Plant	11.8	3.9

Finally, the annual diversion accounting reports include the correlation coefficient between simulated and observed daily flows for the WRPs. Generally these correlation coefficients correspond to acceptable fits relative to the studies summarized in Section 4.3.2. For the North Side WRP the correlation coefficient for the WYs 1986-1999 ranged from 0.62-0.90 with a mean of 0.805. For the Stickney WRP the correlation coefficient for the WYs 1990-1999 (prior to 1990 TARP pumpage was included in the statistics) ranged from 0.72-0.86 with a mean of 0.805. For the Calumet WRP the correlation coefficient for the WYs 1990-1999 (prior to 1990 TARP pumpage was included in the statistics) ranged from 0.77-0.91 with a mean of 0.856. Thus, the current parameters are providing acceptable results at the WRPs.

The Hydrologic Engineering Center (1986, p. 7-3) stated that judgments were required to translate information to the ungaged areas, and apparently there is no published detailed information regarding the basis for the adopted values. The Hydrologic Engineering Center (1986, p. 5-2) reported a personal communication from Dennis Dreher of NIPC regarding the transfer of the parameters that stated “Land use comparisons and judgment were used in the process of adopting the parameter values.” The reported results of the recalibration generally are good. Thus, if the current parameters are really the result of the recalibration of Hey et al. (1980), the simulation models may still achieve the ±10 percent accuracy in annual flow estimates found in the original calibration. However, additional comparisons with gaged flows are needed to demonstrate this point given the uncertainty with respect to the parameter transfer. The comparisons of simulated and measured flows at the WRPs are not sufficiently precise to evaluate the accuracy of the rainfall-runoff simulation. Wastewater flow comprises more than 80 percent of the WRP flows. Thus, substantial errors in the rainfall-runoff simulation could be hidden in a 5 percent difference in simulated and measured WRP flows.

Two small watersheds are gaged in the “ungaged” Calumet watershed. Midlothian Creek is a 20 mi^2 watershed (12.6 mi^2 of it gaged at Oak Forest, Ill.) that drains to the Calumet-Sag Channel just downstream from the confluence of the Calumet-Sag Channel and the Little Calumet River at River Mile 30.0 from Lockport. Tinley Creek is a 13.6 mi^2 watershed (11.2 mi^2 of it gaged at Palos Park, Ill.) that drains to the Calumet-Sag Channel near the center of this channel at River Mile 23.1 from Lockport. These gages have been in operation since 1950 and 1951 for Midlothian and Tinley Creeks, respectively. Thus, long term comparison of simulated and measured flows for these gages in the “ungaged” Calumet watershed would greatly increase confidence that the HSPF model parameters were valid for the watersheds to which they are applied in the diversion accounting.

The North Branch of the Chicago River also is gaged at Albany Avenue at Chicago, Ill. This gage is 7.5 mi downstream from the Touhy Avenue at Niles, Ill. gage and measures the flow from an additional 13 mi^2 of drainage area that is within the combined sewer drainage area. Thus, comparison of simulated and measured flow at this gage would provide insight on the quality of the HSPF and SCALP model parameters. For the comparison, it would only be necessary to simulate the runoff from the additional 13 mi^2 of drainage area and combine this with the measured flow at Touhy Avenue. This gage has only been in operation since WY 1990 and it was discontinued from January 22, 1999 to June 23, 2000. Nevertheless, a good test of the HSPF, SCALP, and TNET models can be done using data from this gage.

The final comparison that can be made is for annual flows at the North Branch, Racine Avenue, and 125th Street Pump Stations of the MWRDGC. Combined sewer overflow volumes from large areas (15.82, 32.39, and 5.96 mi^2 for North Branch, Racine Avenue, and 125th Street, respectively) may be approximated at these locations from pump operation records. Storm runoff comparisons at these locations were attempted in the original calibration and re-calibration of H&H models for the CWS (Hydrocomp, 1979; Hey et al., 1980). The original comparisons were not encouraging as summarized by the Hydrologic Engineering Center (1986, p. 5-4):

> "Checks were attempted at the North Branch and Racine Avenue pumping stations for selected storms. However, results were inconclusive because of unknowns associated with operation of the actual systems and uncertainty with respect to contributing drainage areas. Pump station records indicate start/stop times for the pumps at a station. Hydrographs of pumping plant flows were developed using these times with rated pump capacities. There is uncertainty associated with the hydrographs because pumps may not operate at rated capacity; the discharges are affected by the actual hydraulic conditions that exist at the time of operation. The contributing drainage area to a plant is influenced by the operation of sluice gates which may shut off flow from some contributing areas. Conversely, flow may be brought to the plant via interceptors, which effectively increases the contributing drainage area. It was therefore not possible to make reasonable comparisons between computed and simulated results at the plants."

This statement applied to the operation of the pump stations, WRPs, and interceptors prior to the operation of the TARP system. The operational complexities of the interceptors and the pump stations may be simplified with TARP now operational. For example, the minutes of a February 3, 2004, meeting between USACE and MWRDGC personnel at the Racine Avenue Pump Station (RAPS) indicated the following (Fogarty, 2004):

> "In some MWRDGC and USACE documents, it has been stated that the RAPS can serve as a relief for the SWRP by pulling water back from the interceptor running west on 39th Street (Southwest Side 4 as shown in Attachment 4). This operation was not confirmed by MWRDGC during the site visit." *(where SWRP = Stickney Water Reclamation Plant)*

Thus, it seems that some of the operations done in the late 1970s and early 1980s are no longer done. Thus, comparison of simulated and measured flows at the pump stations on an annual basis may be a good check of the CSO flows estimated with SCALP and TNET.

4.3.7 Summary of HSPF Status

This subsection summarizes the status of the HSPF modeling relative to the Supreme Court Decree requirement that the diversion accounting use the "best current engineering practice and scientific knowledge." The HSPF model parameters have never been calibrated for the areas to which HSPF is applied for diversion accounting. The HSPF model parameters have been determined by the transfer of parameters calibrated on hydrologically similar watersheds to the areas to which HSPF is applied for diversion accounting. This approach often is referred to as a "regional" HSPF parameter set. "Regional" calibration of HSPF parameter sets and their application to nearby hydrologically similar watersheds is consistent with the "best current engineering practice and scientific knowledge." To evaluate whether this approach has been appropriately applied for the Diversion Accounting H&H Models three questions must be considered:

1. Was the original calibration done adequately resulting in accurate models?
2. Are the watersheds (diversion accounting watersheds) to which the regionally determined parameters are applied hydrologically similar to the original calibration watersheds?
3. Was the parameter transfer done properly?

These questions are answered in the order of 1, 3, 2 in the following paragraphs.

1. Review of the calibration of the LANDS subroutines of the HSP model (a fore-runner of HSPF) to watersheds in the nearby Des Plaines River, North Branch Chicago River, Little Calumet River, and Hickory Creek basins found that the original calibration accurately estimated overall and annual flows which are very important to diversion accounting. The original calibration also reliably estimated high flows, indicating that estimated CSO volumes might be accurately estimated. Thus, the original model was suitably calibrated for the purposes of the diversion accounting.

3. The values of the HSPF parameters CEPSC, UZSN, LZSN, LZETP, INTFW, LSUR, and KVARY for grassland, and UZSN, LZSN, INTFW, and KVARY for forest currently are outside of the range of calibrated values obtained on nearby watersheds. LZETP, LZSN, and INTFW are among the most important parameters affecting the HSPF simulation. Thus, HSPF parameter transfer on the basis of "regional" HSPF parameters really has not been applied in the HSPF models applied since at least WY 1989, and probably throughout the entire period of using models in the diversion accounting. Further, this implies that the ±10 percent accuracy in the annual flow estimate achieved in the original calibration may not be valid for the HSPF model currently applied in the diversion accounting.

   The changes in the parameter values from the originally calibrated values to the current values probably resulted during a hydrologic recalibration for the North Branch Chicago River and Little Calumet River and a hydrologic testing for the CSSC done by Hey et al. (1980), but no documentation of this fact is available. The reported results of the recalibration generally are good. Thus, if the current parameters are really the result of the recalibration of Hey et al. (1980), the simulation models may still achieve the ±10 percent accuracy in annual flow estimates found in the original calibration. However, additional comparisons with gaged flows are needed to demonstrate this point given the uncertainty with respect to the parameter transfer. The comparisons of simulated and measured flows at the WRPs are not sufficiently precise to evaluate the accuracy of the rainfall-runoff simulation. Wastewater flow comprises more than 80 percent of the WRP flows. Thus, substantial errors in the rainfall-runoff simulation could be hidden in a 5 percent difference in simulated and measured WRP flows. The candidate points for these additional comparisons are:

a. Midlothian Creek at Oak Forest, Ill. (12.6 mi^2 drainage area);

b. Tinley Creek at Palos Park, Ill. (11.2 mi^2 drainage area);

c. North Branch of the Chicago River at Albany Avenue at Chicago, Ill (7.5 mi downstream from the Touhy Avenue at Niles, Ill. gage with flow from an additional 13 mi^2 of drainage area)

d. North Branch, Racine Avenue, and 125th Street Pump Stations of the MWRDGC (drainage areas of 15.82, 32.39, and 5.96 mi^2, respectively)

2. A key assumption of the transfer of calibrated HSPF parameters to "ungaged" watersheds is that the "ungaged" watersheds are hydrologically similar to the "calibration" watersheds. This assumption is reasonable for the transfer of the calibrated model parameters to the ungaged lower Des Plaines River and "ungaged" Calumet watersheds. However, it is questionable for the drainage basins of the WRPs.

The WRP drainage basins are substantially more impervious than the "calibration" watersheds, but this can be reasonably accounted for by varying the proportions of pervious and impervious areas. The delineation of the drainage areas and their division into grassland, forest, and impervious area appears to be acceptable after the WY 1997 land cover modifications. The performance of the 1997 land cover modifications should be monitored as additional years of diversion calculations are completed.

The bigger issue is the proportion of areas drained by combined sewers in the WRP drainage basins relative to the calibration watersheds. Hydrocomp (1979) reported that the percentages of the WRP drainage areas with combined sewers were 62, 73, and 29 percent for the North Side, Stickney, and Calumet WRPs, respectively. Whereas areas drained by combined sewers make up 6 percent of the North Branch of the Chicago River at Niles and 3 percent of the Little Calumet River at South Holland (the "calibration") watersheds. The primary issue is that the combined sewers create a much more efficient drainage network than a natural river system such as found in the Little Calumet River watershed upstream of the South Holland gage and the North Branch Chicago River watershed upstream of the Niles gage. Further, the Third Technical Committee (Espey et al., 1994, p. 60) pointed out that:

> "The subsurface component of HSPF was designed to simulate the flow of water from soil storage into stream channels—thus creating baseflow. This concept is similar but different from the infiltration into the sewers."

This difference may need to be emphasized. The current procedure for computing infiltration into the sewer system combines with 90 percent of the water supply in the WRP drainage basin and yields a reasonable estimate of dry weather flows to the WRPs. However, review of water withdrawal and delivery data in Section 4.6 indicates that a 10 percent consumptive use factor is substantially smaller than the losses from the withdrawal point to households. Thus, as consumptive use increases in future modeling, infiltration must increase to maintain a good flow balance during dry weather flow. Thus, the ground-water flow and interflow portions of HSPF may need to be adjusted in future modeling. The porous nature of the sewer systems and the efficiency and density of the drainage networks make such an increase sewer system infiltration reasonable.

The regional HSPF parameter approach and original calibration of HSPF meet the Supreme Court requirement of using the "best current engineering practice and scientific knowledge." However, because of a lack of documentation on the transfer, additional checks of simulated flow are needed to confirm the accuracy of the HSPF model applied to the diversion accounting. Finally, the 90 percent water supply return/wastewater flow (i.e. 10 percent consumptive use) assumption appears to be inaccurate, and, thus, the HSPF parameters affecting the simulation of infiltration into sewer systems (i.e. subsurface flow) may need to be recalibrated to compensate for an increase in consumptive use and subsequent decrease in water supply return flow.

4.4 COMMENTS ON THE DIRECT APPLICATION OF MODELS IN THE ROMEOVILLE DIVERSION ACCOUNTING

4.4.1 Simulation of Runoff from the Des Plaines River Watershed

For the Romeoville Diversion Accounting the runoff from the Des Plaines River watershed reaching the CWS is one of the primary flow deductions subtracted from the measured flow at Romeoville and is the key output of the H&H models. The simulated Des Plaines River Watershed Flows have several components:

1. Inflow and infiltration from the Upper Des Plaines River watershed which enters separate and combined sewers and becomes influent to the MWRDGC WRPs including inflow and infiltration that reaches the Des Plaines TARP system, which then discharge to the CWS,

2. Runoff from the Des Plaines River watershed which reaches the CSSC via CSOs,

3. Direct runoff from the Des Plaines River watershed to the CSSC (Des Plaines River watershed, South of the CSSC),

4. Infiltration, inflow, and CSOs from the Lemont Service area, and

5. Runoff from the Summit Conduit watershed.

No flow measurement data are available to confirm the accuracy of the simulation of these flows. It has generally been reasoned that since the water budgets for the North Side and Stickney WRPs include the majority of the deductible Des Plaines River watershed runoff, the Des Plaines River watershed simulation is indirectly confirmed in WRP flow balance checks (Budgets 7 and 10) (U.S. Army Corps of Engineers, 1994). Given the questions regarding the HSPF model parameters and the inability of the WRP balances to truly identify modeling inaccuracy (previously discussed), further examination of the Des Plaines River watershed runoff is necessary.

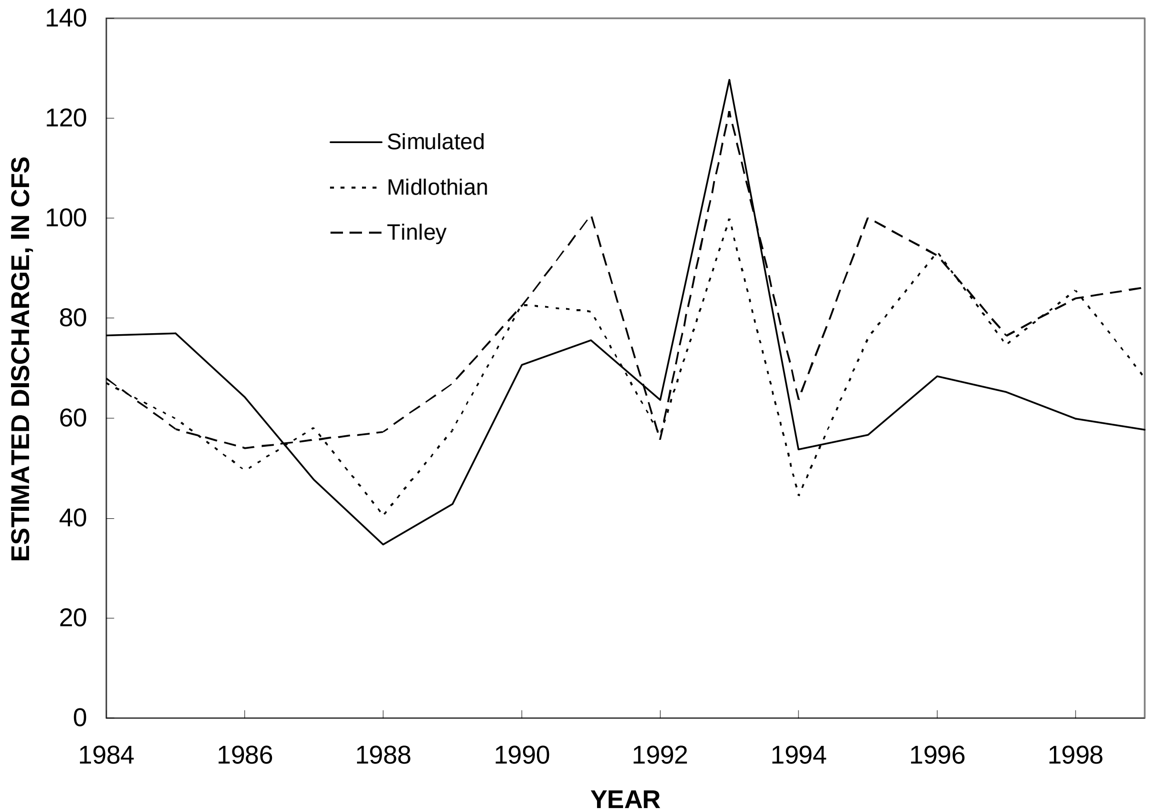
The annual diversion accounting reports include simulated annual flow values for ungaged, separately sewered lower Des Plaines River watershed (57.91 mi^2) and the Summit Conduit watershed (2 mi^2). Annual flows for these areas may be estimated from the measured annual flows for Tinley and Midlothian Creeks using a drainage area ratio (5.35 and 4.75 for Tinley and Midlothian Creeks, respectively). Before the H&H models were applied to the diversion accounting, flows measured on Hart Ditch at Munster, Ind., were used to estimate the ungaged lower Des Plaines River watershed flows. In WYs 1983-1985, the Hart Ditch flows were used for comparison with the simulated lower Des Plaines River watershed flows. The Hart Ditch watershed is over 25 miles east of the lower Des Plaines River watershed, and the U.S. Army Corps of Engineers (1990, p. 24) found “Because of the difference in localized precipitation between the watersheds, the Hart Ditch comparison does not provide any substantial insight on the accuracy of the lower Des Plaines runoff simulation.” Thus, the U.S. Army Corps of Engineers (1990, p. 25) discontinued the Hart Ditch comparison because “the Hart Ditch watershed does not provide a good verification and because the lower Des Plaines River watershed is indirectly verified by other (WRP) budgets”. The Tinley and Midlothian Creek watersheds are much closer to the lower Des Plaines River watershed (Tinley Creek borders the lower Des Plaines River watershed). Further, Shrestha and Melching (2003) used flows from Midlothian Creek scaled by area ratio to estimate ungaged flows to the CWS with good success in their hydraulic modeling of the CWS. Therefore, the drainage area ratios to Tinley and Midlothian Creeks may be a good way to evaluate flows simulated for the lower Des Plaines River watershed.

Figure 4.4-a shows the simulated annual flows for the lower Des Plaines River and Summit Conduit watersheds and the annual flows estimated for these watersheds by drainage area ratio with Tinley and Midlothian Creeks. For more than 60 percent of the years the simulated annual flow is less than the estimated annual flow, and the under-predictions typically are in the range of 20-40 percent. Thus, the Des Plaines River watershed flows may be underestimated by the current H&H models. This conclusion is supported by the comparisons of simulated and measured annual flows at the Upper Des Plaines Pump Station for WYs 1984-1994 for which the annual S/R ratios are listed in Table 4.4-a.

Table 4.4-a: Upper Des Plaines Pump Station Comparisons of Simulated and Measured Annual Flows (WYs 1984-1994)

1984	0.83	1987	0.82	1990	1.08	1993	0.92
1985	0.89	1988	0.72	1991	1.01	1994	0.86
1986	0.85	1989	0.82	1992	0.98		

Figure 4.4-a: Comparison of annual mean flow for the ungaged, separately sewered lower Des Plaines River watershed and Summit Conduit simulated with the Hydrological Simulation Program – Fortran and estimated by area ratio with Midlothian and Tinley Creeks.



The comparison at the Upper Des Plaines Pump Station has many potential errors:

1. The flow through each pump is measured with orifice plates that were installed with the pumps. The orifice plates may have insufficient lengths of pipe between the plate and upstream flow disturbances, i.e. pipe bends, to obtain accurate flow measurements.

2. The Upper Des Plaines Pump Station meters have not received any maintenance in over 20 years and require calibration (U.S. Army Corps of Engineers, 1990).

3. Weekly charts are used to record the flow rate through the discharge lines continuously. Daily discharge is determined from an analysis of the recorder charts. The charts often are not changed weekly, and timer also appears to be questionable (Burke, 1990). Further, Espey et al. (1981) noted that the interpretation of the pen trace may lack the necessary attention and precision; namely improper pen setting, absence of comparison of computed and weekly integrated flow, and failure to use subdividing techniques when flow changes rapidly and frequently. This has led to the loss of many days of record as listed in Table 4.4-b by year and number of days.

Table 4.4-b: Days Lost in the Upper Des Plaines Pump Station Recorder Charts Data (1986 – 1994)

1986	138	1989	31	1992	125
1987	90	1990	145	1993	157
1988	68	1991	73	1994	125

During high flows, much of the water is bypassed around the measurement devices, and, therefore, values less than the true flow from the Upper Des Plaines Pump Station drainage area are reported. This means that the under simulation may be even greater than the previously listed comparisons indicate.

Despite these errors the comparisons at the Upper Des Plaines Pump Station and for the lower Des Plaines River watershed area ratio comparison indicate potential underestimation of Des Plaines River watershed runoff. This requires further evaluation.

The increased values of LZSN, LZETP (grassland only), and UZSN relative to the originally calibrated values result in increased water in storage and increased evapotranspiration, and, thus, decreased runoff. Therefore, the adjusted parameter values could contribute to the undersimulation of flow from the Des Plaines River watershed. This question could be addressed by comparing observed and simulated flows for Tinley and Midlothian Creeks as previously suggested. If these flows are not consistently undersimulated, then the parameter changes probably are not adversely affecting the simulation of flows for the Des Plaines River watershed.

The undersimulation at the Upper Des Plaines Pump Station also may result because of the lack of hydrologic similarity between baseflow to natural streams and infiltration to combined sewer systems, which has been extensively discussed in Section 4.3.4. The results obtained by Burke (1990, p. 33) for WYs 1983-1985 indicate that the model performs well for periods of rainfall, but for non-rainfall days the simulation is consistently low. This result indicates that subsurface runoff produced in HSPF is low. Distribution system losses in suburban areas have been found to be less than for the City of Chicago (Section 4.6). Thus, perhaps the consumptive losses for the Des Plaines River watershed could stay closer to their current 10 percent, whereas the infiltration to the combined sewers could increase similar to the increases in infiltration applied in the City of Chicago to compensate for increased consumptive loss (and decreased water supply return flow as wastewater) in future modeling.

If Romeoville Accounting is to be used in the future, gaging at the Upper Des Plaines Pump Station must be improved so that meaningful comparisons can be made at this station and the Des Plaines River watershed flows can be properly tested and adjusted. The Fifth Technical Committee is aware that the USACE has placed rating of the Upper Des Plaines Pump Station on hold, while Lakefront Accounting has been developed and evaluated. It now is time to re-evaluate rating and improving the flow measurements at this location. In 1993, the U.S. Geological Survey (USGS) proposed using dye dilution to check the rating of the orifice plates (Kevin Oberg, Steve Melching, and Art Schmidt, 1993, written commun.). Given the advances in non-invasive flow measurement methods since 1993, it seems the USGS should be able to propose additional means to rate the orifice plates and to measure the by pass flows. Further, installation of a data logger to replace the strip charts could virtually end the problems of lost data.

4.4.2 Re-Evaluation of Infiltration to the Combined Sewer System

As previously noted in Section 4.3.4 infiltration to combined sewers is similar to but different from baseflow to a natural stream. Also, if the consumptive use is increased from 10 percent, it will be necessary to adjust the HSPF parameters affecting subsurface flow to compensate for the lost water supply return flow (i.e. wastewater flow). One way to independently evaluate this adjustment of subsurface flow might be to utilize combined sewer flow data collected by Waite et al. (2002). To aid in the design of the McCook and Thornton Reservoirs of TARP, Waite et al. (2002) collected data on flows to TARP drop shafts and combined sewer overflows at locations in Riverside and Evanston, Ill., from March 1997 to December 1999. Because of the complexity of the drop shaft and combined sewer overflow structures, it was necessary to monitor several inflow and outflow pipes/conduits and determine the flows by mass balance at points where flow could not be measured. Those inflows from well defined drainage areas compose potential sites to study sewer infiltration. The potential sewer infiltration study areas using data collected by Waite et al. (2002) are the Gage Street Pipe in Riverside with a drainage area of 210 ac. (0.33 mi^2) and the Lake Street Pipe in Evanston with a drainage area of 1,738 ac. (2.72 mi^2). If household water meter data are available for these drainage areas, only household consumptive use would need to be approximated. Thus, infiltration during low flow periods could be more accurately determined and compared to simulation results.

4.4.3 Groundwater Infiltration in the Calumet TARP System

The Fourth Technical Committee (Espey et al., 2001, p. 40) recommended that the analysis of groundwater infiltration into the Calumet TARP tunnels needs to be reviewed using data from more than one year. The Fifth Technical Committee would like to re-iterate this suggestion. The simulated groundwater seepage into the Calumet TARP tunnels is listed below.

Table 4.4-c: Simulate Groundwater Seepage (in cfs) into the Calumet TARP Tunnels

1987	17.3	1990	6.6	1993	6.7	1996	9.5	1999	11.2
1988	17.0	1991	21.4	1994	3.5	1997	9.5		
1989	6.7	1992	21.1	1995	6.5	1998	11.3		

The procedure for estimating the groundwater infiltration into the Calumet TARP tunnels was adjusted in 1989. Thus, the average of values from 1989 to 1999, 10.4 cfs, is representative of the current estimation procedures. Also from 1989 to 1999 the simulated annual mean flow for the Calumet TARP system was consistently less than the measured annual mean flow with a S/R ratio of 0.695 over this period or an average annual shortfall of 14 cfs.

In their revision of the H&H models of the Calumet watershed Burke (1999, p. 27) noted the contribution of groundwater seepage into the tunnels through the lining and joints “has yet to be accurately determined. MWRDGC estimate seepage flow in the range 7 to 30 cfs.” Burke (1999, p. 30) further stated:

> “Presently there is no reliable method for quantifying the amount of infiltration into the tunnels. For modeling purposes, base flow was included in the model as steady flow hydrographs of 2.5 to 5.0 cfs, resulting into a combined flow of about 32.5 cfs at the TARP pump station. The flow of 32.5 cfs was used as it is close to the MWRDGC estimates.”

Since a recently revised TNET model is using a base groundwater inflow of 32.5 cfs at the pump station and the average annual shortfall in Calumet TARP flows is 14 cfs from 1989-1999, a review of the value used in the diversion accounting modeling is needed since current estimates are more than 20 cfs less than the value used by Burke (1999).

4.4.4 Indiana Water Supply Through the Grand Calumet River

The Grand Calumet River has a summit. On one side of the summit, the flow is toward Lake Michigan and on the other side the flow is westward into Illinois. The position of this summit is variable and dependent on the elevation of Lake Michigan.

Prior to WY 1991 flow in the Grand Calumet River reaching Illinois was estimated on the basis of a statistical relation for which the independent variables were the elevation of Lake Michigan and the flow in Hart Ditch (U.S. Army Corps of Engineers, 1990). This flow then was compared to the daily sum of water supply pumpage from Lake Michigan to East Chicago, Hammond, and Whiting, Indiana. If the Grand Calumet River flow was greater than the combined water supply pumpage, the daily deduction from the Romeoville flow was set equal to the combined water supply pumpage. If the Grand Calumet River flow was less than the combined water supply pumpage, the daily deduction from the Romeoville flow was set equal to the estimated Grand Calumet River flow. In WY 1992, a streamflow gage was added on the Grand Calumet River at Hohman Avenue near the Illinois-Indiana border by the USGS. The computation of the deduction continued in the same way with the measured Grand Calumet River flow replacing the estimated Grand Calumet River flow. No consideration of consumptive use was made in these computations.

Beginning in WY 1993, the deduction was computed on the basis of relations involving Lake Michigan elevations and the water supply pumpage for Hammond, Whiting, and East Chicago. These relations were determined on the basis of an UNET hydraulic model developed for the Grand Calumet River system (U.S. Army Corps of Engineers, 1997a). The modeling study found that the summit normally occurs between river miles 5.54 and 4.229 (U.S. Army Corps of Engineers, 1997a) where the Little Calumet River is river mile 0. The Hammond Sewage Treatment Plant (STP) is located near river mile 4.25. Thus, most of the time Hammond and Whiting water supply pumpage from Lake Michigan reaching this STP flows to Illinois and is a deduction from the discharge measured at Romeoville. The East Chicago STP is located near river mile 5.40. Thus, only during times of high lake levels does East Chicago water supply pumpage from Lake Michigan reaching this STP flow to Illinois. Specifically, the model derived relations are:

$$\text{Flow} = 0.45\ \text{HW} \qquad \text{CCD} < 0.3\ \text{ft}$$
$$\text{Flow} = (0.22\ \text{CCD}^3 - 0.15\ \text{CCD}^2 + 0.06\ \text{CCD} + 0.45)\ \text{HW} \qquad 0.3\ \text{ft} \le \text{CCD} < 1.5\ \text{ft}$$
$$\text{Flow} = \text{HW} + ((\text{CCD} - 1.5)/0.3)\ \text{EC} \qquad 1.5\ \text{ft} \le \text{CCD} < 1.8\ \text{ft}$$
$$\text{Flow} = \text{HW} + \text{EC} \qquad \text{CCD} \ge 1.8\ \text{ft}$$

where HW is the sum of water supply pumpage for Hammond and Whiting, EC is the water supply pumpage for East Chicago, and CCD is the lake level in feet relative to the City of Chicago Datum measured at Calumet Harbor. Beginning in WY 1997 the water supply pumpage has been adjusted using a 10 percent consumptive use factor (U.S. Army Corps of Engineers, 2001b).

Details on the derivation of the Indiana water supply pumpage flow relations are not available. However, details on the calibration of the UNET model used to develop these relations are available (U.S. Army Corps of Engineers, 1997a). In calibrating the hydraulic model, simulated flows and stages were compared to values measured at the Hohman Avenue (river mile 3.172) and Gary (river mile 10.768) gages. The comparison of measured and simulated stages and flows at Hohman Avenue for November 1991 to September 1994 is presented graphically in U.S. Army Corps of Engineers (1997a) and this comparison is summarized in the Table 4.4-d.

Table 4.4-d: Summary of differences in stage and flow calibration results at the Grand Calumet River at Hohman Avenue at Hammond, Ind. streamflow gage for the UNET model of the Grand Calumet River System.

Approximate Period	Typical Stage Difference	Typical Flow Difference
12/09/91 – 06/20/92	Simulated 0.2-0.3 ft low	Simulated and measured similar through 5/21/92, simulated 25% high afterwards
06/21/92 – 08/03/92	Simulated 0.1 ft high	Simulated and measured similar
08/03/92 – 10/15/92	Simulated 0.4-0.6 ft high	Simulated 25% high
10/15/92 – 05/15/93	Simulated and measured similar	Simulated 25-100% high through 1/21/93, then simulated and measured similar through 4/10/93, finally simulated 25% high
05/15/93 – 06/10/93	Measured steadily increasing to 1 ft high	Simulated and measured similar
06/10/93 – 07/25/93	Simulated 1 ft low	Simulated 50% low
07/25/93 – 08/05/93	Measured steadily decreasing to no difference	Simulated 50-20% low
08/05/93 – 08/11/93	Simulated and measured similar	Simulated 20% low
08/11/93 – 10/15/93	Simulated 0.2-0.5 ft high	Simulated 20-30% low
10/15/93 – 03/05/94	Simulated and measured similar	Simulated 20-10% low through 11/22/93, simulated and measured similar afterwards
03/05/94 – 03/31/94	Simulated 0.2 ft low	Simulated 20-40% low
03/31/94 – 06/25/94	Simulated and measured similar	Simulated and measured similar
06/25/94 – 07/25/94	Simulated 0.2 ft high	Simulated 20-40% low
07/25/94 – 08/20/94	Simulated and measured similar	Simulated 20-40% low
08/20/94 – 09/23/94	Simulated 0.2-0.3 ft low	Simulated 20-40% low

The flow in the Grand Calumet River is very complex because of the low water-surface slopes and the interaction among Lake Michigan, the Grand Calumet River, and the CWS. This complexity is illustrated in Table 4.4-d. At times the simulated stage and flow both are high relative to the measured values, at other times they are both low relative to the measured values, and at still other times the measured and simulated flows and stages agree reasonably well. These are the type of results expected for any model on any river system. The complexity of the system is reflected in the following modeling results:

1. the results for August 11 to October 15, 1993, when the simulated stage is 0.2-0.5 ft high, but the simulated flow is 20-30 percent low, or

2. the many periods during which simulated and measured flows were similar but stages differed substantially or simulated and measured stages were similar but flows were substantially different.

The U.S. Army Corps of Engineers (1997a) attributed some of the fluctuations in the agreement between measured and simulated stages to the growth in aquatic vegetation throughout the year. They noted that when vegetation is at a minimum, winter months (e.g., January 21-April 10, 1993, and November 22, 1993-March 5, 1994), the agreement between simulated and measured flows and simulated and measured stages is reasonable. Conversely, between May 15 and June 10, 1993, the measured water surface rose 1 ft compared to the simulated water surface while the measured and simulated flows agreed well. They attributed this result to the growth of aquatic vegetation and the resulting decrease in flow conveyance. However, from June 10 to July 25, 1993, the 1 ft undersimulation of stage continued during a period when flow was undersimulated by 50 percent. With respect to the diversion calculations the U.S. Army Corps of Engineers (1997a, p. A-10) stated: "vegetation effects along the river may need adjustment to balance flows east and west from the Hammond STP. Too much water may be sent East in the model." This statement is supported by the fact that more periods in Table 4.4-d indicate low simulated flows than high flows.

The equations for estimating Indiana water supply pumpage reaching the CWS derived from the UNET model are clearly a great improvement over previous procedures (i.e. assuming all flows from the Hammond and East Chicago STPs go to Illinois). However, the quality of the stage agreement during UNET calibration often is very poor and the USACE original evaluation indicates too much flow may be directed East in the model resulting in an underestimate of the Indiana Water Supply pumpage deduction (Column 5 in the Diversion Accounting Table). The UNET model should be revised using more recent data and accounting for changes in roughness during the growing season for aquatic vegetation. Once better agreement between measured and simulated stages are obtained or the errors in stage and discharge are consistent, new equations for estimating Indiana water supply pumpage reaching the CWS can be derived from the revised UNET model. The derivation of new equations should be completely detailed for review by a future Technical Committee for Review of Diversion Flow Measurements and Accounting Procedures.

4.4.5 TNET Model Application

As discussed previously TNET solves the full dynamic equations of motion for open channel flow with closed conduit flow approximated using the Preismann slot concept. The full dynamic equations of motion are based on the assumption of gradually varied flow for which use of a hydrostatic pressure distribution is valid. However, flows in the TARP tunnels are not always gradually varied. For example, water-hammer type pressure waves resulting from the rapid closure of gates or switching off pumps in the TARP system yield rapidly varied flow for which use of a hydrostatic pressure distribution is not valid. However, it should be noted that water hammer is rare because the TARP tunnels are seldom pressurized as the MWRDGC closes the drop shaft gates (except the uncontrolled drop shafts) much earlier than when the runnels are a full capacity. Further, the sudden influx of flow from the drop shafts also results in rapidly varied flow. These short comings of the model necessitate the shortening computational time steps during periods of rapidly varied flow and restricting drop shaft inflows to avoid rapidly varied flow, and, thus, avoid computational instabilities that could result in computational failure.

The TNET model primarily was developed for design and operational planning of TARP, i.e. estimating how the TARP system would react to different magnitude, timing, and patterns of inflow. Thus, operation rules for the pump stations were programmed into TNET. Pumping from the Mainstream Pumping Station to the Stickney WRP is determined on the basis of the minimum of (1) available capacity at the Stickney WRP and (2) pumping capacity at the Mainstream Pumping Station (U.S. Army Corps of Engineers, 1994). Available capacity is determined as the difference between treatment capacity and simulated inflow from interceptor sewers. Rules also were developed to distinguish between times when normal pumping/secondary treatment capacity or maximum pumping/primary treatment capacity is applied. Similar procedures are applied at the Calumet TARP Pumping Station (U.S. Army Corps of Engineers, 1994). The following discussion of procedural limitations of TNET is modified from U.S. Army Corps of Engineers (1994).

Although effort was made to incorporate TARP operating procedures into the TNET model, it was not feasible to incorporate all features of the operating procedures. First, operating procedures for Calumet TARP are divided into three categories—dry weather, wet weather, and emergency operations—whereas for Mainstream TARP wet weather is divided into "typical" and "extreme" storms. Dry weather operations tend to focus on operating TARP in the most economical fashion. Therefore, dry weather flows are allowed to accumulate, and then are pumped at night once there has been sufficient accumulation.

There are two major short comings of the model in simulating pumpage of dry weather flows. First the model cannot determine the optimum pumping time, therefore, pumping can be initiated at any time if pumping is needed as indicated at the pump sense point. The pump sense point activates/deactivates the pumping algorithm of the model based on water-surface elevation in the tunnel. Because of these computational rules the simulated TARP pumpage is sometimes out of phase with the observed record. The simulated pumpage tends to occur sooner and more frequently than actual pumpage in order to maintain computational stability during simulation (U.S. Army Corps of Engineers, 2004). Second, the TNET model cannot simulate the designated operation of the high head pump, but simulates based on available pumping capacity.

A third limitation of the TARP TNET models is the inability to "forecast" storms. The MWRDGC operational procedures call for dewatering accumulated dry weather flow from the tunnel system prior to a storm to maximize storage for CSOs. This procedure cannot be reproduced with the TNET model computing pump operations "on the fly" for design and operational planning purposes. A related limitation for the Mainstream TARP TNET model is the inability to change gated drop shaft operating procedures given the severity of the "forecast" storm.

A fourth limitation is the limited number of sense points in the model, and the inability of the model to simulate gate closure based on an average water-surface elevation within a tunnel reach.

The U.S. Army Corps of Engineers (2001) suggested that the limitations discussed above needed to be fixed as an "Area for Improvement" in the diversion accounting. However, it is not necessary to fix these limitations to improve the diversion accounting simulations. All the limitations discussed by the U.S. Army Corps of Engineers (1994) relate to computing pump operations "on the fly". This type of computational procedure is necessary for TARP design or operational planning, but it is not necessary for diversion accounting. For diversion accounting, the actual operations are known and do not need to be synthesized with programmed "operational rules". In order to provide a check on the distribution of flows into the TARP system and overflows to the CWS in the diversion accounting the following computational procedure is suggested. For diversion accounting, use the measured stage at the TARP pumping stations as the downstream boundary condition and compute the outflow, i.e. pumpage. If the computed outflow exceeds the actual pumpage, decrease TARP inflow and increase CSOs. Conversely, if the computed outflow is less than the actual pumpage, increase TARP inflow and decrease CSOs. Water-surface elevations measured at the TARP pump location could be used to ensure that adjustments in TARP inflows and CSOs are properly distributed throughout the system. In this way inflow gate operations can be indirectly considered and CSOs can be more correctly estimated.

At present the Mainstream and Des Plaines TARP tunnels only have stage sensors at the pump station; however, the MWRDGC is planning to add more sensors throughout these systems. Until these sensors are operational the proposed changes to the TNET modeling cannot be done for the Mainstream and Des Plaines TARP tunnels. However, multiple stage sensors are available in the Torrence Avenue and Little Camulet River legs of the Camulet TARP system to see if it results in improved simulation of TARP overflows.

4.5 COMMENTS ON THE DIRECT APPLICATION OF MODELS IN THE LAFEFRONT DIVERSION ACCOUNTING

In the Lakefront Accounting the runoff diverted from the Lake Michigan watershed was set equal to an agreed upon constant value based on an average runoff determined through a period of record analysis. The components of runoff included in this period of record analysis included:

1. Simulated total inflow (surface runoff) and infiltration (subsurface runoff) components of interceptor flow and overflows for all 137 SCAs found within the Lake Michigan watershed and within the 3 MWRDGC WRP service areas,

2. Simulated total runoff, sewered and unsewered, from the 84 mi^2 “ungaged” Calumet watershed,

3. Runoff determined by streamflow separation techniques for the streamflow gages on the North Branch Chicago River at Niles and the Little Calumet River at South Holland,

4. Runoff determined by streamflow separation and a simulation analysis for the Grand Calumet River, and

5. Baseflow entering the canal and watershed channels between gages and the downstream end of the diverted watershed.

Total simulated area is approximately 361 mi^2, while the total area for which runoff was determined using streamflow separation techniques is approximately 305 mi^2. The average annual runoff determined by a long-term simulation for 1990 land use conditions considering meteorological input for the period 1951-1994 and by streamflow separation over the same period was found to be 785 cfs. Thus, a value of 800 cfs was selected to represent average annual runoff in the Lakefront Accounting procedure. The following paragraphs discuss the procedure applied to determine this long-term average annual runoff and the reasonableness of this procedure.

The simulation was done using the land use percentages determined for WY 1990 based on 1990 aerial photographs (Rust Environment and Infrastructure, 1993a). The 25-gage precipitation network had only been established in 1990, thus, long-term data from the original 13 gage precipitation network had to be used. Because many problems had been found with the consistency and quality of precipitation catch of most of these gages (Vogel, 1988) and correction factors developed by the ISWS were applied when data from these gages were used in diversion accounting (U.S. Army Corps of Engineers, 1990), the U.S. Army Corps of Engineers (1996) decided to focus on three precipitation gages for the period of record analysis: Midway Airport, O’Hare Airport, and University of Chicago. These gages were selected because, along with the

Park Forest gage, they were the only gages of the 13 gages, which required no adjustment or virtually no adjustment by the ISWS for use in diversion accounting (their records were consistent over the period of analysis). They also were selected to provide a better representation of the spatial distribution of precipitation over the watershed. The O'Hare record prior to June 1, 1962, was synthesized using the program PRECIP developed by the Hydrologic Engineering Center. Both Midway and University of Chicago precipitation gages were used as index gages for filling in O'Hare precipitation prior to June 1, 1962.

In the streamflow separation approach the sanitary portion of the sewage effluent from the treatment plants and the sanitary portion of the CSOs are subtracted from the measured streamflow at the North Branch Chicago River at Niles and Little Calumet River at South Holland gages. All streamflow records were adjusted to reflect WY 1990 conditions by multiplying recorded streamflows by adjustment factors based on simulations (with HEC-1) of the 2-year and 50-year frequency events for the years 1950, 1976, and 2000 on the North Branch Chicago River and 1976 and 2000 on the Little Calumet River. The 2-year and 50-year events were selected because they represent an average event and an extreme event (U.S. Army Corps of Engineers, 1996).

Estimation of runoff for the Grand Calumet watershed was more complex (as described by the U.S. Army Corps of Engineers (1996)) because of the short period of operation of the Grand Calumet River at Hohman Avenue at Hammond, Ind., gage. Flows for WYs 1983-1992 at the Illinois-Indiana state line obtained from the regression equation involving Lake Michigan stage (daily values beginning 1970, monthly values earlier) and Hart Ditch flow. Using these regressions and the runoff computation (previously described), the runoff was zero for 82.4 percent of the period of record. An examination of the treatment plant records showed a minimum discharge at the Hammond STP of 25 mgd (about 35 cfs). For the East Chicago STP the minimum is 16 mgd (25 cfs). The minimum discharge was chosen as having the minimum amount of inflow to the sewer system in proportion to the sanitary flow. This minimum discharge was considered to be the Lake Michigan water supply for the communities tributary to the Grand Calumet River. This change in water supply flows resulted in a 62 percent decrease in flow deducted from the total flow. Using this new approach based on the new stream gage and the hydraulic model based equations, only 22 percent of the period had zero runoff.

The ground-water flow to the CWS downstream of the gages was estimated to be approximately 4 cfs on the basis of ground-water flux data collected by the USGS in June 1992.

The primary issue with respect to the accuracy of the period of record analysis is a comparison to a similar analysis done by NIPC (Hey et al., 1987) that yielded an average annual runoff of 636 cfs, substantially less than the USACE 785 cfs. The U.S. Army Corps of Engineers (1996) gave the following reasons for the difference in the two results:

1. Different Periods of Record (NIPC = 1949-1979, USACE = 1951-1994),

2. Changes Model Parameters (i.e. Watershed Characteristics),

3. Determination of Runoff from Streamflow Areas (Little Calumet River at South Holland, North Branch Chicago River at Niles, and Grand Calumet River at Hohman Avenue), and

4. Precipitation data used in the models (NIPC used only Midway Airport, USACE used Midway Airport, O'Hare Airport, and University of Chicago).

Each of these differences is discussed in the following paragraphs.

To evaluate the effect of the period of record of the two simulations the U.S. Army Corps of Engineers (1996) focused on comparing the period of common record for the two studies with the entire period for the USACE study. They found that the weighted Lake Michigan watershed precipitation from the 3 gages used in the USACE study was 34.5 in. over the common period (1951-1979) and 37.8 in. for 1980-1994. Thus, in the comparison of simulated runoff they found that for the common period (1951-1979) the USACE model yielded a mean annual runoff of 742 cfs. Thus, 40 cfs of the 150 cfs difference between the USACE and NIPC values result because of the heavier rainfall between 1980 and 1994.

The U.S. Army Corps of Engineers (1996) also noted that the model revisions (Burke, 1990; U.S. Army Corps of Engineers, 1990) incorporated in the WY 1984 accounting resulted in a large improvement in simulated to recorded ratios at the MWRDGC WRPs when compared to model results from the NIPC model. A comparison of the annual mean S/R ratio for the NIPC and USACE diversion accounting at the three WRPs (U.S. Army Corps of Engineers, 1990) is given in Table 4.5-a:

Table 4.5-a: Annual Mean S/R Ratio for NIPC and USACE Diversion Accounting

	1984		1985	
Water Reclamation Plant	NIPC	USACE	NIPC	USACE
North Side	0.92	0.97	0.96	1.00
Stickney	0.99	0.99	1.02	1.03
Calumet	0.83	0.89	0.90	0.96

The small difference in the S/R values for the Stickney WRP results because the Mainstream TARP drainage basin was not significantly revised from the original delineation by NIPC (Burke, 1990, p. 8). If it is assumed that the Calumet WRP runoff is increased 6 percent of the total Calumet WRP flow (366 cfs for 1987-1999) and the North Side WRP runoff is increased 5 percent of the total North Side WRP flow (425 cfs for 1987-1999) because of the model revisions for the WYs 1984-1989 diversion accounting, an additional 43 cfs of the difference between the NIPC and USACE values result from the model revisions.

In the NIPC study, the runoff from the Little Calumet River at South Holland, North Branch Chicago River at Niles, and the Grand Calumet River at the Indiana-Illinois state line were determined by simulation. Whereas the USACE values for these watersheds are determined by streamflow separation adjusted for 1990 land use as previously described. The U.S. Army Corps of Engineers (1996) argues that streamflow separation is superior to modeling in these areas since it helps to account for the complex hydraulics of the rivers in the southeast portion of the diverted watershed. In general, streamflow separation is better than simulation, but once the attempt to update the flows to 1990 land use is applied this statement is no longer true. Increased imperviousness decreases infiltration and, thus, low flows decrease. The USACE procedure applies a 9.2 percent increase to flows less than the 2-year flow from 1951 for the North Branch Chicago River and a 6.3 percent increase to flows less than the 2-year flow from 1976 for the Little Calumet River, when in fact these low flows should decrease. Because the adjustment procedure varies with time and event magnitude the total magnitude of the overestimate cannot be determined by the Fifth Technical Committee, but an inappropriate increase in the period of record analysis results because of the incorrect updating of measured streamflow.

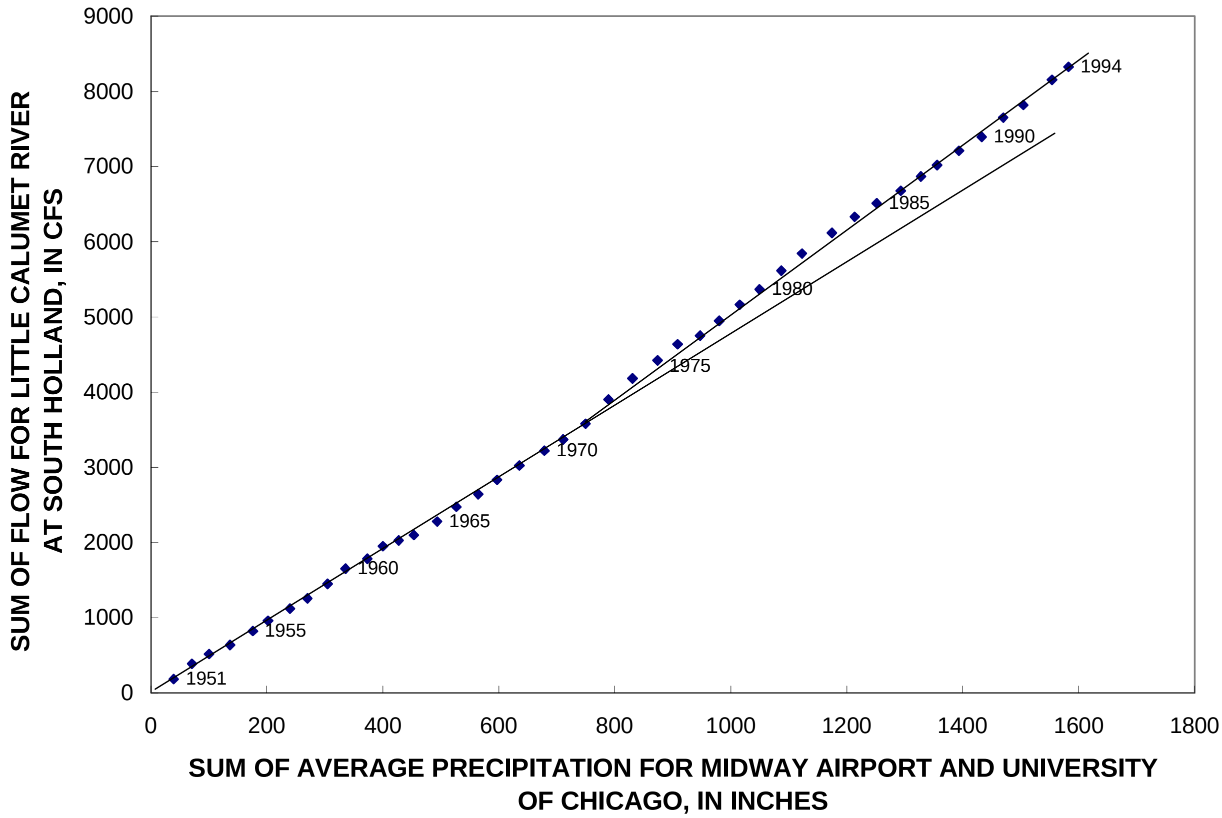
The consideration of multiple raingages in the USACE analysis should result in less runoff from the USACE Analysis than the NIPC analysis. From a double mass analysis Vogel (1988) found that the Midway Airport and University of Chicago yielded nearly identical rainfall. Their double mass analysis was found to have a slope of nearly 1 (0.999) and a correlation coefficient of 0.999. Whereas the O'Hare gage collected 4 percent less rainfall than the average of the Midway Airport and University of Chicago gages (Vogel, 1988). Thus, the rainfall input for the USACE study should be slightly less than that used by NIPC for the common data period.

The remaining difference between the NIPC and USACE values must result from the large increase in impervious area for the WY 1990 diversion accounting models (Table 4.3-e). As noted previously, the U.S. Army Corps of Engineers (1997b) found this land cover distribution to yield overestimated CSO flows, and, thus, the U.S. Army Corps of Engineers (2001b) adjusted the impervious percentages beginning in WY 1997 (Table 4.3-e). The USACE recognized these issues in the period of record analysis (U.S. Army Corps of Engineers, 1996). For example, the runoff from the "ungaged" Calumet watershed was simulated assuming 25 percent impervious land cover instead of the 40 percent determined in the WY 1990 diversion accounting. The CSOs also were adjusted. The adjustments were accomplished by multiplying the CSOs yielded by the WY 1990 H&H models by 0.89. This reduced the CSOs from the WY 1990 H&H models to the average of the CSOs from WY 1989 and 1990 models. This correction factor is similar to the 0.88 correction factor which is the ratio of the pre- and post-1990 slopes obtained by the double mass analysis shown in Figure 4.3-b.

The attempts to compensate for the overestimate in the percentage of impervious area in the WY 1990 H&H models are interesting. However, a more reasonable period of record analysis would be obtained using the WY 1997 H&H model adjustments of impervious area. If such a simulation were done, rather than estimating the O'Hare Airport data prior to June 1, 1962 using the Midway Airport and University of Chicago gages, the measured data at the National Weather Service Arlington Heights gage should be used. Vogel (1988) found this data to be consistent with the O'Hare Airport gage, and use of this gage would better account for spatial variability in precipitation than the estimates from the southern portion of the diverted Lake Michigan watershed.

Such a new simulation would be necessary if Lakefront Accounting was selected and the consumptive use was increased from 10 percent as Section 4.6 has suggested may be necessary. The Fifth Technical Committee feels that a new period of record analysis of runoff with revised models would be valuable even if Lakefront Accounting is not selected because it would provide an overall evaluation of variations in runoff. The H&H models for the diverted Lake Michigan watershed would be recalibrated such that infiltration into the sewer system increased to compensate for the decrease in water supply return flow/wastewater (i.e. the increase in consumptive use). The resulting increase in runoff should cancel the effect of the increase in consumptive use on the Lakefront Accounting procedure, but the adjustments would make the revised Lakefront Accounting conform with the Supreme Court's requirement that the diversion accounting be done according to the "best current engineering practice and scientific knowledge."

Figure 4.5-a: Double mass analysis of annual mean flow for the Little Calumet River at South Holland versus the average total annual rainfall for the Midway Airport and University of Chicago precipitation gages for Water Years 1951-1994. Trend lines show relation for 1951-1972 and for 1973-1994.



The streamflow separation should be revised as follows to more correctly adjust earlier runoff for 1990 land use conditions. Riggins and Yen (1995) proposed using double mass analysis of annual mean flow from an urbanizing watershed against reference precipitation stations or runoff from nearby rural watersheds to detect the effect of urbanization on runoff. Riggins and Yen (1995) presented several examples from the Des Plaines River watershed to illustrate the concept. Figure 4.5-a shows a double mass analysis of the sum of the annual mean flow from the Little Calumet River at South Holland versus the sum of the average of the annual total precipitation at the Midway Airport and University of Chicago gages for the WYs 1951-1994. Figure 4.5-a indicates that the flow substantially increases relative to rainfall after 1972. If the measured annual mean flow from 1951-1972 were to be consistent with that for 1973-1994, it would have to increase by 19 percent. This large increase may result in part due to an increase in wastewater flow, which also results from urbanization, and does not constitute a runoff adjustment factor for this watershed. The example presented here is just an illustration of how the double mass curve method could be used. In actual application, the annual runoff after streamflow separation should be summed and plotted versus the sum of representative precipitation. Precipitation in or near the Little Calumet River above South Holland or the North Branch Chicago River above Touhy Avenue watersheds would be better reference precipitation stations for these watersheds than Midway Airport or the University of Chicago. Riggins and Yen (1995) should be consulted for additional ideas on the double mass curve approach to estimating urbanization effects on runoff.

4.6 CONSUMPTIVE LOSS ANALYSIS

The U.S. Army Corps of Engineers (1996) studied and modeled the water supply for metropolitan Chicago. The results of the study indicated a range of consumptive loss estimates for water-supply pumpage. The issue of consumptive losses arises because of changing to Lakefront Accounting. The 1980 Modified Supreme Court Decree definition of diversion includes: "domestic pumpage from the lake by the state and its municipalities, political subdivision, agencies and instrumentalities, the sewage and sewage effluent derived from which reaches the Illinois waterway." Therefore, the domestic pumpage from Lake Michigan measured by water supply utilities must be reduced by the losses from the withdrawal point from Lake Michigan through the treatment plant and distribution system (leakage) and at the point of use. These losses are termed "consumptive use" for Lake Michigan Diversion Accounting. Initial investigations by the U.S. Army Corps of Engineers (1996) for WYs 1991 and 1992 were based on influent records at the three main MWRDGC Water Reclamation Plants (WRPs): Stickney, North Side, and Calumet. The results of this investigation were reported in the draft Lakefront Technical Analysis (U.S. Army Corps of Engineers, 1996) and the results are shown in Table 4.6-a.

Table 4.6-a: U.S. Army Corps of Engineers Consumptive Loss Estimation Results

Methodology	Consumptive Loss (percent)
Continuous Period Analysis	6.0
Dry Weather Periods	15.2
Continuous – Dry Weather Merged Analysis	8.2
Continuous – Dry Weather Merged-Ratio Analysis	8.7
Continuous Period – Positive Values	16.1
Continuous Period – 0 percent Minimum Value	9.8
Continuous Period – 3 percent Minimum Value	11.1
Continuous Period – 5 percent Minimum Value	12.1

Consumptive loss values varied significantly for the period of analysis. In the continuous period analysis consumptive loss values ranged –4.6 to 18.2 percent and -0.4 to 25.4 percent in the dry weather period analysis. In general, the U. S. Army Corps of Engineers (1996) concluded that it was impossible to select either a consumptive use value from this analysis, or a "potential range". However, if extreme values were discounted, a potential range of 8-12 percent could be derived. The extreme values discounted in the study include 6 percent (continuous period analysis), 15.2 percent (dry weather periods), and 16.1 percent (continuous period – positive values). The USACE recognizes that an 8-12 percent loss is low compared to other "accepted" ranges of 10-16 percent. Analysis by the Illinois Environmental Protection Agency (1991) of "Consumptive Use" determined a value for the Rockford and Kankakee areas of 13 and 14 percent, respectively. The Fifth Technical Committee agrees with the Fourth Technical Committee that the total losses in the water/wastewater system could be significantly higher than the 8-12 percent range, as suggested by the draft Lakefront Technical Analysis (U. S. Army Corps of Engineers, 1996).

The Fifth Technical Committee believes that there is some misunderstanding with regards to the definition of "consumptive use" as defined by the 1980 Modified Supreme Court Decree. In the Supreme Court Decree, and, thus, in diversion accounting, consumptive use represents the total loss between domestic pumpage and the resulting effluent from the domestic treatment plants. All water losses in the water-treatment plant, water-distribution system, consumer facilities (domestic, manufacturing, etc.), and wastewater-collection and treatment system should be included. This is different from the typical definition of consumptive use which includes only losses at the point of use such as households, businesses, or industrial facilities.

The Illinois Department of Natural Resources (IDNR) presented information to the Fifth Technical Committee (January 8, 2003) with regards to unaccounted-for-flow (UFF) in the water supply delivery system. This information specified a goal for UFF not to exceed 8 percent. The permittee which exceeded the 8 percent goal in WY 2000 are listed in Table 4.6-b. This list of permittes with UFF exceeding 8 percent includes the City of Chicago, the largest water supplier in the diverted Lake Michigan watershed. This information suggests "losses" greater than 8 percent in the water distribution system. The UFF does not include the "maximum unavoidable leakage" which is calculated as a function of length of pipes of various ages, type of pipe, and type of joints. Thus, the UFF is less than the consumptive use as defined for diversion accounting.

Table-4.6-b: WY 2000 Permittee Which Exceed 8 Percent UFF

System	UFF (percent)
Chicago	13.3
Chicago Heights	8.5
Citizens Utilities Company-Arrowhead	11.9
Darien	15.6
Forest View	16.2
Highland Park	8.6
Homewood	8.8
Lake Bluff	10.3
Libertyville	9.2
Lyons	10.6
Markham	24.9
Merrionette Park	24.8
Niles	20.6
North Chicago	13.1
Northfield	8.9
Northlake	8.8
Oak Brook	10.2
Riverdale	9.4
Robbins	10.2
Round Lake Park	9.9
Schiller Park	13.2
South Chicago Heights	16.5
Summit	8.9
Tinley Park	13.5
Westchester	9.3
Willow Springs	9.6
Wilmette	9.0
Woodridge	9.8
Worth	16.8

IDNR's analysis of the UFF data from the LMO-2 reports in which IDNR excludes in-plant loss, maximum unavoidable leakage, household domestic use, and sanitary sewer line loss, suggests water loss rates ranging from 0 to 24.9 percent. Use of the LMO-2 UFF data as a measure of the consumptive use would not be consistent with the consumptive loss as specified by the 1980 Modified Supreme Court Decree.

Table 4.6-c summarizes the Fifth Technical Committee's analysis, which is consistent with the 1980 Modified Supreme Court Decree, of the LMO-2 data for consumptive loss. The public supply systems listed in Table 4.6-c represent the WY 2000 top 5 percent by raw annual pumpage. The consumptive loss values presented in Table 4.6-c represent any loss other than metered use, un-metered use, or hydrant use and include any line loss, plant loss, or other losses to the system.

The raw pumpage values listed in Table 4.6-c include any Lake Michigan pumpage and any aquifer pumpage for the system prior to treatment. In WY 2000, the calculated consumptive losses range from 4.3 percent for Schaumburg to 15.4 percent for Chicago. The corresponding total consumptive loss for WY 2000 compared to the total annual pumpage of the top 5 percent was 14.5 percent. For data available for WY 2001, consumptive losses range from 4.3 percent for Schaumburg to 15.1 percent for Waukegan.

Table 4.6-c: Summary of Illinois Department of Natural Resources (IDNR) LMO-2 Data on Lake Michigan Water Allocation, Raw Water Pumpage, and Consumptive Loss (2000-2001)

WY 2000

System	Allocation (mgd)	Raw Annual Pumpage[1] (mgd)	Metered Use (mgd)	Un-metered Use (mgd)	Hydrant Use (mgd)	Consumptive Loss[2] (mgd)	Consumptive Loss to Raw Annual Pumpage (percent)
Arlington Heights	9.667	8.909	8.108	0.150	0.080	0.571	6.4
Bedford Park	16.970	11.270	10.698		0.020	0.552	4.9
Chicago	713.021	649.238	283.104	249.610	16.766	99.758	15.4
Des Plaines	8.049	8.392	7.280		0.064	1.048	12.5
Evanston	9.941	9.778	8.804		0.015	0.959	9.8
Glenview (from Wilmette)	11.218	9.491	8.510		0.010	0.971	10.2
Naperville	16.234	15.656	14.629		0.008	1.019	6.5
Schaumburg	11.010	10.458	9.909		0.101	0.448	4.3
Skokie	10.950	10.351	9.147	0.036	0.048	1.120	10.8
Waukegan	8.587	8.390	7.034		0.080	1.276	15.2
Subtotal	815.647	741.933	367.223	249.796	17.192	107.722	
Reported Total for All Systems	1215.192	1117.136					
Relative Proportion of Top 5 percent	67%	66%					
Relative Proportion to Raw Annual Pumpage				34%		14.5%	

WY 2001

System	Allocation (mgd)	Raw Annual Pumpage[1] (mgd)	Metered Use (mgd)	Un-metered Use (mgd)	Hydrant Use (mgd)	Consumptive Loss[2] (mgd)	Consumptive Loss to Raw Annual Pumpage (percent)
Arlington Heights	9.695	8.843	8.101	0.151	0.063	0.528	6.0
Bedford Park	16.950	10.748	10.256		0.024	0.468	4.4
Chicago	717.837	636.567	286.580	248.867	16.465	84.655	13.3
Des Plaines	8.067	8.052	7.273	0.002	0.077	0.700	8.7
Evanston	9.967	9.695	8.772		0.010	0.913	9.4
Glenview (from Wilmette)	-----	-----	-----	-----	-----	-----	-----
Naperville	17.094	16.411	15.210		0.008	1.193	7.3
Schaumburg	11.162	10.423	9.879		0.099	0.445	4.3
Skokie	10.974	10.245	9.173	0.009	0.046	1.017	9.9
Waukegan	8.663	8.517	7.153		0.080	1.284	15.1
Subtotal	810.409	719.501	362.397	249.029	16.872	91.203	
Reported Total for All Systems	-----	-----					
Relative Proportion of Top 5 percent	-----	-----					
Relative Proportion to Raw Annual Pumpage				35%		12.7%	

[1] Raw water pumped to the water reclamation plant prior to treatment.
[2] Equals Raw Annual Pumpage – (Metered Use +Un-Metered Use + Hydrant Use)

Out of the 195 public supply systems, the 10 listed in Table 4.6-c supplied 66 percent of the water withdrawn in WY 2000 and the City of Chicago withdrew 58 percent of the total. It should be noted that the City of Chicago has a large amount of un-metered flow and if it were considered consumptive loss the City of Chicago would have a consumptive loss of 53.8 percent. Arlington Heights and Skokie also record un-metered use on LMO-2 reports and further investigation is needed into the origin of these un-metered uses to determine if they should be considered consumptive loss. Programs such as the City of Chicago's installation of upgraded and new meters are beneficial in this regard. In addition, the WY 2000 LMO-2 report for Skokie does not match Evanston's LMO-2 report in which Evanston reports how much water it sells to Skokie. The WY 2001 LMO-2 reports match so it is believed to be a measurement error.

The values listed in Table 4.6-c were determined on the basis of raw water supplied by direct diverters or received by a secondary user from a direct diverter. It is the Fifth Technical Committee's understanding that IDNR uses the LMO-3 data for Lake Michigan Diversion Accounting purposes, whereas LMO-2 data are used to audit water use and document a basis for water-supply allocation. The value of Lake Michigan Pumpage Accountable to the State of Illinois listed in Column 11 of the Diversion Accounting Report is not necessarily based on raw water withdrawals. The values listed in Column 11 are a summation of withdrawals submitted to IDNR in monthly LMO-3 reports by the water supply utilities and other users that directly divert water from Lake Michigan (Table 4.6-d).

Further evaluation of the LMO-2 and LMO-3 data for the purpose of characterizing consumptive use should recognize the potential problem associated with mixing primary diverter and secondary supplier records for gross (or raw) pumpage and net (i.e. after in-plant-treatment) pumpage. Considering the primary diverters for example, the City of Chicago reports finished-water pumpage whereas Evanston and Highland Park report raw pumpage. For the secondary-supply communities, the reported raw water pumpage on the LMO-2 reports, for example, the Village of Glencoe, would not reflect line losses that might occur prior to their receiving water from a primary diverter such as the City of Chicago.

The point being made is that if LMO-3 and, thus, Column 11, contains a mixture of raw and finished water numbers, a single, system-wide average value for consumptive use is not appropriate. The Fifth Technical Committee recommends, especially if a shift is made to Lakefront Accounting, that the IDNR should encourage the water supply utilities to provide consistent data on the LMO-3 reports. Because some communities may not have raw water withdrawal data, the Fifth Technical Committee recommends that if practicable, all water supply utilities should provide finished water data on the LMO-3 reports. An alternative approach would be to adjust a metered raw-water pumpage using a documented adjustment factor to account for in-plant use. Use of finished water data also would remove one piece of consumptive use (in plant use) from the estimation, however it must recognized that the "domestic pumpage" defined and used in the Decree is being interpreted as raw-water pumpage less in-plant treatment loss.

Table 4.6-d: Primary Diverters that Pump Directly From Lake Michigan for Their Own Use and/or Wholesale to Other Communities

[Data pertaining to quantity of raw or finished water pumped is supplied to IDNR monthly on the LMO-3 report; Source (T.Y.Su, USACE, written commun., June 2004)]

Diverter	Raw/Finished Pumpage Reported to IDNR on LMO-3 Report
Acme Steel	Raw
Bombardier	Raw
Burnham*	Raw
Calumet City*	Raw
Central Lake County JAWA	Raw
Chicago	Finished
Chicago Heights*	Raw
Evanston	Raw
Glencoe	Raw
Highland Park	Raw
Highwood	Finished
John G. Shedd Aquarium	Raw
Kenilworth	Finished
Lake County Public Works	Finished
Lake Forest	Finished
Lansing*	Raw
LTV Steel Company	Raw
Lynwood*	Finished
Northbrook	Finished
North Chicago*	Raw
U.S. Steel Corporation	Raw
Waukegan	Finished
Wilmette	Finished
Winnetka	Raw

* Denotes users who receive their water from Indiana, not directly from Lake Michigan.

5.0 UNCERTAINTY ANALYSES OF DIVERSION FLOW COMPONENTS

The Fifth Technical Committee was tasked with reviewing methods for characterizing the uncertainty of annual diversions calculated using the Romeoville and Lakefront Accounting Systems. The accuracy of the diversion quantities and the reliability of the equipment and methods used to determine those quantities are important factors to consider when evaluating the relative efficacies of these two different accounting systems.

Prior Technical Committees, the USGS, and the USACE have all addressed uncertainty in various components of the diversion at one time or another, using one method or another. Not surprisingly, each uncertainty analysis has been described in its own unique lexicon. Terminology used in one analysis is different than in another. Uncertainty and errors are expressed in absolute terms of variances, relative terms as a coefficients of variation, standard errors of estimate, confidence intervals, root-mean-square, first-order second-moment analysis, and so forth. The diversity of these texts has the real potential to lead to an inconsistent consideration of uncertainties in the context of the uncertainty in the annual reported diversion.

However, some general concepts are common to the various uncertainty analyses. Sources of error have been identified in terms of being random or systematic which are important to distinguish between. In general terms, uncertainty related to random errors can be reduced by making more measurements and averaging the results. However, repeated measurements will not reduce the uncertainty associated with a systematic error in a known direction. The bias associated with a systematic error in a known direction persists. Another source of bias is associated with errors that occur systematically but in a direction that is not known. Like random error, this type of bias can be reduced by making more measurements. Recognition of these fundamentally different types of error leads to the consideration of the overall error in a discrete measurement (sometimes termed “unit value”) of the prescribed flow characteristic and ultimately to the consideration of the overall uncertainty in the annual value calculated from the aggregated unit values.

The following sections summarize the primary findings and recommendations reported by others in regards to the uncertainty of various diversion flow components. The synopsis serves as a basis for comments offered by the Fifth Technical Committee at the end of each section.

5.1 FOURTH TECHNICAL COMMITTEE ERROR ANALYSIS

The Fourth Technical Committee described an extensive evaluation of the error associated with the discharge at the Romeoville gaging station (Espey et al., 2001). The primary gage is an AVM for which an index-velocity rating has been developed. During periods when record from the primary gage is not available, discharge is determined using regression equations that relate the discharge at Romeoville with the discharge reported by MWRDGC at the Lockport Powerhouse, Lock, and Controlling Works.

Measurement errors related to the cross-sectional area of flow and ADCP-measured discharge were evaluated in terms of being random or systematic. At a stage of 25.50 ft, the cross-sectional area associated with the stage-area rating established in 1984 and used to determine discharge is reportedly 2.0 percent lower than measured during a field survey in June 1991, and 2.9 percent lower than a more recent survey in October 1993. The continued use of the same stage-area rating introduces a systematic error, termed a “bias” by the Fourth Technical Committee in the index-velocity rating. This is because the ADCP-measured discharge is divided by the rated area for the stage during the measurement. Furthermore, the Fourth Technical Committee reported an average bias in calculated discharge of 0.04 percent that is apparently low because “the error in the index-velocity rating … will tend to cancel the error in the stage-area rating…”.

ADCP measurement methods were critically examined. Random errors are reportedly associated with the measurement of water velocity, boat velocity, water depth, and the pitch and roll of the instrument. The random error estimated for 59 ADCP measurements was 0.9 percent of total discharge. Systematic errors associated with using a 1/6-power curve-fitting method to estimate unmeasured discharge at the top and bottom of the flow section and operator error associated with following established procedures were estimated to range from 0.2 to 0.7 percent. The analysis noted that the total width used in the 59 ADCP measurements averaged 2.1-percent less than the surveyed width of the measurement section. The Fourth Technical Committee concluded that although theoretical accuracies on the order of 0.5 percent are possible, a more appropriate upper limit is the ± 5 percent ADCP calibration standard used by the USGS (Lipscomb, 1995).

Measurements number 52 through 77 made at the Romeoville gage were evaluated using linear regression to define an index-velocity rating that was conditioned to have a zero intercept. The standard error for an individual observation (i.e. an instantaneous velocity) determined using the rating equation is 0.21 ft/s for velocities between 0 and 2.3 ft/s. The corresponding standard error of the average of the predicted mean velocities from the regression equation for a given index velocity is 0.04 ft/s.

The uncertainty analysis prepared by the Fourth Technical Committee concluded with an error analysis of annual mean discharge reported for Romeoville during WYs 1990 through 1996. The analysis describes a “potential bias” in annual mean discharge for two scenarios. The first scenario assumes that the apparent 2.1-percent difference in surveyed channel width and width reported for ADCP measurements was found to have no effect on the discharge calculations. The second scenario assumes that the difference does indeed have an effect, and the effect consistently causes discharge to be under-estimated. In both scenarios, the dominant source of error is the error in the index-velocity rating.

The error associated with the “without width error scenario” ranges symmetrically about zero between ± 2.6 to 3.5 percent for WYs 1990 through 1996. Alternatively, the error reported for the “with width error” scenario reflects a similar range in relative error, but the error for each year is shifted to center about –2.1 percent. This comparison illustrates the fundamental difference between bias in a known direction, and the other forms of bias combined with random error.

The error analysis reported by the Fourth Technical Committee is noteworthy for a number of reasons.

1. It documents an overall error for the most critical flow-monitoring location in the diversion accounting program. The apparent error in annual discharge reported for the Romeoville gage is consistent with best current engineering practice and scientific knowledge.

2. It represents a critical analytical evaluation of the overall stream-gaging procedure associated with using the latest acoustic technology for the synoptic and continuous measurement of discharge.

3. It helped elicit interest and support for the follow-up studies of flow uncertainty in pumping station records and annual diversions that are summarized next.

4. Finally, it has provoked considerable thought and discussion between members of the Fourth and Fifth Technical Committee with regards to the nature of the various sources of errors being random or systematic and to the co-dependency of variables in the index-velocity approach to flow measurement.

It should be noted that in January 2003 the USGS explained to the Fifth Technical Committee that the apparent changes in cross sectional area among the various measurements resulted from a shifting of the point of discharge measurement used to develop the index-velocity rating. In the early years of the AVM operation, conventional current meter discharge measurements were made from the old Romeoville Road Bridge. Later when the old Romeoville Road Bridge was removed, ADCP discharge measurements were made from a boat at a location approximately midway between the upstream and downstream transducers. Once the new Romeoville Road Bridge was constructed the USGS began making ADCP discharge measurements from a tethered boat on the downstream side of the bridge. Thus, the cross-sectional area and width of the cross section at which discharge measurements have been made has changed substantially throughout the years.

In the early 1990s in response to comments from the Third Technical Committee the USGS established the stage-area rating on the basis of an average of cross sectional area data collected using detailed soundings at the locations of the upstream and downstream transducers and a point midway between these transducers. It was felt that this average would be most representative of the cross-sectional area over which the AVM path velocities were measured, and as such a more reliable index-velocity rating could be developed. The flow measured with the ADCP is divided by the area from the stage area rating to get the cross-sectional average velocity at the AVM section for the development of the index velocity rating. Soundings are periodically made at the AVM location to check for changes in the cross sectional area.

Station analyses prepared for WYs 1997 through 2002 indicate that stage-area rating number 1 was used for the entire period, but there is no mention of any analysis of potential “drift” in the stage-area rating. It is unclear whether the rating has been evaluated for stability; although the CSSC is a rock-cut channel. It is recommended that the stage-area rating be evaluated periodically to ensure there is no bias in the flow calculated using the Romeoville AVM system because of changes in cross-sectional area.

5.2 USGS ERROR ANALYSIS

Beginning in WY 2002, the USGS initiated a study to determine the uncertainty in the computation of discharge at four gaging stations equipped with acoustic velocity meters (AVMs). The stations are the CSSC at Romeoville, Chicago River at Columbus Drive, Calumet River at O’Brien Lock and Dam at Chicago, and North Shore Channel at Wilmette. Daily mean and annual mean discharges were calculated and evaluated for each gaging station for WYs 1997 through 1999.

During periods of missing record, discharge is estimated using backup equations that relate gaged flow to flows reported by MWRDGC in IDNR’s termed LMO-6 records. The uncertainty associated with a backup equation is factored on a time-weighted basis in the calculation of overall uncertainty in the annual flow record. Nearly two-thirds of the record developed for the Calumet River at O’Brien Lock and Dam was determined in this manner. Records collected at the North Shore Channel at Wilmette during WY 2000 were evaluated for the influence of ADCP-AVM error because the previous 3 years of record were estimated until the gaging station was established and calibrated in September 1999.

In the early drafts of their error analysis the USGS evaluated the influence of two procedural differences in the approach to developing an index-velocity rating. One issue was whether the index-velocity rating should have a zero intercept and only the slope of the rating should be calibrated or whether an unconstrained linear regression should be used to develop the index velocity rating with both the intercept and slope nonzero. The "official" index-velocity rating developed for the Romeoville AVM has a zero intercept, which is appropriate for the configuration of the AVM paths and the field conditions of the CSSC at Romeoville. However, the USGS has not established an official policy regarding the use of zero or non-zero intercepts for index velocity ratings for AVMs.

The second evaluation addressed the "grouping" of concurrent ADCP and AVM measurements made consecutively during several hours when water conditions were presumably stable. The "official" index-velocity ratings for the AVMs at O'Brien Lock and Dam, Columbus Drive, and Wilmette are based on grouped data, whereas that at Romeoville is based on ungrouped data. Alternate ratings were developed using a regression analysis of the individual "ungrouped" measurements at lakefront AVMs.

It is important to note that material reviewed by the Committee and discussed herein is provisional and subject to change. A preliminary draft report was provided to the Fifth Technical Committee for review in early 2003, and the Committee met several times with the primary USGS investigators to discuss the subject. The Fifth Technical Committee (S. Melching, written communication, April 2003) offered comments and suggestions in the form of a colleague review of the preliminary draft. Revised drafts which address additional work performed by the USGS and additional colleague review were provided to the Committee in September 2003 and June 2004. The Fifth Technical Committee (S. Melching, written communication, December 2003) offered comments and suggestions in the form of a colleague review of the revised September draft. The draft report (Duncker et al., and others, 2004) is still undergoing internal review by the USGS.

Error models were developed to characterize the uncertainty associated with discharge records developed from AVM measurements and the uncertainty associated with discharge records estimated on days when AVM measurements were not available. AVM error models were developed for daily discharges that are computed using a single AVM index-velocity rating (such as at the Romeoville, Columbus Drive, and Wilmette gages), and for situations like the O'Brien gage in which daily discharges are computed using two index-velocity ratings (IVR's). The effect of ADCP measurement error is explicitly considered using random variables for the slope and y-intercept of a linear model for ADCP bias. Sensitivity to this bias was estimated by considering a variation in the intercept of 0.01 ft/s and a similar variation in slope of 0.01. The slope variation of 0.01 represents a 1-percent error when the index velocity rating slope is 1.0.

The Fourth Technical Committee opined that an appropriate upper limit for the potential error in an ADCP measurement is 5 percent which is consistent with the ADCP calibration standard used by the USGS (Lipscomb, 1995). More recent work described by Mueller (2002) and González-Castro et al. (2000) substantiates this limit. It should be noted that this 5 percent potential error is a random error whereas the 1 percent error considered by Duncker et al. (2004) is a bias error affecting the index-velocity rating. Thus, there is no inconsistency between the analysis done by the USGS (Duncker et al., 2004) and the standard estimate of ADCP accuracy.

Equations are presented for stage-area relations, index-velocity ratings, and regressions based on analysis of MWRDGC LMO-6 data for estimated missing AVM record. Most equations are linear in form and represented by a slope and y-intercept. Nonlinear equations were developed to estimated missing record at the Columbus Drive gage.

With the exception of the index-velocity rating for the Romeoville gage, the stage-area and index-velocity ratings developed for the stations are linear functions with parameters determined by linear regression. The y-intercept for the Romeoville IVR is assumed to be zero as the data suggest, because of the uniformity in channel geometry and vertical velocity distribution.

The mathematics in the report are rigorous, but the evaluations performed by the USGS and provisional findings are both interesting and thought provoking. Results are summarized Table 5.2-a.

Table 5.2-a: Average annual discharge and related uncertainty estimated for the AVM gages
[Source: Dunker et. al., 2004; "Relative uncertainty without ADCP error" is the range in the coefficient of variation associated with an uncertainty analysis based on an assumed value of zero for both the intercept and slope terms in the ADCP error model; "Relative uncertainty with ADCP error" is the range in coefficient of variation assuming values of 0.01 for both the intercept and slope terms]

Gaging Station	Water years evaluated	Average discharge (cfs)	Relative uncertainty without ADCP error (percent)	Relative uncertainty with ADCP error (percent)
Romeoville	1997 - 1999	2,944 to 3,231	0.6	2.1 to 2.2
Wilmette	2000	26.3	32	47
Columbus Drive	1997 - 1999	202 to 464	2.8 to 10	12 to 34
O'Brien	1997 - 1999 non-estimated days only	242 to 330	9.4 to 24	24 to 48

The primary findings and conclusions offered in the draft USGS report are summarized as follows.

The uncertainty in annual discharge is quite sensitive to ADCP-measurement error. Values provided in the Table 5.2-a indicate that in most instances, the consideration of a change in the index velocity rating y-intercept of 0.01 ft/s and change in slope of 0.01 in the model for ADCP-measurement bias leads to a relative uncertainty in annual flow that is 2 to 4 times the uncertainty assuming no ADCP error bias.

The USGS uncertainty analysis also concludes that a bias in the ADCP measurement and associated index velocity rating "dominates" the overall uncertainty in annual average discharge. The authors indicate that this uncertainty can be reduced by making more ADCP measurements.
Autocorrelation of errors (over time) in the stage-area and index-velocity ratings is briefly addressed in the report. The authors conclude that autocorrelation with respect to area errors is such a small portion of the overall error that the effect is negligible. Furthermore, based on a limited evaluation of ADCP and AVM measurements at the Columbus Drive gage, they report that a comparison of uncertainties calculated with and without the influence of a lag-one autocorrelation coefficient of 0.5 were "negligibly different."

The error analysis performed by the USGS for the four AVM gages is noteworthy for the following reasons:

1. It documents a need for the continued investigation and development of protocols for establishing index-velocity ratings, particularly in regards to when zero and non-zero intercepts are appropriate. Site-specific characteristics such as channel stability, range

and variability of stage, and range and variability of AVM index velocity should be considered. Additional guidance is needed regarding what represents an independent measurement of discharge for rating purposes. The Fourth Technical Committee recommended that consecutive discharge measurements be grouped and averaged for rating analysis because the measurements used for rating analysis show a strong serial correlation (Espey et al., 2001). This is in contrast to the preliminary findings described for this analysis that the influence of autocorrelation may not be as significant.

2. It documents a need for the continued investigation and documentation of ADCP measurement error and the related influence on index-velocity ratings. The approach considered herein in which the regression coefficients of an "error model" were treated as random variables is an innovative application of an established technique (Draper and Smith, 1998) and is useful in characterizing the sensitivity of uncertainty to measurement error. The error terms prescribed for the analysis are described by the authors as "reasonable and conservative." It is the Fifth Technical Committee's recommendation that the USGS further evaluate a potential ADCP bias error of 2 percent. Relative to the analysis completed to date that characterizes the slope term as a 1-percent error, the recommended evaluation would serve to document a sensitivity analysis and help define the linear or nonlinearity on the uncertainty in AVM flow records that could be associated with ADCP measurement bias.

3. It prompts a recommendation to consider alternative approaches to developing index-velocity ratings when there is physical evidence that a linear regression model is inadequate. Nonlinear and piece-wise linear regression analysis of the stage-rating and/or the index-velocity rating, should be considered in those cases.

4. It demonstrates how useful an independent backup flow-measurement method is. This is of critical importance to stations such as the Romeoville AVM gage in which the uncertainty in gage record comprises a relatively large portion of the overall uncertainty in the reported diversion. The current method used by the USGS is a regression equation that relates daily discharge at an AVM station with daily discharge reported by MWRDGC on LMO-6 reports for the nearby flow-regulation structure. This is an appropriate approach if the validity of the regression is periodically checked.

5. Last of all, the study provides reasonable preliminary measures of the uncertainty in annual discharge that might be expected for the primary gage in the current Romeoville Accounting System and the three gages that would gain more prominence if the Lakefront Accounting System is adopted. The range in relative uncertainty calculated for the Romeoville gage for WYs 1997 through 1999 is similar to that reported by the Fourth Technical Committee for WYs 1990 through 1996.

5.3 USACE MUNICIPAL PUMP-STATION ERROR ANALYSIS

Water-supply pumpage has accounted for about 55 percent of the more recent annual diversions from Lake Michigan. The Lakefront Accounting procedure would rely even more heavily on the records of withdrawal, because the runoff and consumptive use components are fixed, and water-supply pumpage would account for an even greater percentage of the flows to be measured using the Lakefront Accounting procedure.

The USACE retained Mead & Hunt, Inc. in 2002 to evaluate the accuracy of municipal withdrawals from Lake Michigan. A total of 12 pump stations maintained by the City of Chicago and 6 suburban water treatment plants were evaluated. The evaluations include a description of the meters used, the calibration that is done for the meters, the backup system for the flow metering and data management, a detailed error analysis for short periods (three 2-week periods) of data, and a calculation of the uncertainty associated with the annual pumpage. Pumping stations and water treatment plants were visited and device installations were examined. A technical report describing the field inspection, findings, and recommendations was prepared for each station (Mead and Hunt, 2003a – 2003r).

Draft reports prepared for the City of Evanston Water Treatment Plant and the City of Chicago Thomas Jefferson and Mayfair Pumping Stations (Wahlin and Replogle, 1998a – 1998c) were reviewed by the Fourth Technical Committee. Comments and recommendations offered by the Fourth Technical Committee were incorporated in the final reports prepared for all 18 facilities.

The final report for the City of Evanston Water Treatment Plant (Mead and Hunt, 2003m) presents an extensive discussion of the sources of potential error associated with the measurement of flow at pumping stations. Errors are characterized as random or systematic in nature. The primary distinction between the two is that influence of random errors can be reduced by increasing the number of measurement made. Systematic errors are consistently positive or negative in nature. Systematic errors are considered "bias" in measurements. Systematic errors are further characterized as bias in a known direction, bias in an unknown but consistent direction, and bias in an unknown direction. The influence of bias in an unknown direction like random error can be reduced by increasing the number of measurements made whereas the influence of bias that is known or unknown but in a consistent direction cannot be reduced.

The report also describes how the errors associated with various factors are combined mathematically to estimate the overall error associated with a discrete measurement. Recognizing that the value of interest is an annual flow volume, the report further describes the mathematics associated with aggregating the error associated with discrete measurements into daily and annual flow volumes. Results are described as average uncertainty (CV_V) and average 95-percent confidence interval (CI_V) in relative terms of the coefficient of variation (i.e. the standard deviation of flow divided by the mean flow) using the following equations:

$$CV_V = CV_{\text{direction known bias}} \pm CV_{\text{RMS bias and random error}}$$

$$CI_V = CV_{\text{direction known bias}} \pm 1.96CV_{\text{RMS bias and random error}}$$

in which:

$CV_{\text{direction known bias}}$ = error associated with bias uncertainty of known direction, and

$CV_{\text{RMS bias and random error}}$ = square root of errors associated with bias uncertainty of unknown direction, bias of unknown but consistent direction, and random error.

In addition to the quantitative evaluation of uncertainty in the annual flow record, the report prepared for each plant also describes quality-assurance issues including the back-up measurement systems, a summary of noted inadequacies in the metering systems, and recommendations for long-term quality assurance/quality control and improvements.

The primary findings associated with the 18 facility evaluations are summarized in Table 5.3-a in which relative uncertainties are also summarized in terms of the WY 2000 flow-weighted average. The bias of known direction was most commonly negative which indicates an under-reporting of discharge, although the range in relative uncertainties associated with 95-percent confidence interval range between –1.00 and +0.21 percent. The flow-weighted average bias of known direction is –0.34 percent. A larger portion of overall uncertainty is associated with random errors and all other biases. These latter errors range between ±0.04 and ±32.1 percent and have a flow-weighted average of ±2.48 percent based on WY 2000 flow records. On the basis of this flow-weighted evaluation a coefficient of a variation of 0.03 (3 percent) was selected as conservative for domestic pumpage withdrawals in the uncertainty analysis of the Romeoville and Lakefront Accounting Systems done by the Committee in Section 5.5.

Table 5.3-a: Estimated 95-Percent Confidence Intervals for Error in Annual Pumpage and Associated Facility Quality Assurance Status

Plant	Volume Pumped During WY2000** (Mgal)	$CI_{direction\ known\ bias}$	$CI_{RMS\ bias\ and\ random\ error}$	Backup Data Recording System	Independent Flow Measurement Check	Lower Limit of Uncertainty	Upper Limit of Uncertainty	Average Relative Portion of Total Uncertainty
Lakeview *	13,443	-0.50%	27.15%	N	N	-27.65%	26.65%	75.74%
Thomas Jefferson *	20,446	-0.50%	0.55%	Y	N	-1.05%	0.05%	0.13%
Mayfair *	55,518	-0.26%	1.74%	Y	Y	-2.00%	1.48%	5.42%
Chicago Avenue *	19,921	-0.72%	0.80%	N	N	-1.52%	0.08%	0.26%
Cermak *	13,864	-1.00%	0.47%	Y	N	-1.47%	-0.53%	0.13%
Central Park Avenue *	34,108	-0.30%	1.47%	Y	Y	-1.77%	1.17%	1.49%
Springfield Avenue *	33,876	-0.10%	1.51%	Y	Y	-1.61%	1.41%	1.49%
68th Street *	22,039	-0.47%	0.76%	Y	N	-1.23%	0.29%	0.22%
Roseland *	44,918	-0.32%	1.49%	Y	Y	-1.81%	1.17%	2.66%
Western Avenue *	23,546	-0.50%	2.57%	Y	Y	-3.07%	2.07%	2.16%
Southwest *	39,536	0.00%	0.84%	Y	N	-0.84%	0.84%	0.63%
Lexington *	32,266	-0.50%	0.63%	Y	Y	-1.13%	0.13%	0.38%
Central Lake County Joint Action Water Agency Facility **	6,222	-0.50%	0.04%	Y	Y	-0.54%	-0.46%	0.01%
Evanston	3,532	0.00%	0.41%	Y	Y	-0.41%	0.41%	0.00%
Highland Park	3,970	0.21%	32.09%	Y	Y	-31.88%	32.30%	9.23%
Northbrook	2,159	0.00%	1.74%	Y	N	-1.74%	1.74%	0.01%
Waukegan	2,959	0.00%	2.55%	Y	Y	-2.55%	2.55%	0.03%
Wilmette	4,503	0.00%	0.04%	Y	Y	-0.04%	0.04%	0.00%
Total	376,827							100.00%
Flow-Weighted Average		-0.34%	2.48%					
Flow Lacking Backup or Verification				33,364	131,408			
Relative Portion Lacking Backup or Verification				8.9%	34.9%			

* City of Chicago facility. **Reported by State of Illinois on LMO-2 report.

The overall uncertainty associated with annual flow volumes ranges between –3.1 and 2.6 percent at 16 of the 18 facilities. The notable exceptions are annual flows reported for the City of Chicago Lakeview Pumping Station and City of Highland Park Water Treatment Plant that have relative uncertainties of ±27 and ±32 percent, respectively. The uncertainty at the Lakeview Pumping Station is reportedly largely attributable to venturi meters that are oversized relative to the magnitude of flow thus causing a low differential pressure and a correspondingly high relative metering error (Mead and Hunt, 2003d). The primary source of uncertainty at the Highland Park Water Treatment Plant is associated with pressure sensors that have a range considerably higher than the pressures produced in the venturi and orifice plates (Mead and Hunt, 2003n). These two facilities alone contribute to an estimated 85 percent of the total uncertainty in the combined annual flows reported by the 18 facilities.

With regards to quality assurance, quality control, and back-up metering systems the overall situation documented by the inspections is fairly reasonable. Only 2 of the 18 facilities, the City of Chicago Lakeview and Mayfair Pumping Stations, lack back-up data recording systems. The combined pumpage at these two facilities during WY 2000 is 8.9 percent of the combined 18-facility total for the water year. Eleven of the 18 facilities have independent flow-measurement checking capabilities, hence there is a deficiency in this regard. The combined pumpage during WY 2000 at the 7 facilities that lack an independent metering system is 35 percent of the total annual pumpage of all facilities combined.

The more frequently occurring recommendations offered in the technical review reports are as follows:

1. Calibration of the venturi meters to determine if manufacturer rating curves are still valid,

2. Occasional inspection and measurement, if physically possible, of the inlet and throat of the venturi meters to determine the presence and effects of corrosion and tuberculation, and

3. Implementation of an independent check of the flow-measurement system.

The facility inspections and error analysis performed under contract with the USACE by Mead and Hunt, Inc. and the associated reports prepared for the 18 pumping facilities are excellent sources of information. The USACE is to be commended for supporting these studies that will benefit all stakeholders involved with the Lake Michigan diversion. In particular, the individual municipalities are encouraged to implement the recommendations offered to the greatest extent practicable independent of the methodology used to account for the diversion.

The 18 evaluations are particularly noteworthy for reasons which are summarized as follows:

1. Many of the recommendations offered by the Fourth Technical Committee were incorporated in these reports.

2. The implementation of these evaluations demonstrates how the on-going cycle of technical review with recommendations, followed by consideration and implementation of said recommendations, with subsequent cycle of review is proving beneficial in assuring that best current engineering practices and scientific knowledge are being applied in the accounting process.

3. The nearly order-of-magnitude higher uncertainty associated with pumping records at the City of Chicago Lakeview Pump Station and City of Highland Park Water Treatment Plant should be addressed, particularly if the Lakefront Accounting System is adopted.

4. Recommendations associated with metering retrofits should be implemented, particularly if the Lakefront Accounting System is adopted.

5. The recommendation for calibration of the venturi meters to determine if manufacturer rating curves is consistent with earlier Technical Committee recommendations and should be pursued.

6. The recommendation for occasional inspection and measurement, if physically possible, of the inlet and throat of the venturi meters to determine the presence and effects of corrosion and tuberculation is also consistent with earlier committee recommendations and should be pursued. The recommendation is qualified as "occasional" because there is evidence that these effects may occur very gradually. T.Y. Su (written commun., June 2004) informed that the City of Chicago inspected one 66 in. inlet water main (approach to the Venturi) in the South Filtering Plant in 2003 while the water line was taken out of service for maintenance/repair. The diameter was measured by a micron-meter and it was found that the pipe diameter changed from 66 to 65.991 in. after 30 years in service. (Verbal communication with Conrad Bazylewski of the Department of Water Management, City of Chicago on July 11, 2003).

5.4 USACE PRELIMINARY OVERALL COMPARATIVE ERROR ANALYSIS

In August 2003, the USACE gave a presentation to the Fifth Technical Committee which described an approach for evaluating the overall uncertainty associated with both the Romeoville and Lakefront Accounting Systems. The presentation summarized the primary components of each accounting method, described the error distribution assumed for each component, and summarized a method of analysis. Results from a preliminary analysis of records for WYs 1997 through 1999 were presented to demonstrate to the method of analysis.

The primary components of the Romeoville Accounting System addressed in the discussion are as follows:

1. Romeoville AVM gage record,

2. Diversions upstream from the Romeoville gage,

3. Ground-water pumpage subsequently discharged to the CSSC,

4. Water supply pumpage from Indiana reaching the CSSC,

5. Runoff from the Des Plaines River watershed reaching the CSSC,

6. Lake Michigan pumpage by federal facilities discharged to the CSSC, and

7. Lake Michigan pumpage not discharged to the canal.

The primary components of the Lakefront Accounting System addressed in the discussion are as follows:

1. Water supply pumpage at 18 primary municipal facilities,

2. Direct diversion measured by the 3 lakefront AVM gages,

3. Runoff from the Des Plaines River watershed reaching the CSSC, and

4. Consumptive use.

It is important to note that the runoff and consumptive use components of the Lakefront Accounting System are fixed at 800 and 168 cfs, respectively. The proposed method of analysis is Monte-Carlo simulation of annual flows and associated uncertainties. It is a standard methodology used by the USACE for risk analysis. The method is implemented using the Palisade @RISK software version 3.5, an “Add-In” for Microsoft Excel. The first step in applying the Monte-Carlo simulation is to construct a model in the spreadsheet that represents the accounting method being tested.

The model for the Romeoville Accounting System is represented by the following equation in which all terms represent average annual flow in cfs:

$D_R = X1 + X2 - X3 - X4 - X5 - X6 + X7$

In which:
D_R = Annual diversion based on Romeoville Accounting,
X1 = Discharge of CSSC at Romeoville,
X2 = Diversions upstream from the Romeoville gage,
X3 = Ground-water pumpage subsequently discharged to the CSSC,
X4 = Water supply pumpage from Indiana reaching the CSSC,
X5 = Runoff from the Des Plaines River watershed reaching the CSSC,
X6 = Lake Michigan pumpage by federal facilities discharged to the CSSC, and
X7 = Lake Michigan pumpage not discharged to the canal.

The model for Lakefront Accounting System is represented by the following equation in which all terms represent average annual flow in cfs:

$D_L = Y1 + Y2 + Y3 - Y4$

In which:
D_L = Annual diversion based on Lakefront Accounting,
Y1 = Sum of discharges measured at the 3 lakefront AVM gages,
Y2 = Sum of pumpage at 18 pumping stations and water treatment plants,
Y3 = 800 = Estimated long-term average runoff from the Lake Michigan watershed reaching the CSSC, and
Y4 = 168 = Estimated average consumptive use.

The second step is to prescribe the error distribution and associated statistical descriptors such as mean and standard deviation. Two different types of error distributions were proposed. A normal distribution was prescribed for most flow components. However, a log-normal distribution was prescribed for components that are relatively small in magnitude, such as diversion upstream from the Romeoville gage, but have a large standard deviation.

By assuming that the independent variables in each model are not correlated, the following models for uncertainty in the annual diversion were expressed for each accounting method as follows based on the first-order variance method:

$Var(D_R) = Var(X1) + Var(X2) + Var(X3) + Var(X4) + Var(X5) + Var(X6) + Var(X7)$

$Var(D_L) = Var(Y1) + Var(Y2) + Var(Y3) + Var(Y4)$

In which "Var" is the variance of the prescribed flow component, the square root of which represents the standard deviation. The first-order variance analysis essentially was applied by the Committee in its analysis of the uncertainty in the Romeoville and Lakefront Accounting Systems as discussed in Section 5.5.

The third step in the Monte-Carlo simulation is to calculate hypothetical outcomes for literally thousands of randomly selected outcomes for each component in the model. The fourth step is to statistically summarize the results of all the simulated outcomes (i.e. hypothetical annual diversions) to describe the variability (i.e. uncertainty) in the results.

The USACE described a very preliminary application of Monte-Carlo simulation for the diversion quantities calculated for WYs 1997 through 1999 for discussions purposes only. The parameters assigned for the modeling were assumed in many instances or based on data that were deemed provisional. As such, no formal results of analysis are available for discussion. However, the Committee was asked for comments regarding the approach.

The Fifth Technical Committee offers the following in regards to the proposed method for evaluating the uncertainty of diversions calculated using the Romeoville and Lakefront Accounting procedures.

- The overall approach of using Monte-Carlo simulation to characterize uncertainty is sound and technically defensible. It is consistent with "current best engineering practice." The Palisade software is commercially available and is well documented. The Fifth Technical Committee did not, however, run any tests to verify its capability. However, Committee member C.S. Melching assisted the USACE in the original Monte Carlo analysis of Romeoville and Lakefront Accounting using @RISK in the Lakefront Accounting technical analysis (U.S. Army Corps of Engineers, 1996), and found that the software appeared to be working properly.

- The first-order variance method is an appropriate means of characterizing the uncertainty of a sum of linear functions. However, the assumption that the various independent variables are not correlated is not entirely appropriate. The most notable example is the terms Y2 and Y4 which represent the pumpage for water supply and consumptive use, respectively. Clearly these two parameters are correlated. The degree to which other terms are correlated could be examined by evaluating the components published in previous annual diversion reports.

- Although the runoff and consumptive use terms in the Lakefront Accounting model (Y3 and Y4) are fixed, it is appropriate to assign a variance to these components. They are recognized as estimates of long-term averages, hence it is appropriate to expect an uncertainty. Three approaches to considering the uncertainty in runoff were developed by the Committee and applied in the comparison of the uncertainty in the Romeoville and Lakefront Accounting Systems described in Section 5.5. Consumptive use has been assumed to be 10 percent of pumpage; however, there are indications it could be higher. A standard deviation of 30 percent would not seem unreasonable to assume.

- Uncertainty should be viewed as just one factor in the consideration of which accounting method to use for calculating annual diversion. There are other factors such as the number of primary flow-monitoring locations to maintain, quality assurance/quality control, and overall cost to consider as well.

5.5 COMPARISON OF UNCERTAINTY IN LAKEFRONT AND ROMEOVILLE ACCOUNTING

The two accounting methods report accounting values that are conceptually different and incorporate different averaging periods, which makes a direct comparison of the two procedures difficult. Romeoville Accounting involves measurement of the total flow leaving the diverted Lake Michigan watershed and then adjusting this value for flows that bypass the Romeoville site and for flows that pass Romeoville but are not part of the accountable flow (approximately 8 and 10.5 percent of the diverted flow, respectively). The primary value for Romeoville Accouting is a 40-year running average of the annual diverted flows.

Lakefront Accounting involves measurement of all flows diverted out of Lake Michigan—specifically water-supply pumpage from the lake and open-channel flow past three diversion measurement locations, the North Shore Channel at Maple Avenue in Wilmette, the Chicago River at Columbus Drive, and the Calumet River at O'Brien Lock and Dam. Runoff from the diverted Lake Michigan watershed is set by the Memorandum of Understanding to 800 cfs and a credit for consumptive use is set by the Memorandum of Understanding to 168 cfs. The primary value for Lakefront accounting is a 5-year running average of the annual diverted flows.

One of the problems with comparing diversion flows from Romeoville and Lakefront Accounting is how to address the uncertainty of runoff from the diverted Lake Michigan watershed and the consumptive use. One possible approach is to treat these as deterministic values. Since these have been set by the Memorandum of Understanding, one can argue that these are fixed values with no variabilty. This would effectively remove runoff from the diverted Lake Michigan watershed and the consumptive use from the accounting and change the diversion limit to 2,568 cfs diverted from Lake Michigan. Hence, the uncertainty in the accounting is only the uncertainty in the measurements at the diversion points.

If, on the other hand, the intent is to maintain the existing diversion limit of 3,200 cfs, including runoff from the diverted Lake Michigan watershed, the variability introduced by approximating the runoff and consumptive use by fixed values also needs to be addressed. This variability needs to include the year-to-year variability about long-term average runoff and consumptive use, the uncertainty in the long-term averages, and any trends in the long-term averages. It would appear from the language in the draft proposed decree (No. 3 dated January 17, 2001) that at least runoff is acknowledged to be variable, as 800 cfs is identified in paragraph 3(b)iii of this draft as an "estimate."

For a simple first approximation of uncertainty/error in the Accounting Systems, it can be assumed that the variability of each component of the Accounting Systems can be represented by a normal distribution. For the sum (Z) of independent normally distributed random variables (A, B, C, ...):

Z = A + B + C + ... + n

where n is the number of independent random variables and subtractions can be represented as C = -C1, for example, the variance of Z can be computed as the square root of the sum of squared standard deviations of each of the variables in the summation:

$Var(Z) = (S_A^2 + S_B^2 + S_C^2 + ... + S_n^2)^{½}$

where S_i is the standard deviation of variable i, which can be computed as the mean value of variable i times its coefficient of variation (COV).

In order to compute the total variance for each Accounting System it is necessary to estimate the standard deviation or COV of each component of the Accounting Systems. The determination of these COVs and the application of the uncertainty analysis to the Romeoville and Lakefront Accounting Systems are discussed in the following sections.

5.5.1 Romeoville Accounting

Accounting for diversion of water from Lake Michigan currently is based on calculation of the diverted water leaving the CSSC at Lockport, Illinois. Since 1984, the USGS has operated an acoustic velocity meter (AVM) measuring the flow in the CSSC at Romeoville, IL. This station historically accounts for about 92 to 97 percent of the total accountable diversion. However, this gage also measures flows that are not part of the accountable diversion. These include: (1) groundwater pumpage discharged into the CSSC or its tributary channels (**GW**); (2) water-supply pumpage from Indiana reaching the CSSC (**IN**); (3) runoff from the Des Plaines River watershed that reaches the CSSC (**DES**); and (4) Lake Michigan pumpage by Federal facilities that reaches the CSSC (**FED**). All of these values need to be determined and deducted from the flow measured at Romeoville to determine the total accountable diversion. In addition, some of the domestic pumpage from Lake Michigan is discharged to streams that bypass the gage at Romeoville. This includes water that discharges from wastewater treatment facilities that do not discharge to the CSSC (**WWTF**) and the sanitary portion of combined sewer overflows attributable to Lake Michigan domestic water supply that does not discharge to the CSSC (**CSO**). Furthermore, some water is diverted (**DIV**) from the CSSC upstream from the Romeoville gage. These values need to be determined and added to the flow measured at Romeoville to determine the total accountable diversion. Hence, the diversion-accounting flow (**DA**) for the current (Romeoville) Accounting System can be described mathematically as:

$DA = ROM + WWTF + CSO + DIV - (GW + IN + DES + FED)$

Where **ROM** is the annual mean discharge measured by the Romeoville AVM. The coefficient of variation for annual flows for the Romeoville AVM record is 0.04 (4 percent). The results of the USGS analysis of the uncertainty in the AVM flow measurements (Duncker et al., 2004) summarized in Table 5.2-a indicate that the error in annual flows for the Romeoville gage is on the order of 2.1 to 2.2 percent. While not criticizing the USGS analysis, the Committee was reluctant to conclude such a small error for an acoustic device that samples a portion of the flow rated on the basis of measurements from another acoustic device that samples a larger portion of the flow. Achievement of 2 percent error would seem to require everything to be operating at the highest quality nearly all the time. Thus, the 4 percent was chosen as a conservative value by the Committee for the analysis.

The additions and deductions are determined by several methods that are clearly documented in the annual accounting reports and the reports of the Fourth Technical Committee. The following is a brief summary of how these are obtained and how the uncertainties in these values were estimated.

WWTF discharges that do not discharge to the CSSC are considered as equal to the metered domestic supply of Lake Michigan water to communities served by WWTFs that do not discharge to the CSSC or its tributaries. Since these are based on metering of water-supply pumpage, the uncertainty is estimated using a coefficient of variation of 0.03 (3 percent) based on results of an analysis of domestic water supply metering done in Section 5.3.

CSOs attributable to Lake Michigan domestic water supply that does not discharge to the CSSC are based on simulations of the rainfall-runoff and sewer-flow hydraulics for areas that are (a) served by combined sewers that do not discharge to the CSSC or its tributaries; (b) receive water supply from Lake Michigan; and (c) are not already accounted for by the **WWTF** value. The uncertainty in this value is estimated using a coefficient of variation of 0.10 (10 percent), which is based on an estimate of the uncertainty in the runoff modeling described in Section 5.5.2.

GW pumpage discharged into the CSSC or its tributary channels consists of two parts. The first is groundwwater pumpage whose effluent is discharged into the CSSC or its tributaries. This is determined from meter and pumpage records; however, the accuracy of the groundwater pumpage records is not as high as that for the Lake Michigan pumpage. Thus, a 0.10 (10 percent) coefficient of variation was assumed for the groundwater pumpage. The second component is groundwater seepage into the TARP system. This is determined based on hydrologic and hydraulic modeling of the TARP tunnels. Therefore, the uncertainty in this value is estimated using a coefficient of variation of 0.10 (10 percent), which is based on an estimate of the uncertainty in the runoff modeling (see Section 5.5.2). Allocation of GW among these two components was done based on data supplied in the annual diversion accounting reports for WYs 1997-1999 (U.S. Army Corps of Engineers, 2001b and 2004, respectively) in Table 5.5-a (all values in cfs):

Table 5.5-a: Allocation of Groundwater

Component of Groundwater, Column 4	1997	1998	1999
Groundwater pumpage for domestic water supply	33.2	27.3	26.5
Groundwater infiltration to the TARP tunnels	58.7	71.4	91.3

Water-supply pumpage from Indiana reaching the CSSC is determined partly from meter and pumpage records (Grand Calumet River) and partly from gage records. These flows represent between 1 and 2 percent of the diversion-accounting flow and less than ½ percent of the variance. Thus, any change in the comparison of uncertainty between Romeoville and Lakefront Accounting from a rigorous calculation of the coefficient of variation for these flows is expected to be negligibly small. Therefore the uncertainty in these flow was estimated using a coefficient of variation of 0.10 (10 percent), which is the same as the accuracy for hydrologic simulation.

Runoff from the Des Plaines River watershed that reaches the CSSC is determined from hydrologic simulation. Hence, the uncertainty in this value is estimated using a coefficient of variation of 0.10 (10 percent), which is based on an estimate of the uncertainty in the runoff modeling (see Section 5.5.2).

Lake Michigan pumpage by Federal facilities that reaches the CSSC is determined from pumpage and sluice-gate records. Therefore, the uncertainty is estimated using a coefficient of variation of 0.03 (3 percent) based on results of an analysis of domestic water supply metering done in Section 5.3.

5.5.2 Lakefront Accounting

Lakefront Accounting is based on measurement of the water diverted from Lake Michigan and pre-determined values to account for the runoff from the diverted Lake Michigan Watershed (an addition) and the consumptive use of domestic water-supply pumpage (a deduction). Water diverted from Lake Michigan may be either by pumpage for domestic water supply or in the channels of the Chicago Waterway. The amount of water leaving Lake Michigan by means of the channels of the Chicago Waterway is measured by USGS gaging stations on the Chicago River at Columbus Drive, the Calumet River at O'Brien Lock and Dam, and the North Shore Channel at Maple Avenue in Wilmette. The diversion-accounting flow based on Lakefront Accounting can be defined mathematically as:

$$DA = WS - CU + R + DD$$

where **WS** is water-supply pumpage, **CU** is consumptive use, **R** is runoff from the diverted watershed, and **DD** is direct diversion from Lake Michigan. The domestic-supply pumpage is determined based on meters at the various water-treatment facilities and pumping stations. The uncertainties in the direct diversion measurements have been estimated in Table 5.5-b on the basis of Duncker et al. (2004) and uncertainties in water-supply pumpage were estimated on the basis of the review of water-supply pumpage errors presented in Section 5.3.

Table 5.5-b: Coefficient of Variation for Lakefront Accounting

Site/Component	Coefficient of variation (percent)*
Columbus Ave AVM	18
O'Brien AVM	24
Wilmette AVM	47
Domestic water-supply pumpage	3

*Statistics for AVMs based on averages for water years 1997 thorugh 1999.

Consumptive use is very difficult to isolate and determine based on the complexity of the system and the difficulty and expense in obtaining field measurements. This value has been fixed at 168 cfs based on the mediation agreement. The coefficient of variation is assumed to be 30 percent, based on a preliminary uncertainty analysis of the Lakefront Accounting done by the U.S.Army Corps of Engineers (1996).

The runoff from the diverted Lake Michigan watershed has been fixed at a value of 800 cfs by the mediation agreement. This is based primarily on simulation of a 44-year (1951-1994) period and sensitivity analyses of the model results. Description of the modeling and other analyses that led to adoption of this value are presented by the U.S. Army Corps of Engineers (1996). These results include comparisons of the simulated runoff and runoff determined from the approved accounting reports for the period 1983 through 1992 and simulated annual runoff for the period 1951-1994. These are used below to estimate the uncertainty in the yearly computation of total diversion resulting from natural year-to-year variability in the runoff relative to the constant 800 cfs of runoff used for Lakefront Accounting.

The uncertainty in the runoff used for Lakefront Accounting comprises several components and may be viewed in three different ways.

1. One way is to consider the uncertainty in the diversion, diversion-accounting flow (DA) for a given year using natural year-to-year variability in simulated runoff as the measure of the runoff uncertainty for a given year. The value of 800 cfs represents an estimate of the long-term mean-annual discharge from the diverted watershed. However, the actual runoff in any given year may deviate significantly from this value based on hydrologic conditions in the watershed and precipitation across the watershed. This year-to-year deviation can be termed the '**natural variability**.' The magnitude of the natural variability was estimated from the standard deviation of the values from the 44-year simulation (219 cfs) about the mean value (785 cfs). The result of the uncertainty calculation using this assumption is listed as Lakefront Accounting "standard deviation-natural variability" in Tables 5.5-c to 5.5-f.

2. The Fifth Technical Committee believes that a fair comparison between the two Accounting Systems is a comparison of the conceptual basis behind each method on an annual basis. That is, consideration of the uncertainty in the computed runoff for each year in addition to the uncertainty in the water supply pumpage and direct diversions when evaluating the Lakefront Accounting System. If on a year-by-year basis the two

accounting systems have similar uncertainty, then over a 40-year period they also will have similar uncertainty. In order to use this approach an estimate of the model error in estimating annual runoff must be evaluated. Any model prediction is subject to errors from a variety of sources, such as: (a) how 'correctly' the mathematical representation in the model simulates the actual physical processes; (b) errors in the parameters and coefficients used as input to the model; (c) errors in the data used as input to the model; and (d) numerical errors (e.g., truncation, roundoff, etc.) in the model. Experience with the application of the model to the diversion accounting is used to estimate the COV of computed annual runoff.

In the year-to-year comparison of the two Accounting Systems, the COV in the computed runoff in the Lakefront Accounting and the Des Plaines runoff in the Romeoville Accounting were taken as 10-percent. This selection is based on the accuracy achieved in the simulation of annual flows during the original calibration and verification of the LANDS model (a forerunner of the currently applied Hydrological Simulation Program–Fortran, HSPF). The LANDS model was calibrated to 5 years of flow data (WYs 1965-1969) at 4 streamflow gages in the North Branch Chicago River Basin–West Fork of the North Branch at Northbrook, North Branch Chicago River at Deerfield, Skokie River at Lake Forest, and North Branch Chicago River at Niles–and at 2 streamflow gages in the Little Calumet River Basin–Thorn Creek at Thornton and Little Calumet River at South Holland–and to 2 years of flow data (WYs 1968-1969) for the Skokie River near Highland Park (Hydrocomp, 1977c and d). The LANDS model then was verified for 5 years of flow data (WYs 1970-1974) at all of these sites. In total, errors in the estimation of 67 years of flows at seven sites were evaluated in the original calibration/verification of LANDS. These errors were found to be normally distributed with a mean of 0.975 percent, a standard deviation of 11.4 percent, and an average of the absolute values of the errors of 8.77 percent. Hey et al. (1980) slightly improved the original calibration, however, they only reported the improvements in the overall and monthly simulations, the annual summaries were not reported. Thus, the final calibration may have had a standard deviation of annual errors less than 10 percent.

The transposition of the calibration/verification errors in annual mean flow estimates to the runoff simulations in the Accounting Systems has some potential flaws that are discussed here.

A. The parameters of the LANDS and HSPF models that have been applied to the ungaged, diverted Chicago, Calumet, and Des Plaines River watersheds have been transferred and modified from the calibrations on the gaged Little Calumet River and North Branch Chicago River Basins using the regional parameter sets concept first proposed by Lumb and James (1976). It is reasonable to assume that the model uncertainty is somewhat higher on watersheds using transferred parameters compared to the original calibration watersheds. However, experience in the Chicago area, i.e. Lake County (Duncker et al., 1996), among other locations around the country indicates flow estimation accuracy on watersheds using transferred parameters is only slightly poorer than on the original calibration watersheds. Further, the flow comparisons at the water reclamation plants generally show errors in annual flows less than 5 percent. Indicating that the transferred parameters appear to be yielding reasonable results.

B. The original sample of 67 errors in annual runoff simulations does not include independent errors because some gages are downstream of other gages and neighboring sites are used for the same period. On the other hand, Donigian et al. (1984) reported that a good calibration of HSPF should have errors in the annual mean flow of 10 percent or less. Given that HSPF appears to be well calibrated to the calibration watersheds and appears to work acceptably (although more study is necessary to verify this as discussed in detail in Section 4) for the ungaged watersheds, a 10 percent COV seems reasonable.

C. Finally, for the Computed Runoff in the Lakefront Accounting System, runoff from 305 of the 673 mi^2 of diverted watershed is determined from USGS streamflow measurements on the North Branch Chicago River at Niles (drainage area = 100 mi^2) and Little Calumet River at South Holland (drainage area = 205 mi^2) each adjusted to remove wastewater flows. The daily discharge values at these gages are rated as good except for those in winter which are rated as poor. The USGS streamflow rating system is as follows (Rantz et al., 1982a):

Excellent = about 95 percent of the daily discharges are within 5 percent of the true value.
Good = within 10 percent
Fair = within 15 percent
Poor = less than fair accuracy

For normally distributed variables the 95 percent confidence limits approximately equal the two standard deviation confidence intervals. Thus, USGS "good" daily flow estimates have an error COV of about 5 percent, and "poor" daily flow estimates have an error COV of around 10 percent. Considering the calibration accuracy of LANDS/HSPF and the measurement accuracy at the USGS gages, a COV of 10 percent for the computed runoff values seems reasonable.

The result of the uncertainty calculation using this assumption is listed as Lakefront Accounting "standard deviation-model error" in Tables 5.5-c to 5.5-f.

3. The third approach to dealing with the uncertainty in the runoff term in the Lakefront Accounting is to consider it to be completely deterministic, and also to consider the consumptive use term to be completely deterministic. In this case only the uncertainty in the domestic pumpage and the direct diversions (measured at Columbus Drive, O'Brien Lock and Dam, and Maple Avenue in Wilmette). The resulting computed uncertainty then is compared to the computed diversion relative to the 2,568 cfs limit to determine the COV of the Lakefront Accounting for comparison with the COV for the Romeoville Accounting. The result of the uncertainty calculation using this assumption is listed as Lakefront Accounting "Standard deviation when runoff and consumptive use are deterministic" in Tables 5.5-c to 5.5-f.

5.5.3 Comparison of Uncertainty Between Lakefront and Romeoville Accounting

Tables 5.5-c to 5.5-e provide a summary of the estimated uncertainties in the diversion-accounting flows based on Romeoville and Lakefront Accounting for WYs 1997 through 1999. The estimated uncertainties in diversion-accounting flows based on Romeoville Accounting were

131, 126, and 120 cfs for WYs 1997, 1998, and 1999, respectively. These correspond to coefficients of variation of 4.2, 4.1, and 4.1 percent, respectively.

The estimated uncertainties in diversion-accounting flows based on Lakefront Accounting using natural year-to-year variabilities are 253, 247, and 238 cfs for WYs 1997, 1998, and 1999, respectively. These correspond to coefficients of variation of 8.0, 8.1, and 8.4 percent, respectively. The estimated uncertainties in diversion-accounting flows based on Lakefront Accounting using the estimated model error are 150, 139, and 121 cfs for WYs 1997, 1998, and 1999, respectively. These correspond to coefficients of variation of 4.8, 4.6, and 4.4 percent, respectively. Finally, if the runoff from the diverted Lake Michigan watershed and the consumptive use are treated as fixed and invariant, the estimated uncertainty in diversion-accounting flows based on Lakefront Accounting is 117, 103, and 78 cfs for WYs 1997, 1998, and 1999, respectively. When estimating the coefficient of variation for these flows, it is appropriate to consider the variation about the measured diversion rather than about the value adjusted for runoff and consumptive use. These correspond to coefficients of variation of 4.6, 4.2, and 3.6 percent, respectively.

The comparison of the Lakefront Accounting concept using the model error and the Romeoville Accounting shows that the Romeoville Accounting System has slightly less uncertainty (about 10 percent smaller total COV) than the Lakefront Accounting System because of the low uncertainty of the Romeoville Acoustic Velocity Meter. The comparison of the Lakefront Accounting System considering the runoff and consumptive use as deterministic shows that the two systems have similar uncertainty (i.e. differences equal to ±10 percent). The relatively small difference in uncertainty between the two Accounting Systems indicates that for practical purposes they have equivalent uncertainty, and, thus, neither of these Accounting Systems can be rejected on the basis of unacceptable uncertainty.

5.5.4 Comparison over Averaging Periods

The uncertainties previously described can reasonably be treated as unbiased or randomly distributed about the true value for that parameter. As a result, when multiple years of calculated diversion flows are averaged together, the uncertainties will decrease in proportion to the square root of the number of years that are averaged. Thus, for an identical averaging period, the decrease in the uncertainty will be the same for either accounting method, and, therefore, the relative magnitude of the uncertainty from different accounting methods will remain unchanged. However, since Lakefront Accounting is based on a 5-year moving average and Romeoville Accounting is based on a 40-year moving average, the relative magnitude of the uncertainty in the final accountable flows will differ significantly from the relative magnitude of the annual values.

To illustrate the effect of averaging periods on uncertainties in diversion accounting, average annual values for the input values for each accounting method (e.g., Columbus Drive, O'Brien Lock and Dam, Romeoville, and Wilmette flows; water-supply pumpage, other additions and subtractions) from 1997 through 1999 were used, along with the coefficient of variation for each of these values, to estimate the annual diversion flow and associated uncertainty for this period (Table 5.5-f). Table 5.5-g shows the uncertainties in diversion flows estimated by treating the values from Table 5.5-f as representative and determining the resulting uncertainties for 5-year and 40-year averaging periods. While actual accounting flows and associated uncertainties will deviate from these values because of dynamic conditions in the watershed, these values provide a reasonable estimate of the relative magnitudes of the uncertainties in the diversion flows. Lakefront Accounting, when the runoff and consumptive use are treated as fixed and invariant, results in smaller uncertainties in annual diversion flows and for a constant averaging period than

Romeoville Accounting. However, when the different averaging periods are taken into consideration (i.e. 5-year period for Lakefront Accounting and 40-year period for Romeoville Accounting), the uncertainties in accountable, long-term average flows based on Romeoville Accounting are smaller than those from Lakefront Accounting, even if the runoff and consumptive use do not contribute to the uncertainty.

Table 5.5-c: Summary of components of diversion accounting and associated uncertainties for Romeoville and Lakefront Accounting for Water Year 1997.

Romeoville Accounting

Component	Value (cfs)	Standard deviation (cfs)	Coefficient of variation (percent)	Variance	Percent of Variance from this component
Romeoville AVM	3,230.9		4.0	16,701.9	97.2
Additions					
Pumpage not discharged to canal	234.4				
Water supply to communities that do not discharge to CSSC	232.9		3.0	48.8	0.3
CSO overflows from domestic water supply	1.5		10.0	0.0	0.0
Diversions above gage	2.5		10.0	0.1	0.0
Subtractions					
GW pumpage discharged into CSSC	91.9			0.0	0.0
Water Supply Pumpage	33.2		10.0	11.0	0.0
Seepage Into TARP	58.7		10.0	34.5	0.2
Water Supply from Indiana	65.6		10.0	43.0	0.3
Runoff from Des Plaines watershed discharged into CSSC	189.3		10.0	358.3	2.1
Pumpage by Federal Facilities	6.8		3.0	0.0	0.0
Total	**3,111.7**		**Variance:**	**17,197.7**	**100.0**
Standard deviation:				**131.1**	

Lakefront Accounting

Component	Value (cfs)	Standard deviation (cfs)	Coefficient of variation (percent)	Variance	Percent of Variance from this component
Columbus AVM	464		18.0	6,976	10.9
O'Brien AVM	238		24.0	3,263	5.1
Wilmette AVM	48		47.0	509.0	0.8
Domestic Pumpage	1,774		3.0	2,832	4.4
Total Measured Diversion[1]	**2,524**		**Variance:**	**13,580**	
Fixed Values with Natural Variability					
Runoff	800	219.0		47,961.0	74.8
Consumptive Use	168		30.0	2,540.2	4.0
Total Diversion[2] – Natural Variability	**3,156**		**Variance:**	**64,081**	**100.0**
Actual Values for 1997 with Estimated Variability					
Runoff	776.6		10.0	6,031	
Consumptive Use	177.4		30.0	2,832	
Total Diversion[3] – Actual Values	**3,123.2**		**Variance:**	**22,443**	
Standard Deviation[3] – Fixed Values with Natural Variability				253	
Standard Deviation[3] – Actual Values with Model Error Variability				150	
Standard Deviation[3] - Runoff and Consumptive Use are Deterministic				117	

[1] Consumptive Use and Runoff are deterministic with zero variance; Total Diversion equals Total Measured Diversion.
[2] Total Diversion is sum of Total Measured Diversion, Runoff, and Consumptive Use.
[3] Square root of the total variance listed for the approach.

Table 5.5-d: Summary of components of diversion accounting and associated uncertainties for Romeoville and Lakefront Accounting for Water Year 1998.

Romeoville Accounting

Component	Value (cfs)	Standard deviation (cfs)	Coefficient of variation (percent)	Variance	Percent of Variance from this component
Romeoville AVM	3,119.6		4.0	15,571.0	97.5
Additions					
Pumpage not discharged to canal	255				
Water supply to communities that do not discharge to CSSC	253.5		3.0	57.8	0.4
CSO overflows from domestic water supply	1.5		10.0	0.0	0.0
Diversions above gage	2.4		10.0	0.1	0.0
Subtractions					
GW pumpage discharged into CSSC	98.4			0.0	0.0
Water Supply Pumpage	27.3		10.0	7.5	0.0
Seepage Into TARP	71.4		10.0	51.0	0.3
Water Supply from Indiana	59.1		10.0	34.9	0.2
Runoff from Des Plaines watershed discharged into CSSC	158.7		14.0	493.6	1.6
Pumpage by Federal Facilities	1.1		3.0	0.0	0.0
Total	**3,057.3**		**Variance:**	**15,974.2**	**100.0**
Standard deviation:				**126.4**	

Lakefront Accounting

Component	Value (cfs)	Standard deviation (cfs)	Coefficient of variation (percent)	Variance	Percent of Variance from this component
Columbus AVM	357		18.0	4,129	6.8
O'Brien AVM	225		24.0	2,916	4.8
Wilmette AVM	50		47.0	552	0.9
Domestic Pumpage	1,800		3.0	2,916	4.8
Total Measured Diversion[1]	**2,432**		**Variance:**	**10,514**	
Fixed Values with Natural Variability					
Runoff	800	219.0		47,961	78.6
Consumptive Use	168		30.0	2,540	4.2
Total Diversion[2] - Natural Variability	**3,064**		**Variance:**	**61,015**	**100.0**
Actual Values for 1998 with Estimated Variability					
Runoff	773.6		10.0	5,985	
Consumptive Use	180.0		30.0	2,916	
Total Diversion[2] - Actual Values	**3,025.6**		**Variance**	**19,414**	

Standard Deviation[3] – Fixed Values with Natural Variability	247
Standard Deviation[3] – Actual Values with Model Error Variability	139
Standard Deviation[3] – Runoff and Consumptive Use are Deterministic	103

[1] Consumptive Use and Runoff are deterministic with zero variance; Total Diversion equals Total Measured Diversion.
[2] Total Diversion equals sum of Total Measured Diversion, Runoff, and Consumptive Use.
[3] Square root of the total variance listed for the approach.

Table 5.5-e: Summary of components of diversion accounting and associated uncertainties for Romeoville and Lakefront Accounting for Water Year 1999.

Romeoville Accounting

Component	Value (cfs)	Standard deviation (cfs)	Coefficient of variation (percent)	Variance	Percent of Variance from this component
Romeoville AVM	2,944.5		4.0	13,872.1	97.2
Additions					
Pumpage not discharged to canal	261.7				
Water supply to communities that do not discharge to CSSC	260.2		3.0	60.9	0.4
CSO overflows from domestic water supply	1.5		10.0	0.0	0.0
Diversions above gage	2.6		10.0	0.1	0.0
Subtractions					
GW pumpage discharged into CSSC	107.4			0.0	0.0
Water Supply Pumpage	26.5		10.0	7.0	0.0
Seepage Into TARP	91.3		10.0	83.4	0.6
Water Supply from Indiana	23.3		10.0	5.4	0.0
Runoff from Des Plaines watershed discharged into CSSC	156.9		10.0	246.2	1.7
Pumpage by Federal Facilities	1.4		3.0	0.0	0.0
Total	2,917.2		Variance:	14,275.1	100.0
Standard deviation:				119.5	

Lakefront Accounting

Component	Value (cfs)	Standard deviation (cfs)	Coefficient of variation (percent)	Variance	Percent of Variance from this component
Columbus AVM	201		18.0	1,309	2.3
O'Brien AVM	169		24.0	1,645	2.9
Wilmette AVM	38		47.0	318.5	0.6
Domestic Pumpage	1,783		3.0	2,862.3	5.1
Total Measured Diversion[1]	2,191		Variance:	6,134	
Fixed Values with Natural Variability					
Runoff	800	219.0		47,961	84.7
Consumptive Use	168		30.0	2,540	4.6
Total Diversion[2] **– Natural Variability**	**2,823**		**Variance:**	**56,635**	**100.0**
Actual Values for 1999 with Estimated Variability					
Runoff	759.0		10.0	5,761	
Consumptive Use	178.3		30.0	2,861	
Total Diversion[2] **– Actual Values**	**2,771.7**		**Variance:**	**14,756**	
Standard Deviation[3] **– Fixed Values with Natural Variability**				238	
Standard Deviation[3] **– Actual Values with Model Error Variability**				121	
Standard Deviation[3] **- Runoff and Consumptive Use are Deterministic**				78	

[1] Consumptive Use and Runoff are deterministic with zero variance; Total Diversion equals Total Measured Diversion.
[2] Total Diversion equals sum of Total Measured Diversion, Runoff, and Consumptive Use.
[3] Square root of the total variance listed for the approach.

Table 5.5-f: Summary of components of diversion accounting and associated uncertainties for Romeoville and Lakefront Accounting for mean annual conditions, 1997-1999.

Romeoville Accounting

Component	Value (cfs)	Standard deviation (cfs)	Coefficient of variation (percent)	Variance	Percent of Variance from this component
Romeoville AVM	3,098.3		4.0	15,359.5	97.3
Additions					
Pumpage not discharged to canal	250.4				
Water supply to communities that do not discharge to CSSC	248.9		3.0	55.7	0.4
CSO overflows from domestic water supply	1.5		10.0	0.0	0.0
Diversions above gage	2.5		10.0	0.1	0.0
Subtractions					
GW pumpage discharged into CSSC	102.8				
Water Supply Pumpage	29.0		10.0	8.4	0.0
Seepage Into TARP	73.8		10.0	54.5	0.3
Water Supply from Indiana	49.3		10.0	24.3	0.2
Runoff from Des Plaines watershed discharged into CSSC	168.3		10.0	283.2	1.8
Pumpage by Federal Facilities	3.1		3.0	0.0	0.0
Total	**3,027.7**		**Variance:**	**15,785.7**	**100.0**
Standard deviation:				125.6	
Lakefront Accounting					
Columbus AVM	340.7		18.0	3,760	6.3
O'Brien AVM	210.7		24.0	2,556	4.3
Wilmette AVM	45.3		47.0	454	0.8
Domestic Pumpage	1,786		3.0	2,870	4.8
Total Measured Diversion[1]	**2,382**			**9,640**	
Fixed Values with Natural Variability					
Runoff	800	219.0		47,961	79.7
Consumptive Use	168		30.0	2,540	4.2
Total Diversion[2] – Natural Variability	**3,014**		**Variance:**	**60,141**	**100.0**
Actual Values with Estimated Variability					
Runoff	770		10.0	5,925	
Consumptive Use	179		30.0	2,870	
Total Diversion[2] – Actual Values	**2,974**		**Variance:**	**18,435**	
Standard Deviation - natural variability				245	
Standard Deviation – model error				136	
Standard Deviation when Runoff and Consumptive Use are Deterministic				98	

[1] Consumptive Use and Runoff are deterministic with zero variance; Total Diversion equals Total Measured Diversion.
[2] Total Diversion equals sum of Total Measured Diversion, Runoff, and Consumptive Use.

[3] Square root of the total variance listed for the approach

Table 5.5-g: Estimated uncertainties (in cfs) in diversion-accounting flows for 5-year and 40-year averaging periods.

Accounting method	5-year average	40-year average
Romeoville	56.2	19.9
Lakefront—Runoff and Consumptive Use Natural Variability	110	38.7
Lakefront—Runoff and Consumptive Use Model Error	60.8	21.5
Lakefront—Runoff and Consumptive Use Fixed and Invariant	43.8	15.5

6.0 FLOW MEASUREMENT

6.1 OVERVIEW

The Fourth Technical Committee critically examined every element of the Romeoville and Lakefront Accounting Systems. Since that review was completed in 2001, there has been no change in the components of the water budgets prepared using either system. There are no new sources or sinks of water that must be accounted for to characterize the diversion. In addition, the committee is not aware of any significant changes in the types of data collected or number of monitoring locations. Activities of the various data-collection agencies have focused on system and procedural upgrades to improve the accuracy and reliability of data. The progress made in improving the reliability of these measurements is reviewed in the following sections.

The following sections summarize the Committee's evaluation of the primary water-measurement activities that support the Romeoville and Lakefront Accounting Systems. Stream-gaging at sites equipped with acoustical velocity meters (AVMs) is discussed first, followed by a brief discussion of the conventional stream-gaging stations that support the H&H modeling. Two precipitation networks are the addressed, followed by a summary of the municipal water-supply pumpage that was discussed in Section 5.3. The concluding section is a summary of the overall evaluation. Figure 6.1-a illustrates the primary system of waterways and locations of the controlling works and locks that regulate the discharge of water throughout the system. The figure also illustrates the locations of the AVMs.

6.2 EVALUATION OF ACOUSTIC FLOW MONITORING ACTIVITIES

6.2.1 Chicago Sanitary and Ship Canal at Romeoville, IL

The USGS gaging station at Romeoville (Station No. 05536995) is the primary measuring location for Lake Michigan diversion accounting. The station is located immediately north of the Romeoville Road bridge on the east side of the canal, approximately 5 miles north of the Lockport Lock and Dam. Flow in the canal is very dynamic as it is regulated by the MWRDGC structures upstream and downstream primarily for navigation, power generation, and maintaining water quality. Flow is also affected by discharges from three water reclamation plants.

CSSC discharge is monitored using an AVM system, hence the gaging station is often referred to as the Romeoville AVM gage. The primary components of the gage currently are a 3-path Accusonic Model 7510 AVM, a ParaScientific PS-2 pressure transducer, a Campbell Scientific CR10 datalogger, and telephone telemetry. A SonTek Argonaut-SL (Side Looking) Acoustic Doppler Velocity Meter (ADVM) and Design Analysis H-350 stage sensor are installed as backup metering systems. The SonTek velocity meter and Design Analysis stage sensor were installed in 2000 and 2001, respectively.

A description of the gaging station and history of instrumentation are documented in a station description dated February 27, 2002 that was provided to the Committee by the USGS in January 2003. Station analyses prepared by the USGS do not indicate any serious equipment malfunctions during WYs 1997 through 1999, the accounting years the Committee was tasked with reviewing.

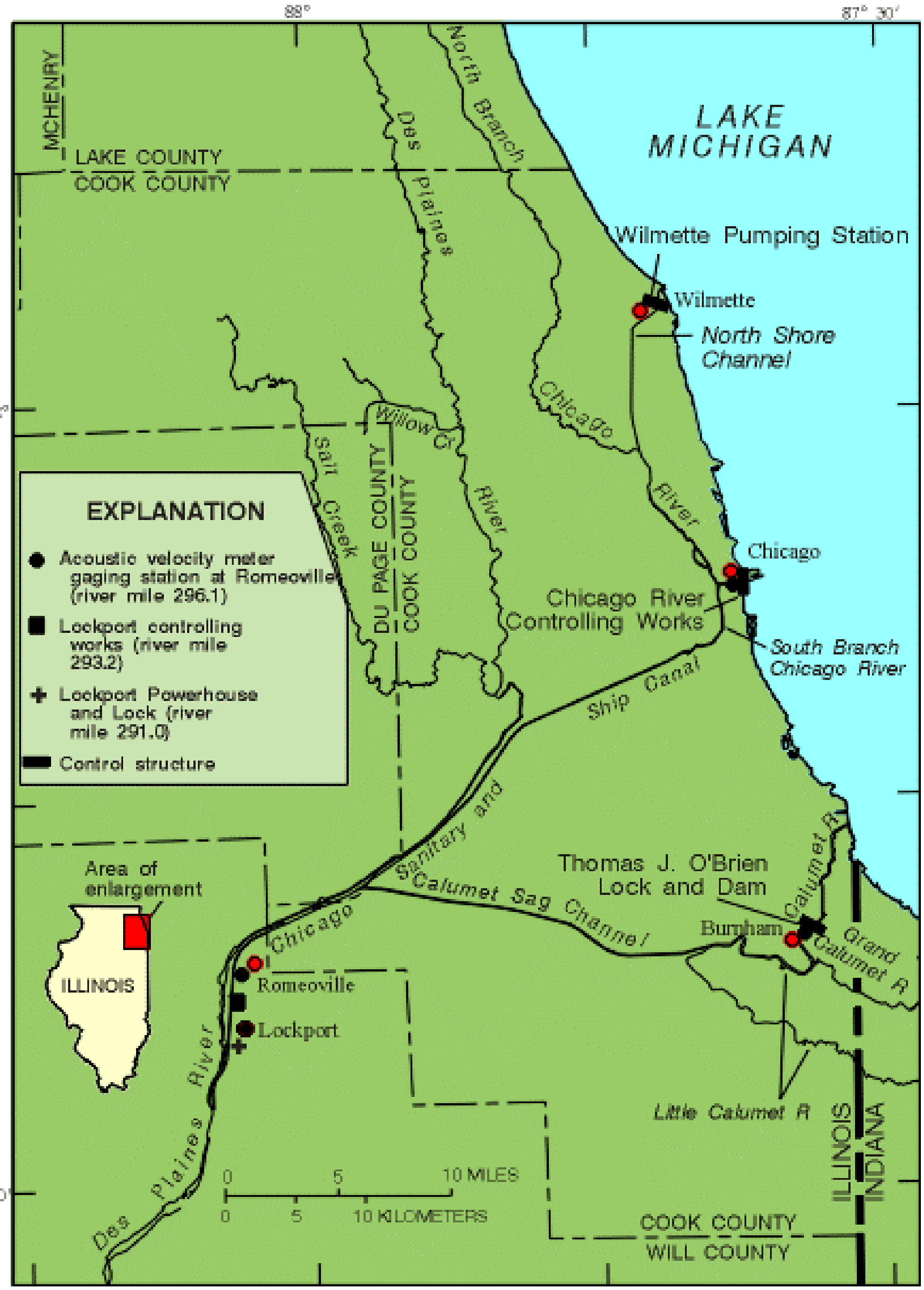


Figure 6.1-a: Location and primary elements of the Chicago Waterway System, controlling works, and Acoustic Velocity Meters maintained by the USGS.

[Source: USGS web site http://il.water.usgs.gov/proj/lmda/; AVM gages denoted by red dot]

Discharge is measured using an index-velocity approach (Rantz, 1982b) in which stage and an "index" velocity are continuously measured as predictor variables for cross-sectional flow area and average velocity, the product of which represents discharge. Field surveys are performed to establish the relationship between stage and channel cross-sectional area. Synoptic measurements of discharge are made at the Romeoville station using an RD Instruments Workhorse Acoustic Doppler Current Profiler (ADCP) concurrently with measurements of the index velocity and stage. The discharge measured using the ADCP is divided by the area associated with the stage at the time of the discharge measurement to determine an average flow velocity. This process is repeated for various flow conditions to establish a relationship between the index velocity and average velocity. The area and velocity relations are referred to herein as stage-area and index-velocity ratings.

A Quality Assurance Plan (QAP) for the Romeoville AVM system dated April 21, 1998 was made available to the Committee for review. The plan summarizes site specific procedures for gage inspections, discharge measurement, routine maintenance, data analysis, treatment of missing AVM record, and final record review. The QAP serves a very important purpose in that it summarizes procedures for standardization and documentation of streamflow records collected at the gage. Relative to conditions observed by the Technical Committee during visits in 2003, it is recommended that the QAP be updated to reflect current conditions.

The number of days of missing AVM record during WYs 1997 through 1999 totaled 42 days, or 3.8 percent of the 1,095-day period of record (Duncker et al., 2004, in review). The number of estimated days varied between 11 in 1997 and 17 in 1999.

During periods of missing AVM record at the Romeoville AVM gage, the discharge of the CSSC is “estimated” using regression equations to calculate the average daily flow at the Romeoville gage as a function of discharges reported by the MWRDGC from the downstream Lockport Powerhouse, Lock, and Controlling Works. The daily flows recorded by the MWRDGC are documented in the IDNR LMO-6 reports. The regression equations used to estimate discharge are described by Melching and Oberg (1993). The MWRDGC substituted turbine flow measured by AVMs in the turbine draft tubes for flows estimated from the turbine ratings on December 1, 1996 (the turbine AVM flows also had been reported for a brief period in 1994). Thus, when estimating missing record the turbine, lockage, and leakage flow is used without adjustment, whereas the powerhouse sluice gate and controlling works flows are modified as indicated in Melching and Oberg (1993).

The Fourth Technical Committee (Espey et al., 2001) offered several Recommendations and Findings (RF) regarding the Romeoville AVM gage that are re-visited below.

RF #10 reads “The total width measured by 59 ADCP Romeoville measurements from July 22, 1993 to October 24, 1995 averaged 2.1 percent less than the surveyed width of the cross section. It is recommended that the USGS investigate further to determine: (a) whether this error persists in more recent data; (b) whether this is an error in distance measurement or the result of ADCP compass errors; and (c) the effect of this on the discharge rating.”

The USGS responded that the 2.1-percent difference in width is accountable to the irregularity of the channel. In addition, ADCP measurements are now made using a “tethered-boat” (Rehmel and others, 2003), which is more accurately described as a miniature surf board. A tether is lowered from the Romeoville Road bridge to the left bank where the boogie board and ADCP are attached. The assemblage is then placed in the water and slowly towed from one side of the canal to the other to measure discharge. Care is being taken to start each measurement at nearly the same location. This has lead to more consistent measurements of width by the ADCP (J. Duncker, written commun., October 2003). Procedures observed during a field visit on

September 5, 2003 when a series of discharge measurements were made at the gage were made in manner consistent with quality-assurance procedures developed by the USGS (Lipscomb, 1995).

RF #11 reads "The regression analysis used to develop backup equations to estimate flows when the Romeoville AVM is not functioning properly should be repeated to develop new backup equations for periods when the turbine AVMs are the reported flows at Lockport"

The USGS responded (J. Duncker, written commun., October 2003) that updated regressions have not yet been developed, but that the USGS does plan to do so. Given the relatively small percentage (3.8 percent) of missing record reported for the Romeoville AVM gage during WYs 1997 through 1999, the reliability of the flow record published for this period is expected to have been only minimally affected by the uncertainty associated with the estimated record.

The station analysis for WY 2001 indicates that the Accusonic 7410 AVM stopped collecting data correctly on August 31, 2001. The system including transducers and mounting pipes were replaced with an Accusonic 7510 in October. This upgraded system was made operational on April 1, 2002. Path lengths were re-measured. The reported length of 239 ft is 1-percent longer than the 236-ft lengths reported for the previous installation. The daily discharge reported for the period from September 19, 2001 to March 31, 2002 was estimated based on the IDNR LMO-6 records provided by MWRDGC for the Lockport, Powerhouse, Lock and Controlling Works.

Two recommendations made by the Fourth Technical Committee (Espey et al., 2001) remain valid and should be addressed. The Committee recommends that the regression analysis used to develop the backup equations based on LMO-6 data reported for Lockport be repeated considering only those days when turbine AVMs, not turbine ratings, are used to measure turbine discharge. Furthermore, it is recommended that the USGS request from MWRDGC on an annual basis, written documentation of the days when the turbine rating is used.

Table 3 in the USGS draft uncertainty analysis of mean daily discharge during WYs 1997 through 1999 (Duncker et al., 2004, in review) indicates that 82 observations were used to define the index-velocity rating. A total of 59 measurements were available for review by the Fourth Technical Committee (Espey et al., 2001). Station analyses for WYs 2000 through 2000 indicate 11 series of ADCP measurements have been made subsequent to WY 1999. Station analyses prepared for WYs 1998 through 2002 indicate that measurements made during these years define a change in the coefficient of the index-velocity rating, but that additional ADCP measurements are needed to determine if the rating needs to be modified. During the 5-year period, 17 series of ADCP measurements were made.

The Committee recommends that the USGS re-evaluate the index-velocity rating at the Romeoville gage and, based on that evaluation, conclude whether a rating change is warranted or not. This is especially important considering the installation of the Accusonic 7510 AVM in 2001 and the different path configuration of this AVM versus that of the Accusonic 7410 AVM. Comparison of measured and estimated inflows (not including CSOs) to the CWS done by Shrestha and Melching (2003) for 8 periods between August 1, 1998 and July 31, 1999 indicated that the Accusonic 7410 AVM flows were 1.2-7.7 percent less than the total inflow. Whereas this same comparison done for 3 periods between April 1 and September 30, 2002, indicated that the Accusonic 7510 flows were 3.5-6.0 percent greater than the total inflow. This indicates a potential inconsistency between the two AVMs that may be related to the rating of the new AVM.

It is the conclusion of the Fifth Technical Committee that the Romeoville AVM system has been operated and maintained in a manner during the period of review that is consistent with best engineering practice and scientific knowledge.

6.3 ROMEOVILLE AVM SYSTEM RELOCATION

In April 2002, a $1.5 million electronic "dispersal barrier" was installed within the CSSC approximately 1,500-feet upstream from the Romeoville gage to deter the downstream migration of the round Goby into the Illinois River from Lake Michigan. The barrier became operational too late to halt the migration of the Goby, but now it is operated to deter the migration of the Asian Carp from the Illinois River to Lake Michigan. The barrier is composed of 13 electrified cables strung in an array across the bottom of the CSSC. The barrier is electrified to the extent that it deters but does not kill fish. For almost a year, the barrier appeared to have worked perfectly.

Wisconsin Sea Grant identified several events that demonstrate the need for a more robust system (www.seagrant.wisc.edu/outreach/nis/). In April 2003, one of the common carp tagged to test the effectiveness of the barrier made its way upstream from the barrier. Passage of the fish through the barrier was attributed to the passage of a barge through the array of cables. Field testing in December 2003 demonstrated that barges reduce the strength of the electrical field and that the effect of the field may be greatly diminished immediately adjacent to the barge hull. Last of all, the barrier malfunctioned for a short period of time during April 2003, thus, demonstrating the need for a second barrier array powered by an independent supply.

The USACE and State of Illinois are currently funding the design and construction of a second barrier. Staff from the Rock Island and Chicago USACE Districts, USGS, MWRDGC, University of Illinois, IDNR, Smith-Root, Inc., Illinois River Carriers' Association, Wisconsin Sea Grant, and Commonwealth Edison discussed the location for the second barrier array. After reviewing the river charts, identifying potential use conflicts and real estate needs, a location immediately upstream from the Romeoville gage was selected. In addition to the second electrified barrier, an acoustic "bubble array" barrier has been evaluated and remains a potential alternative backup system.

The Fifth Technical Committee was informed in August 2003 that the Romeoville AVM system would have to be relocated. The USGS briefed the Committee with regards to the influence the barriers might have on the ability to continue accurately measuring flows at the Romeoville AVM gage. The USGS documented through field study that the existing electrical barrier influences the internal compass of its ADCP. As reported by the Fourth Technical Committee (Espey et al., 2001) and RD Instruments (1996), compass error will not effect the magnitude of discharge measured by an ADCP using bottom tracking in lieu GPS (global positioning system) monitoring to track vessel position. Compass error will, however, interfere with the transit length measured by the ADCP. A bigger concern is the potential effect that a large electrical field could have on the submerged AVM transducer cables. Technical representatives for Accusonic could not guarantee that there would be no measurable effect on line velocities sensed by the existing array of transducers.

The Committee was further briefed in regards to a reconnaissance of three alternative sites by the USGS. Site characteristics were discussed with the Committee as were the pro's and con's of each site. Each site was then inspected in the field by the Committee and USGS. Based on the joint discussions and the field visit, the USGS concluded that an alternative site located 5.9 miles upstream from the Romeoville Road bridge would likely be a satisfactory location for an AVM system. The station would be located in the DuPage County Forest Preserve along the right bank on property owned by the MWRDGC. The CSSC at this section is straight, and there is evidence that the area is used infrequently by barges that temporarily moor along the banks.

The Committee concurs with the location recommended by the USGS. In addition, the committee recommends the following in regards to this matter.

1. Construct a new gaging station as soon as practicable using essentially the same monitoring equipment, including backup sensors, and configuration as are installed at the existing station.

2. Establish the necessary stage-area and index-velocity ratings at the new station as soon as practicable; prioritize the measurement of discharge at extreme conditions (high and low) as flow conditions will allow.

3. Continue to operate the existing Romeoville AVM system for as long possible to provide data that characterize the correlation of flows at the existing and new stations. If the fish barrier operation is found to not substantially affect the operation of the existing AVM (assuming the existing AVM can remain in place once the fish barrier is installed), the existing AVM should remain the primary gage of the Romeoville Accounting System.

4. Complete the necessary regression analyses to establish backup equations for calculating daily flows at the new station based on the flows reported by MWRDGC for the CSSC at Lockport.

5. Prepare a Quality Assurance Plan for the new station consistent with an updated edition for the existing station.

6.3.1 Chicago River at Columbus Drive at Chicago, IL

The USGS gaging station at Columbus Drive (Station No. 05536123) would be a primary measuring location if the Lakefront Accounting System is adopted because it measures the direct diversion of water from Lake Michigan through the Chicago River Controlling Works (CRCW) and any leakage through the control structures, breakwater, and nearby turning basin bulkhead. The station is located underneath the Columbus Drive Bridge, approximate 0.4-mi west of the Chicago River Controlling Works (CRCW) on the left (south) bank. Flow is very dynamic as it is regulated by the MWRDGC structures upstream and downstream from the gage.

Discharge is monitored using an AVM system installed during November 1996. The current primary components of the gage are a 4-path AFFRA Deltaflex AVM, a Design Analysis H-350 self-purging stage sensor, a Campbell Scientific CR10 datalogger, and telephone telemetry.

An upward looking RD Instruments 600 kHz Workhorse ADCP with real-time telemetry has been continuously deployed since May 2003 as a backup sensor. A stage sensor on the downstream (west) side of the Chicago River Lock is used as a backup for stage records. A string of 6 temperature probes were installed on the right bank in December 1999.

A description of the gaging station and history of instrumentation are documented in an undated station description that was provided to the Committee by the USGS in January 2003. The elevations of velocity paths described in the station analysis are out-of-date as the transducers were relocated to achieve more reliable readings.

Discharge is measured using an index-velocity approach similar to the Romeoville AVM gage. A field survey was performed on March 26, 1997 to establish a stage-area rating. Synoptic measurements of discharge are made using an ADCP deployed on a tethered boat. A tether suspended from the Columbus Drive bridge is lowered to the right bank where the tethered-boat with ADCP are attached. The assemblage is then placed in the water and discharge is measured by slowly towing the boat from one side of the channel to the other. The station description indicates that a quality-assurance plan has been developed for the station.

The Fourth Technical Committee extensively reviewed the variability of velocity measured using acoustic velocity meters at this site. ADCP measurements have documented bi-directional flow, particularly during low-flow conditions. Strong winds from the west, particularly during low-flow conditions, cause water near the surface to move eastward toward the lake and deeper water to move westward. Such conditions were observed during a field visit to the station on September 3, 2003 when representatives of the USGS and the Technical Committee met with Randy Marsden, a senior technical representative and product manager for RD Instruments, a manufacturer of some of the acoustic meters used by the USGS. During the visit, a series of discharge measurements were made using an RD Instruments Workhorse ADCP. Discharges of about 300 cfs were measured. Steady winds to the east created bi-directional flow that was readily apparent in the ADCP record.

The ADCP cannot measure near-surface or near-bottom velocities; however, the software provided with the ADCP allows the analyst to prescribe certain pre-programmed shapes for an assumed vertical velocity profile. The vertical distribution of velocity in steady, open-channel flow typically increases from zero at the channel bottom to a maximum, or near-maximum, velocity at the water surface. The profile is often represented using a $1/6^{th}$ or similar power function. When bi-directional flow exists, the velocity at the bottom is zero and increases with shallower depths, but then deflects back through zero to some velocity in the opposite (i.e. negative) direction that is maximum at the water surface. In these instances, a $1/6^{th}$ power function may not accurately represent the vertical velocity distribution.

Mr. Marsden recommended that the USGS consider using the 3-point slope method implemented by RD Instruments in its WinRiver software version 10.05. The WinRiver software was developed by RD Instruments in cooperation with the USGS. Guidance on the use of the 3-point slope method is documented in USGS Office of Surface Water Technical Memorandum 2003.04.

An even more common cause of bi-directional flow occurs during low flow periods when discretionary diversion is not being taken at the CRCW. When the flow coming from Lake Michigan is small, water from the North Branch of the Chicago River, which is denser than the lake water because of sediment and other pollutants, can form a density current along the bottom of the Chicago River, which still slopes downward toward Lake Michigan. Two layer flow resulting from density differences also are suspected of influencing the acoustic signals. Sharp density gradients will cause acoustic signals to reflect off the flow interface, thus, producing erroneous velocity readings.

The influence of density differences on flow patterns in the Chicago River main stem near the junction with the North Branch of the Chicago River is being investigated by the University of Illinois. A physical model of the channel has been constructed and scaled to geometries determined by field survey. The model is being used to evaluate how the flows from the North Branch of the Chicago River mix with Chicago River flows from Lake Michigan during low-flow conditions and different temperature regimes. During low-flow conditions, the discharge of the

North Branch of the Chicago River primarily is effluent from the North Side WRP, whereas water at the eastern extent of the Chicago River near the lake is much colder during winter. Density differences may be a source of the variability that the acoustic meters are measuring.

An index-velocity rating developed for velocity path 3 was used to compute discharge during WYs 1997 and 1998 (Duncker, 2004, in review). An index-velocity rating developed for path 4 was used to compute discharge during WY 1999 when an irregular shift in path 3 velocity was observed. The cause of the shift is not known, but may have been the result of mixing of water with different temperatures.

The number of days of missing record during WYs 1997 through 1999 totaled 112 days, or 10.2 percent of the 1,095-day period of record (Duncker et al., 2004, in review). The number of estimated days varied between 11 in 1998 and 64 in 1997.

Considerable effort has been expended by the USGS to develop backup equations for the Columbus Drive station. Concurrent records of daily flows reported by the MWRDGC for the CRCW and records available for the AVM between December 2, 1996 and September 30, 1997 were evaluated (Duncker et al., 2004, in review). Separate regression equations were developed for different flow conditions – one for periods of low flow when the MWRDGC reported discharge is less than 50 cfs and another for periods when MWRDGC-reported discharge exceeds 50 cfs.

The backup equation developed to estimate high flows between December 2, 1996 and September 1997 for MWRDGC flows greater than 50 cfs is:

$$Q_{USGS} = 1.24Q_{MWRDGC} + 252.9$$

where

Q_{USGS} = daily discharge computed using the AVM, in cfs, and
Q_{MWRDGC} = daily discharge reported by the MWRDGC on LMO-6 reports for the CRCW, in cfs.

The y-intercept of 252.9 is noteworthy. The y-intercept is interpreted as evidence that a significant discharge was being measured by the AVM even though MWRDGC records of flow based on physical measurements of lockages, gate openings, and stages of Lake Michigan indicated there was no flow to the Chicago River.

From late 1997 until the summer of 2000, the State of Illinois spent more than $14 million to wall off the Chicago River turning basin, repair leaks in the breakwaters that separate the lake from the Chicago River, install new sluice gates as part of the new turning basin wall, repair lock gates for the CRCW, and install new pumps to pump leakage from the lake back to the lake, and, thus, reduce the diversion. With the discovery of the density current and the presence of North Branch of the Chicago River flow in the Chicago River main stem, it is unlikely that these pumps will be used in the future. During this same period, the USACE repaired the east and west gates of the CRCW Lock.

The backup equation developed by the USGS to estimate flows subsequent to the repairs being completed is:

$$Q_{USGS} = 1.20Q_{MWRDGC} + 1.90$$

The substantial change in the y-intercepts associated with the pre- to post-repair regressions is an indirect measure of the substantial amount of leakage that would appear to have been eliminated or significantly reduced. The irony is that these repairs while being extremely beneficial for accounting purposes, may have likely contributed to an increased difficulty in reliably measuring low flows at Columbus Drive station.

The Fourth Technical Committee offered several recommendations and findings regarding the Columbus Drive AVM gage, which are now re-visited. Recommendations offered by the Technical Committee (Espey et al., 2001, p. 99) are listed below enclosed by quotation marks, followed by a summary of the USGS response (Duncker, written commun., October 2003).

"Steps should be taken to reduce noise in the path velocities. This may involve upgrades to the AVM transducers and firmware, and also may involve moving paths 2 and 4 to the same plane as paths 1 and 3."

Response – The most recent upgrade is an AFFRA Deltaflex that was installed on November 16, 1999. Also recent hydraulic modeling work on the CWS by Shrestha and Melching (2003) provides further insight on the "apparent" random fluctuations in velocity seen in the Columbus Drive AVM record. Much of the fluctuations in flow and velocity at the lakefront locations that previously have been considered to be "noise", i.e. "apparent random fluctuation," may not be noise. The hydraulic model of the CWS running on a 15-min. time step with stage boundary conditions at the lake also shows considerable variability of flows at the lakefront primarily driven by stage fluctuations at these boundaries and flow fluctuations throughout the system. The fluctuations in the simulated values (Shrestha and Melching, 2003, p. 52) are substantial and result from hydraulic causes (as well as measurement errors in the various inputs). Thus, the "noise" in the velocity data may represent real flow fluctuations, and, thus, is not all part of the measurement error.

"The effect of temperature gradients on the acoustical signal should continue to be investigated. If these prove to be significant, temperature probes should be installed to determine the location of the temperature gradient relative to the AVM paths."

Response – A string of 6 temperature probes was installed on the right bank on December 20, 1999.

"Because of the common occurrence of flow reversals in the vertical, the USGS should continue to investigate use of an upward-looking velocity profiler to augment the data from the horizontal AVM paths. If this proves to improve the rating, such an instrument should be installed and used as part of the daily operation of this site."

Response – An upward looking ADCP had been deployed intermittently since August 1999 until being continuously deployed with real-time telemetry on May 6, 2003.

"Discharge measurements used for rating analysis show a strong serial correlation. Consecutive discharge measurements for a fixed flow condition should be grouped and averaged for rating analysis. Statistical tests for serial correlation should be a standard part of the regression analysis to determine the rating."

Response – The USGS has used "hydrologic judgment" to decide when it was appropriate to group ADCP measurements when developing index-velocity ratings or alternatively to develop a rating based on the individual measurements.

A preliminary finding of the uncertainty analysis recently performed by the USGS that is still undergoing internal review indicates that an evaluation of autocorrelation in index-velocity rating errors determined for the Columbus Drive rating was inconclusive with respect to presence of autocorrelation. Given the dynamic nature of the low-velocity environments associated with the lakefront AVM sites, further evaluation of the influence of autocorrelation is warranted so that the real uncertainty in gaged record can be determined.

"Because the magnitude of the error relative to the magnitude of low flows at Columbus Drive, reflected by the record presented to the Committee, proposed real-time operational decisions based on the AVM record are severely limited."

Response – The IDNR at one time had plans to use the real-time AVM data for "operational decision making" for the pump located in the new sluice-gate structure at the CRCW. The IDNR has since dropped the idea of using the AVM for operational decision making for reasons previously discussed with respect to the operation of the new pump at the CRCW.

"Backup equations should be developed to estimate flow for periods of missing AVM record based on the Chicago River Controlling Works gates. Equations should be developed in terms of present conditions and future construction. As part of this backup system, measurements of Lake Michigan and Chicago River stage and sluice gate opening should be improved."

A related question was asked by Mr. Dan Injerd of the IDNR during the Committee's first meeting in January 2003. Mr. Injerd specifically asked whether the MWRDGC had begun using the new sluice gates to regulate flow and whether the gate-opening indicators on the new sluice gates have been calibrated. The draft uncertainty report presents backup equations based on LMO-6 records reported in 1997 prior to the refurbishment of the controlling works.

Field verification of gate-opening indicators such as those reported by the MWRDGC for the south screw gates at the CRCW on August 11, 2003 (Table 6.3-a) are extremely useful for evaluating differences between AVM and LMO-6 records. Data presented in this table indicate differences in individual gate openings ranging from Gate 2 that under-registered a requested 5-ft opening by about 3.4 percent by opening only 4.83 ft to Gate 3 that over-registered by 1.6 percent.

Table 6.3-a: Results of August 11, 2003 verification of gate-opening indicators on the south screw gates at the Chicago River Controlling Works

[Source: Sergio Serafino, MWRDGC, written commun., October 2003; "Remote Operation Command" is the setting requested by the control center; "Measurement Recorded" is the relative elevation of a reference mark on the gate; "Actual Gate Opening" is the vertical distance moved; and "Opening Indicated" is the valued registered and recorded for LMO-6 calculations at the control center; "Gang Operation" means multiple gates are opened equal amounts to achieve the requested opening]

	Remote Operation Command (ft)	Measurement Recorded at CRCW-S (ft)	Actual Gate Opening (ft)	Opening Indicated in WCR (ft)
		(Distance from top of gate to base of pedestal: 15')		
I) Individual Operation				
Gate 1:	0	15.00	-	0.00
	1	14.50	0.50	0.97
	5	10.00	5.00	4.97
Gate 2:	0	15.00	-	0.06
	1	14.17	0.83	0.96
	5	10.17	4.83	4.97
Gate 3:	0	15.00	-	0.01
	1	14.06	0.94	0.97
	5	9.92	5.08	4.97
Gate 4:	0	15.00	-	0.01
	1	14.08	0.92	0.98
	5	10.13	4.88	4.97
II) Gang Operation				
	0			
Gate 1:	-	15.00	-	0.00
Gate 2:	-	15.06	-	0.06
Gate 3:	-	15.06	-	0.01
Gate 4:	-	15.04	-	0.01

It appears that the USGS with the considerable support of the USACE has applied best engineering practice and scientific knowledge to the measurement of flow at the Columbus Drive gaging station. Factoring in all of the complexities of attempting to measure extremely low velocities at this location, it appears that the flow records developed for WYs 1997 through 1999 are reasonable albeit much more uncertain in relative terms than the record determined for the Romeoville AVM system.

6.3.2 Calumet River Below O'Brien Lock and Dam at Chicago, IL

Similar to the Columbus Drive station, the USGS gaging station at O'Brien Lock and Dam (Station No. 05536358) would be a primary measuring location if the Lakefront Accounting System is adopted because it measures the direct diversion of water from Lake Michigan through the O'Brien Lock and Dam, and any leakage through the control structure. The station is located on the downstream end of the lock guide wall, 1,100 ft below the downstream lock gates. Flow is very dynamic as it is influenced by lockages, the operation of 8 sluice gates in the control structure, and by effluent from the Calumet WRP that discharges to the river about 5 mi downstream.

Discharge is monitored using an AVM system installed during August-September 1996. The current primary components of the gage are a 2-path AFFRA Deltaflex AVM, a Handar SDI-12 shaft encoder operating over a float within the USACE stilling well, a Campbell Scientific CR10 datalogger, and telephone telemetry.

A description of the gaging station and history of instrumentation are documented in a station description dated February 3, 2000 that was provided to the Committee by the USGS in January 2003. The station description indicates that a quality-assurance plan has been developed for the station.

Discharge is measured using an index-velocity approach similar to the Romeoville AVM gage. A field survey was performed on March 24, 1997 to establish a stage-area rating. Synoptic measurements of discharge are made using an ADCP deployed on a tethered boat. Discharge is measured at a location midway between the upstream and downstream transducers. The boat is towed between the edge of the guide wall and a cluster of H-piles located 308 ft out from the guide wall toward the far bank where the channel begins to shallow.

The Fourth Technical Committee extensively reviewed the variability of velocity measured at the gage from its installation through WY 1998 and concluded that the "accuracy of the mean annual discharge at this site cannot be determined by current records." The USGS subsequently performed an evaluation of discharge and uncertainty (Duncker et al., 2004, in review) for WYs 1997 through 1999. During this period, the MWRDGC records of discharge reported on LMO-6 reports for O'Brien Lock and Dam were deemed more reliable than the AVM record for determining mean daily discharge about 60-percent of the time (i.e. when no discretionary diversion or navigation make up flow is taken). Uncertainty in the index velocity rating contributed a much greater portion to the overall uncertainty in annual discharge during this period. The USGS preliminary analysis (Duncker et al., 2004) indicates that the uncertainty associated with non-estimated days of record based on AVM readings ranges from 3 to 10 times the uncertainty associated with the records estimated by regression using LMO-6 data for missing days of AVM record.

A regression equation based on the analysis of days of record when the AVM was operating normally was developed for periods when navigation makeup or discretionary flow is reported. The provisional equation relating daily AVM discharge in cfs to daily LMO-6 discharge in cfs is:

$$Q_{USGS} = 0.822Q_{LMO6} + 149$$

where
Q_{USGS} = estimated mean daily AVM discharge, in cfs, and
Q_{LMO6} = daily flow reported by the MWRDGC in LMO-6, in cfs.

Similar to the estimating equations developed for the Columbus Drive gage, the above equation could be interpreted to indicate there is potentially significant leakage past the lock and dam. Any such leakage will be proportional to the square root of the difference between headwater and tailwater elevations at the structure.

It is important to note that the results discussed herein are provisional and subject to change as the USGS report continues through the review process. Thus, it is preliminary to form any firm conclusions in regards to the matter, but ADCP measurements made on November 5, 1997 and June 11, 1998 when all the sluice gates were "closed" documented discharges of 110 and 151 cfs. The relative difference in stage between upstream and downstream at the structure during the measurements was 3.5 and 3.1 ft, respectively. A lower discharge would have been expected on June 11th because the head difference is less than on November 5th, however, the manipulation of gates in the interim may have changed conditions at the controlling works. The measurements do, however, document an appreciable discharge at a time when operation parameters (gate-opening indicators) indicated no flow.

Considerable effort has been expended by the USGS with the full support of the USACE to improve the reliability of the AVM record. A total of 202 ADCP measurements were considered in the USGS uncertainty analysis to define an index-velocity rating. Many of the measurements were made consecutively, hence, there is a large degree of autocorrelation in the record. Data were grouped to form an equivalent 13 more-or-less "independent" observations in the final rating developed for path 1 of the AVM.

The frequency of equipment malfunctions has diminished considerably. Streamflow records available from the Station analyses list 45 days of missing record during WY 2000, 19 days of missing record during WY 2002, and 40 days of missing record during WY 2003. During WYs 1997 through 1999, the number of days of record estimated because of missing or unreliable AVM record ranged between 213 and 241 days (Dunker et.al., 2004).

Discussions with the USGS and field visits to the station substantiate that this is a very difficult location at which to establish an index-velocity rating. The channel is about 600 ft wide at the gage, and the channel bottom slopes with deeper water near the lock guide wall and shallower water near the left bank. The two transducer paths extend on diagonal paths that converge at the cluster of H-piles located near the middle of the channel where bottom begins to shallow.

With this configuration the paths extend across the entire approach to the lock and partially into a shallow subsection of flow directly downstream from the control structure. Flow releases through the lock and/or control structure, coupled with the uneven channel cross section can create a highly non-uniform and variable distribution of velocity in three dimensions. During periods of "no flow" when all gates are closed and no lockages are performed, ambient velocities are very low and turbulence from factors such as wind can cause bi-directional flow.

The Committee discussed deploying a SonTek side-looking ADVM in alternative locations to evaluate whether a more consistent and stable index velocity rating could be established. The suggestions included deployment on the H-pile cluster "looking" back at the guide wall, and another was a deployment on the upstream side of the outer lock wall looking across the approach channel to the sluice gates. The latter deployment would index only the flow through the gates, hence the MWRDGC records for lockage and leakage through the lock walls would have to be added to the AVM flow record.

Methods used to calculate the more recent records of daily discharge now available for the station have not been evaluated by the Committee.

Daily flows reported for WYs 2000 through 2003 and the associated station analyses for this period were reviewed. Record quality is characterized by the USGS (see Section 5.5.2) as "fair" except for estimated daily discharges which are "poor." Nothing unusual is noted in the station analyses. The most notable aspect of flows recorded during this period are number of days of low and even negative flow.

On September 22, 2003, in response to a request from Mr. Serafino of the MWRDGC, the USACE Rock Island District verified the gate-opening indicators on the four gates at the O'Brien Controlling Works. Each gate was opened to an indicated 5-ft opening and the vertical travel of the gate was measured using a tape measure. Each measurement was "right on the money" (Bob Balamut, lockmaster, written commun., September 22, 2003). Any difference was characterized as less than "a couple hundredths of a foot." The committee appreciates the responsiveness of the USACE to MWRDGC's request. It is recommended that check measurements be made on an annual basis, and that copies of such field verifications be shared with other agencies such as the MWRDGC and USGS.

6.3.3 North Shore Channel at Wilmette, IL

Similar to the Columbus Drive and O'Brien Lock and Dam stations, the USGS gaging station at Wilmette (Station No. 05536101) would be a primary measuring location if the Lakefront Accounting System is adopted because it measures the direct diversion of water from Lake Michigan through the Wilmette Controlling Works (WCW) and any leakage through the control structure. The station is located on the left bank just downstream from the Maple Avenue bridge over the North Shore Channel and about ½-mile downstream from the WCW. Flow is regulated by the WCW and the downstream CRCW and Lockport Lock and Dam. Flow may also be affected by backwater associated with the discharge of treated effluent from the downstream North Side WRP.

Discharge is monitored using an AVM system installed during August-September 1999. The current primary components of the gage are a single-path AFFRA AVM, an acoustic stage sensor, a Campbell Scientific CR10 datalogger, and cell-phone modem. A side-looking SonTek Argonaut SL ADVM was installed on the left bank 20 ft downstream from the Maple Avenue bridge September 13, 2001.

Descriptions of the gaging station and history of instrumentation are documented in an undated station description that was provided to the Committee by the USGS in January 2003 and in station analyses for WYs 2000 through 2002. The station description indicates that a quality-assurance plan has been developed for the station.

Discharge is measured using an index-velocity approach similar to the Romeoville AVM gage. A field survey was performed on September 6, 2000 to establish a stage-area rating. Synoptic measurements of discharge were initially made using a boat-mounted ADCP but are now made using the tethered-boat method.

Station analyses for WYs 2000 through 2002 report 41, 22, and 9 missing days of primary AVM record, respectively, for those years. According to the station analyses, discharges for periods of missing record during this period were estimated using the regression equation:

$Q_{AVM} = 0.960Q_{MWRDGC} + 0.59$

where
Q_{AVM} = daily discharge at the AVM gage, in cfs; and
Q_{MWRDGC} = daily discharge reported by the MWRDGC for the WCW, in cfs.

The regression analysis is briefly described by Duncker and others (2004, in review) who report that the entire record reported for WYs 1997 through 1999 is based on the equation because the AVM system was not installed until late in WY 1999.

The Committee met with the USGS in Urbana, Illinois in February 2003 and discussed the stage-area and index-velocity ratings developed for this station. The channel cross section at the gage is characterized as relatively shallow and bowl shaped. The channel is about 67-ft wide and 9-ft deep in the middle at normal stages.

The linear stage-area rating described in the station analyses is not entirely consistent with the channel characteristics at the site. A nonlinear, or piece-wise linear, rating is expected given the bowl-shaped configuration of the cross section. The curvature of residuals associated with fitting a linear function through a nonlinear distribution of data may contribute to a bias in the parameters determined for both the stage-area and index-velocity ratings. The stage-area rating illustrated in the USGS error analysis report (Duncker et al., 2004) indicates a slight curvature in the rating. However, the variability about the rating is very small compared to the variability of the index-velocity rating. The standard error of the area rating is 0.26 ft^2, or 0.06 percent of the 458 ft^2 cross-sectional area at a control stage of –2.0 ft referenced to Chicago City Datum (CCD). In comparison, the standard error of the index-velocity rating is 0.038 ft/s, or 25% of the approximate 0.15 ft/s ADCP velocity at the midpoint of the index velocity rating.

The Committee recommends that the ratings for this station be re-evaluated to determine whether a nonlinear or piece-wise linear stage-area rating is more appropriate. The rating should be evaluated relative to the range of stage evident in the nearly 4 years of stage record available for the station. A linear rating may be reasonable if the range in stage is relatively small.

During the meeting in 2003, the USGS also described the relatively large amount of discharge described as “edge estimates” associated with the ADCP measurements made at this site. The ADCP cannot reliably measure velocity near the water surface, channel bottom, or channel sides because of signal interference, hence the discharge through these portions of a cross section must be estimated. The amount of interference depends on channel geometry and the type of ADCP that is used. Technology has evolved such that higher frequency ADCPs are enabling accurate flow measurements in shallower flow conditions.

The cross-sectional area during normal stages at the Wilmette station is about 500 ft^2 and the top width is about 67 ft. A 1,200 kHz RD Instruments Workhorse ADCP has typically been used to measure flow. According to the USGS, the combination of cross-section geometry and metering are such that flow must be estimated for about a 22-foot wide subsection adjacent to the left bank and a 15-foot wide subsection adjacent to the right bank in addition to flow through the near-top and near-bottom portions of the cross section. Thus, flow through roughly 50 percent of the area is estimated.

Two recommendations were offered in regards to the matter. The first emphasizes a greater attention to field protocol. Measurements should be made at the same location and transects should begin and end at the same near-bank positions. The ensemble numbers of the first and last "good" ADCP readings should be recorded and "distance-made-good" should be compared for consistency from measurement to measurement.

According to the USGS, boat measurements have been replaced by tethered-boat measurements. Measurements are currently made using 2 people to carefully tow a tethered-boat from one side of the channel to the other.

The second recommendation was to evaluate and implement to the extent practicable a means of measuring a larger portion of flow that has been traditionally estimated. This might include using a conventional current meter to measure near-bank velocities or more current ADCP technology.

On September 3, 2003 Randy Marsden of RD Instruments, Inc. demonstrated the use of the company's 2.0 mHz StreamPro ADCP. The ADCP was mounted on a tethered-boat and attached to a tagline placed across the channel. Meter readings are transmitted in real time from the meter to a Pocket PC by Bluetooth wireless communication technology. The meter is light (5 pounds), hence, a light cord was used as a tagline. The manufacturer reports meter accuracy as 1 percent ± 0.2 centimeter per second (cm/s) with a resolution of 0.1 cm/s. Velocities can be measured for bin cells ranging from 2 to 10 cm in size in depths ranging between 15 and 200 cm (0.5 to 7 ft).

The USGS (J. Duncker, written commun., October 2003) informed that they now have a newer generation of ADCP that will enable measurements to be made in shallower environments. The Committee recommends that concurrent ADCP measurements should be made at the Wilmette station using both the old and new ADCPs, particularly during normal to high flows. Since portions of the channel are more than 7-ft deep, there is a need to determine whether the new meter accurately measures discharge in the deeper sections of the cross section.

The station analysis prepared for WY 2002 indicates that a side looking SonTek ADVM was used for velocity record during the entire water year due to significant noise in the AFFRA AVM record. The index-velocity rating noted in the station analysis is the same as reported in station analyses for WYs 2000 and 2001 when the AFFRA velocity record was reportedly used to calculate discharge. Furthermore, the rating is different than the two ratings provided in table 2 of the uncertainty analysis (Duncker et al., 2004, in review). The slope of the station analysis rating is the same as the rating identified as "Wilmette - 7/14/00 to 9/30/00" whereas the y-intercept in the station analysis is the same as the rating identified as "Wilmette – 10/1/99 to 7/14/00".

It seems unlikely that the index-velocity ratings based on two different acoustic meters would be identical. The SonTek SL ADVM should have a different index velocity rating than the AVM as these two meters are measuring a different index velocity (average velocity at a given elevation for the AVM and the velocity of a specific volume of water for the ADVM). More than likely the station analysis has not been updated to reflect the use of the SonTek SL ADVM. The Committee recommends that this apparent inconsistency be reviewed. If indeed a different rating was used to calculate discharges for WYs 2000 and 2001, the station analyses for these years should be revised accordingly. Furthermore, if the AFFRA AVM is used to calculate discharge, the discrepancy between the regression coefficients shown for the index velocity rating in the station analysis and those listed in the draft uncertainty report also should be resolved.

6.4 EVALUATION OF CONVENTIONAL STREAM-GAGING STATIONS

Records from the following five other stream-gaging stations maintained by the USGS are used in the diversion accounting process:

North Branch Chicago River at Niles, IL (Station No. 05536000)
Little Calumet River at Munster, IN (Station No. 05536195)
Thorn Creek at Thornton, IL (Station No. 05536275)
Little Calumet River at South Holland, IL (Station No. 05536290)
Grand Calumet River at Hohman Avenue at Hammond, IN (Station No. 05536357)

Records from the Hohman Avenue gage are used for estimating the water-supply pumpage from Indiana that flows past the Romeoville gage. Records from the 4 other stations are used together with streamflow separation to estimate the runoff from portions of the diverted Lake Michigan watershed.

In addition, the review of H&H modeling described in Section 4 recommends that reviews should be performed using flow records from two additional stations – Tinley Creek at Palos Park (Station No. 05536500) and Midlothian Creek at Oak Forest (Station No. 05536340).

All of these conventional stream-gaging stations are maintained in accordance with standard operating procedures established by the USGS a long time ago. Rantz and other (1982a and 1982b) is an excellence primer on the subject. Similar to the AVM stations, the measurements of stage and discharge made at a conventional station are reviewed at the end of each year and a station analysis is prepared. Network operations, field and office procedures are formally reviewed every three years in a "surface water review."

Station analyses prepared for WYs 1997 through 1999 for the five stations currently used for diversion accounting do not indicate any noteworthy deficiencies in the nature or quality of the record reported for that period.

6.5 PRECIPITATION MONITORING

Precipitation data are essential input to the H&H modeling that is performed to characterize runoff and to the MWRDGC operation of the Chicago Waterway System. A network of 25 precipitation gages was designed and installed by the ISWS in 1989 (Peppler, 1991). Each monitoring location is equipped with a Belfort universal weighing-bucket, recording precipitation gage. Gages were originally deployed with battery powered graphic (chart) recorders in which an electric chart drive rotates a drum through one complete revolution approximately once per day. Sites were visited weekly to replace the charts and perform routine maintenance.

The ISWS has been operating this network since its inception. Network operations and the data collected are evaluated, and a monthly status report is prepared. Overall network operations and data are summarized and published in an annual report that describes the network design, operations and maintenance procedures, data reduction and quality-control methodology, and an overall analysis of annual and monthly precipitations patterns and trends. The most recent report made available to the Committee addresses monitoring during WY 2002 (Westcott, 2003).

Under contract with the USACE during water year 2001, the ISWS retrofit each raingage with additional equipment to improve accuracy and reliability. Each gage was equipped with a potentiometer and electronic datalogger. The potentiometer measures the vertical deflection of the platform which is correlated through calibration with the volume of water in the bucket. Calibrations are performed monthly using a 5-point calibration method. Accumulated precipitation total is recorded at 10-minute intervals on the datalogger. Graphic recorders were retained as backup instrumentation, although the 24-hour chart-recorder gears were replaced with 7-day gears. Station-visit frequency was changed from weekly to monthly. Thus, four or more pen traces of precipitation catch must be read from the 7-day charts which turn continuously between station visits.

On August 6, 2003 the ISWS escorted the Committee on an inspection of two monitoring Chicago locations – Site No. 10 on private residential property at 527 West 26th Street and Site No. 13 at the Greune Coal Company at 7435 South Union Street. Aspects associated with equipment installation and maintenance were discussed with the ISWS project manager and primary field person.

The network retrofit is noteworthy and the ISWS is to be commended for implementing the retrofit which when coupled with the documented standard operating procedures should ensure that high-quality data continue to be reported for this network.

The MWRDGC maintains a network of raingages throughout the Chicago metropolitan area independent of the ISWS network. A network of 12 Belfort tipping bucket raingages is maintained in the portion of Cook County that lies east of the Des Plaines River primarily for waterways system operation and reporting. Rainfall amounts are reported in internal waterway system operating reports referred to as Storm Synopsis summaries. Prior to WY 1990, the precipitation gages in this network together with similar raingages were used for Lake Michigan diversion accounting purposes.

The Committee has not reviewed the MWRDGC network operation in any great detail. We are aware that MWRDGC routinely inspects the raingages on a quarterly schedule to calibrate and clean the gages and to check telemetry and transmitters (J. Farnan, written commun. to S. Melching, July 31, 2003).

In addition, the Committee was provided a draft report (Lanyon and Yourell, 2002, in review as of January 2004) describing a network evaluation and comparison of 13 years of record collected at the MWRDGC and ISWS networks. The primary findings provided in the draft are that the MWRDGC raingages have fairly consistently registered less precipitation than nearby ISWS raingages. The reported average difference in monthly volume ranges from 0.45 to 1.21 inches. A cumulative rainfall volume time series graph was prepared for each MWRDGC raingage with a superimposed cumulative rainfall volume curve for the nearby ISWS gage. None of the graphs illustrate any distinct change in the relationship between the MWRDGC and ISWS records.

The finding that MWRDGC gages register less rain than the ISWS gages is not unexpected. Weighing-bucket raingages are more accurate, and tipping bucket raingages are known to under-register precipitation particularly during intense rainstorms. What is more important is that there appears to be a consistent relationship over time between the records collected from both networks. This would indicate that with appropriate adjustment the MWRDGC network remains a useful backup to the ISWS network.

The Committee is appreciative of the opportunity to review the MWRDGC's analysis and encourages the continued operation of both networks with the same level of effort on operation and maintenance.

6.6 EVALUATION OF WATER-SUPPLY PUMPAGE

Water is withdrawn from Lake Michigan by two purification plants maintained by the City of Chicago and six suburban water treatment plants. With a combined capacity of 1.4 bgd (billion gallons per day), the City's James W. Jardine and South Water Purification Plants serve nearly 5 million consumers in the City of Chicago and 118 outlying suburbs. The City operates 12 pumping stations to distribute the treated water from the purification plants throughout the service area.

The potable supply provided by the combined lake withdrawals by the City of Chicago and 6 other municipalities accounts for about 55 percent of the more recent annual diversions from Lake Michigan. The City's 2000 Annual Water Use Audit (form LMO-2) submitted to the IDNR lists the following information which better defines the overall magnitude of the water supplied to this major metropolitan area.

Total Lake Michigan pumpage during the year	971.6 MGD
Water sold or provided to other distribution centers	321.0 MGD
Net pumpage distributed to Chicago service centers	646.6 MGD
Service population	2.84 million
Number of existing households	1.06 million
Length of distribution pipe maintained	4,235 miles
Average amount of water mains replaced	>40 miles/year

The City's withdrawals represent about 94 percent of total water supply withdrawn from Lake Michigan during 2000 that is associated with the diversion accounting process.

The USACE retained Mead & Hunt, Inc. in 2002 to document the meters used to measure water-supply pumpage and to evaluate the accuracy of measurements and associated annual volumes pumped. Section 5.3 addresses the findings of the 18 evaluations performed by Mead & Hunt. It is relevant to note here, however, that no serious wide-spread deficiencies were reported by Mead & Hunt, Inc.

These findings are not unexpected. The water supplied to the metropolitan area is a regulated commodity that is bought and sold. There are built-in incentives for maintaining accurate records of the amounts supplied.

Chapter 19, Section 120.2 of the Illinois Revised Statues authorizes the IDNR to allocate water withdrawn from the lake. Allocations are reviewed periodically, and applications for new allocations and changes to existing permitted allocations are reviewed relative to a demonstrated beneficial need that the requested amounts are in the public's best interest. The LMO-2 audit forms that must be completed each year by more than 150 water suppliers in this area serve to document the amount of water supplied and associated type of use, the amount of supply that is metered and un-metered, estimated unaccounted for flow, and age and type of distribution pipe. These audits are an essential element in the State's regulation of water supply.

There is another incentive to maintain accurate water-supply metering for purposes other than regulatory compliance. Simply put, capital improvements to infrastructure are expensive and managers want to document the benefits associated with those expenditures.

For example, the City of Chicago reported in its 2000 LMO-2 report that $50 million was invested during 2000 in a Water Conservation Program designed to address the aging water mains. In addition, the City has experimented and developed two types of "technologically advanced" locking devices (termed custodians) for fire hydrants, surveyed thousands of miles of pipe per year for leak detection and repair, and other educational and operational strategies to reduce unaccounted for flow. Accurate water-supply metering enables both the regulators and regulated communities to monitor the real impacts of these substantial investments in infrastructure upgrades.

The Technical Committee toured the Evanston Water Treatment Plant on August 5, 2003 and James W. Jardine Water Purification Plant on October 17, 2003. The pride and responsibility of line mangers responsible for plant operations and maintenance was evident. It is very apparent to the Committee that goals of providing and maintaining an cost-effective water supply is taken very seriously.

The Technical Committee commends the State of Illinois, City of Chicago, and other regulated water suppliers for the apparent diligence being given by all to the management of the water supply withdrawn from Lake Michigan.

6.7 SUMMARY OF OVERALL EVALUATION

Best current engineering practices and scientific knowledge are being used to measure discharge at gaging stations critical to the accounting of diversion from Lake Michigan. This is evidenced by the continued installation and testing of extremely sensitive acoustic metering systems, by the implementation and refinement of quality-assurance practices, by continued verification of water balances associated with the accounting procedure itself, and by documented peer reviews and findings.

The Fifth Technical Committee recognizes that the technology has continued to evolve with respect to acoustical flow-measurement equipment. However, what is noteworthy is that USACE and USGS through the trials and tribulations of establishing and maintaining the current network of AVMs are establishing a higher, "state of the art" standard. The USGS leadership in this area is to be commended.

Quality assurance practices are documented. The overall Romeoville Accounting System has been described by the U.S. Army Corps of Engineers (2001a). The USGS, through its Office of Surface Water (OSW) and associated Hydroacoustics Work Group among others, is continually working with District offices and manufacturers to refine existing technologies and methods, and to define new applications. Mr. Kevin Oberg, a former staff member of the Illinois District involved with past implementations of AVMs in the diversion accounting, now serves as the national coordinator for ADCP applications and assists in training other personnel nationwide. Those interested in learning more and reviewing the various sources of technical information are directed to a web site maintained by the USGS http://il.water.usgs.gov/adcp/ where interpretive reports and technical memoranda can be downloaded.

The quality of the work performed by the USGS at each gaging station is documented at the end of each water year in a short document identified as a station analysis, copies of which are available from the Illinois District. These documents describe the metering systems used during the year, equipment malfunctions and retrofits, synoptic discharge and leveling surveys, and rating analyses. The analysis concludes with an overall appraisal of the quality of the discharge records and recommendations for follow-up action(s). The Station Analysis is prepared by the primary field person responsible for maintaining the gaging station and is checked by an independent reviewer. In addition to the internal review, a more formal "surface water review" of stream-gaging procedures and documents prepared by the District is performed by an experienced hydrologist from outside the District office. A surface water review is performed every 3 years, and the assessment including findings and recommendations is documented in writing.

The Illinois District of the USGS has dedicated several staff members, Mr. James Duncker and Mr. Kevin Johnson, with a primary responsibility of maintaining the AVM network. Their work has been exemplary and is duly acknowledged by the Committee. The "learning curve" associated with establishing, rating, and maintaining an AVM system is steep, particularly in the challenging settings associated with the lakefront AVM gages. It appears that the District is adequately prepared for succession in project management should an unexpected need arise.

At times the USGS relies on data generated by the MWRDGC to estimate flows during periods when equipment is malfunctioning and primary gaging record is missing. The MWRDGC maintains a network of stage gages and rain gages throughout the Chicago metropolitan area. Although the Technical Committee has not formally inspected and evaluated the various installations, it is aware that MWRDGC maintains the equipment on monthly and quarterly intervals (J. Farnan, written commun. to C. Melching, July 31, 2003). In addition, the MWRDGC maintains numerous other monitoring systems such as the afore-mentioned turbine AVMs at Lockport Powerhouse from which daily records of discharge from hydraulic control structures are calculated and reported to the State of Illinois via the LMO-6 reports.

Field verifications of gate-opening indicators such as those reported by MWRDGC for the south screw gates at the CRCW on August 11, 2003 (Table 6.3-a) are extremely useful for evaluating differences between AVM and LMO-6 records. It is important that the MWRDGC continue to repeat and document such verifications, and for other parties such as the USGS to maintain such data reports on file with the station analyses.

There are no apparent significant deficiencies in the existing network of gaging stations maintained by the USGS. The network operation continues to generate reliable data, particularly at the Romeoville gage where site conditions are most favorable for AVM applications. The uncertainty of the flow record generated by the lakefront AVMs will likely remain higher than at Romeoville because the typical velocities in the lakefront channels are so much lower and subject to turbulence from a variety of sources including wind, boat traffic, and the operational hydraulics of the CWS.

A greater uncertainty has not precluded the realization of benefits associated with the lakefront AVMs. No better example exists than the Columbus Drive gage that has documented clear evidence of significant leakage through the Chicago River Controlling Works and Lock and adjacent breakwater, and the subsequent substantial reduction in leakage effected by the comprehensive repair of those lakefront facilities.

There is a real benefit in maintaining an independent monitoring system at the lakefront locations for the purpose of verifying the flows reported by the MWRDGC and ensuring that there is no change in an index velocity rating if transducers are replaced or relocated, or firmware upgrades are installed. Should the Lakefront Accounting System be implemented, it will be important to establish predictive equations relating the MWRDGC records to the lakefront gage records. In addition, the hydraulic ratings used by MWRDGC to calculate flow records should be verified by synoptic discharge measurements made during different flow conditions.

An independent backup flow-measurement method must be maintained for each AVM gage. This is of critical importance to stations such as the Romeoville AVM gage where the uncertainty in gage record comprises a relatively large portion of the overall uncertainty in the reported diversion. The current method used by the USGS when no primary or secondary AVM record is available is a regression equation that relates daily discharge at an AVM station with daily discharge reported by MWRDGC on LMO-6 reports for the nearby flow-regulation structure. This is an appropriate approach if the validity of the regression is periodically checked. It is suggested that the appropriateness of each estimating equation be documented through a more formal comparative analysis of AVM and LMO-6 records to identify any trends in differences between the records that would suggest one method or the other is providing potentially inaccurate record. The development and maintenance of a long-term double-mass curve would be useful. The results of the analysis should be summarized, similar to rating shifts, in the annual station analysis.

During the Committee's field visit to the station in January 2003, it was noted that there is no outside staff gage on the upstream side of the O'Brien Lock and Dam, hence there is no way to verify if intakes are clogged. Discharge ratings for hydraulic structures such as the sluice gates at O'Brien Lock and Dam are based on the difference in hydraulic head on both sides of the structure. Thus, it is important that measurements of upstream and downstream stage at a structure are referenced to a common datum and that stage sensors remain accurately calibrated.

It is recommended that a reference point (RP) and/or staff gage be established as needed on the upstream and downstream sides of each lakefront hydraulic structure where tape downs can be made in the immediate vicinity of any primary stage sensors maintained by the USGS, MWRDGC, or Corps. Furthermore a field survey should be performed to document RP elevations referenced to a common datum. The field survey should also tie in with other published bench marks such as those reported by the MWRDGC (J. Farnan, written commun. to S. Melching, July 31, 2003).

The Technical Committee concludes with the following primary findings and recommendations related to the AVM gages:

1. Streamflow records developed for WYs 1997 through 1999 and incorporated in the diversion accounting reports for those years are of sufficient accuracy to warrant certification of the diversion by the USACE.

2. The existing Romeoville AVM system should remain in operation for as long as possible even if rating-maintenance activities are reduced.

3. A suitable location for a replacement AVM system appears to have been found 5.9 miles upstream from the existing gage. The replacement station should be installed and rated as soon as possible. Early efforts should be made to characterize the correlation between flow records collected at this gage with concurrent records from the existing Romeoville gage and with MWRDGC records for Lockport.

4. A primary benefit associated with the continued operation of the lakefront AVMs is the ability to verify direct diversion reported by MWRDGC near these locations. The overall efficacy related to the continued operation of these stations, particularly the gage on the Calumet River at O'Brien Lock and Dam, is for others to decide.

5. The various error analyses done by the USGS with respect to the AVM gages and the development of the index-velocity ratings considered a number of procedural issues including: whether the index-velocity rating should have a zero intercept, and under what conditions the ADCP rating measurements should be grouped and when should these

measurements be considered individually in the development of the index-velocity rating. AVMs have been in use for more than 20 years and ADCP measurements have been used to rate them for more than 10 years. The USGS has published site-specific descriptions of AVM installation and index-velocity rating development such as Sloat and Gain (1995) and Morlock and others (2002). It seems that it is now time for the USGS Office of Surface Water to set more formal policies regarding the development of index-velocity ratings for AVMs using ADCP discharge measurements that allow for consistent national procedures.

7.0 FIFTH TECHNICAL COMMITTEE'S RECOMMENDATIONS AND FINDINGS

The following is a summary of the Fifth Technical Committee Recommendations and Findings.

1. In general, the Fifth Technical Committee has determined, based on our review that the Lake Michigan Diversion Accounting is in compliance with the 1980 Modified Decree, with respect to the "best current engineering practices and scientific knowledge."

2. This Fifth Technical Committee is in general agreement with the findings and recommendations made by the Fourth Technical Committee. In most instances, actions have been taken to comply with the recommendations, and progress has been made since the Fourth Technical Committee recommendations were made.

3. From the technology standpoint of "best current engineering practice and scientific knowledge," the progress of Lake Michigan Diversion accounting has been significant and is reflected in a number of specific engineering/scientific areas: 1) basic diverted watershed system data and understanding; 2) hydrologic modeling; and 3) flow measurements.

4. The technology that has evolved with respect to acoustical flow measurements has not only met the standard of "best current engineering practice and scientific knowledge," but the USACE and the USGS are establishing a higher, "state of the art" standard. The USGS leadership in this technical area is to be commended.

5. The annual diversions determinations for WYs 1996, 1997, 1998, and 1999 are satisfactory.

6. Precipitation records collected by MWRDGC between 1990 and 2002 from an independently maintained monitoring network of 12 gages were reviewed and compared by the MWRDGC (Lanyon and Yourell, 2003) with the records from nearby ISWS gages. Preliminary findings indicate that although the values measured by the MWRDGC were consistently less than the values measured by the ISWS, there was no apparent change over time in the relation between the two sets of data. The MWRDGC evaluation documents the availability of a backup network of precipitation gages and historic data that may be useful in future diversion analyses.

7. The issue of consumptive use arises because of changing to Lakefront Accounting which indicates domestic pumpage and because the 1980 Modified Supreme Court Decree definition of diversion includes: "domestic pumpage from the lake by the state and its municipalities, political subdivisions, agencies and instrumentalities, the sewage and sewage effluent derived from which reaches the Illinois waterway." In general, the U.S. Army Corps of Engineers (1996a) concluded that it was impossible to select either a consumptive use value from their analysis, or a "potential range." Consumptive use values varied significantly for the period of analysis; however, if extreme values were discounted, a potential range of 8-12 percent was indicated. The Illinois Department of Natural Resources (IDNR) presented information to the Fifth Technical Committee (January 8, 2003) with regards to unaccounted-for-flow (UFF). Use of the LMO-2 UFF data as a measure of consumptive use would not be consistent with consumptive use as specified by the 1980 Modified Supreme Court Decree. UFF does not include in-plant water-treatment loss, maximum unavoidable leakage, and potential reductions in maximum unavoidable leakage associated with line repair/replacement. The Fifth Technical Committee believes that the

consumptive use in the water/wastewater system could be significantly higher than the 8-12 percent range, suggested by the U.S. Army Corps of Engineers (1996).

8. If a shift is made to Lakefront Accounting, the IDNR should encourage the water supply utilities to provide consistent data on the LMO-3 reports. Because some communities may not measure raw water withdrawal, the Fifth Technical Committee recommends that if practicable, all water supply utilities should provide finished water data on the LMO-3 reports. An alternative approach would be to adjust a metered raw-water pumpage using a documented adjustment factor to account for in-plant use. The alternative approach would require that the LMO-3 reports clearly designate the reported withdrawal as "raw water" or "finished water."

9. For Lakefront Accounting, the long-term average consumptive use of water pumped from Lake Michigan has been fixed at 168 cfs through the year 2010 as part of the mediation agreement, which represents approximately 5 percent of the diversion. The Fifth Technical Committee concluded that the determination of consumptive use from a water budget analysis based on water-supply pumpage, treatment plant flow records and simulation results is consistent with "best current engineering practice." Although the uncertainty associated with consumptive use is high (estimated 30 percent), the Fifth Technical Committee's analysis indicates that its relative contribution to the overall uncertainty in the calculated annual diversion is comparable to the uncertainties associated with measurements of direct diversion and domestic pumpage.

10. For Lakefront Accounting, the long-term average runoff from the diverted Lake Michigan watershed has been fixed at 800 cfs through the year 2020 as part of the mediation agreement (July 29, 1996). In order to re-evaluate the fixed runoff value (800 cfs) in 2020, the capability to accurately simulate the hydrology of the diverted watershed needs to be maintained. The precipitation data currently being collected by the ISWS for this purpose meets the standard of "best current engineering practice and scientific knowledge."

11. Leakage at the Chicago River Controlling Works has been substantially reduced because of repairs to the lock and turning basin walls (completed Summer 2000), combined with recent lower Lake Michigan water levels.

12. AVM and ADCP measurements at the O'Brien L&D AVM gage suggest that there is considerable (100 cfs or more) leakage through the structure. Such leakage will likely increase as lake levels rise. Continuous gaging of flows at this station together with synoptic ADCP measurements during low flow and verification of gate opening indicators will help to better quantify the apparent leakage at this lakefront location.

13. The cumulative deviation of Lake Michigan diversion had increased from 1983 until 1994, when the trend reversed. The Lake Michigan Diversion is estimated through WY 2003, based on flow at the USGS Romeoville gage. The Lake Michigan diversion was estimated at 98 percent of the Romeoville flow and based on the data provided by the USGS and the USACE for 2000-2003, the cumulative deviation has decreased dramatically to approximately 500 cfs WY 2003. This in part can be attributed to the levels of Lake Michigan and the reduction in leakage at the CRCW as a result of the repairs made to the lock gates and completion of a new turning basin wall by the summer of 2000. Furthermore, based on the historical flow trends over the past six years, the Fifth Technical Committee estimates the average Romeoville flow for WY 2004 resulting in approximately "zero" cumulative diversion deficit projected by the end of WY 2004.

14. Implementation of new ADCP current profiler technology should improve the accuracy of flow measurements in shallow channels such as the North Shore Channel at Wilmette and channels

above and below the control structure at O'Brien Lock and Dam. However, challenges remain at O'Brien Lock and Dam and Columbus Drive particularly at low flows where bi-directional flow frequently occurs. The Fifth Technical Committee recommends that the USGS continue to use data from ongoing measurements with different instruments to attempt to develop methods to screen or filter the data.

15. The relocation of the Romeoville AVM gage because of the proposed electric fish barrier resulted in the evaluation of three alternative sites by the USGS. The Fifth Technical Committee reviewed the three alternative sites evaluated by the USGS. The Fifth Technical Committee recommended the site on MWRDGC property 5.9 miles upstream from the present Romeoville AVM site and is pleased that the site has been secured.

16. The Fifth Technical Committee encourages concurrent operation of existing and proposed AVM systems on the CSSC near Romeoville for as long as possible to establish rating and flow correlation. If the fish barrier operation is found to not substantially affect the operation of the existing AVM (assuming the existing AVM can remain in place once the fish barrier is installed), the existing AVM should remain the primary gage of the Romeoville Accounting System.

17. A Quality Assurance Plan (QAP) should be developed for the new AVM system near Romeoville as soon as the gage installation is completed. QAPs for the other AVM gages including the existing Romeoville gage should be updated to reflect current conditions.

18. It is recommended that the index-velocity rating at the Romeoville AVM gage be re-evaluated. A substantial number of additional ADCP measurements have been made since the existing rating was developed, and a new AVM system with a re-configured transducer path was installed in October 2001 and made operational in April 2002.

19. Acoustic metering technology is crucial to the continuation of accurate Lake Michigan diversion accounting, hence, this activity should continue to receive the financial and manpower support it warrants.

20. The USGS should develop some national standards or guidance regarding the development of index-velocity ratings, particularly in regards to when zero and non-zero intercepts are appropriate and when to use grouped or ungrouped data. Site-specific characteristics such as channel stability, range and variability of stage, and range and variability of AVM index velocity should be considered. The Fifth Technical Committee recommends that the USGS further evaluate the upper limits for random and systematic ADCP-measurement error and to characterize the sensitivity of uncertainty in the annual flow to measurement error bias by evaluating some other assumed (perhaps 2 percent) bias in the uncertainty analysis of WY 1997-1999 AVM records.

21. For the AVM/ADCP stream-gaging stations, the record reported for the Romeoville station during WY's 1997 – 1999 is the most accurate (approximately 44 percent coefficient of variation), followed by Columbus Drive (18 percent), O'Brien Lock and Dam (24 percent) and Wilmette (47 percent). Although the USGS uncertainty analysis documents large relative uncertainty in the Lakefront AVM system flow records compared to other records such as the flow at the Romeoville AVM gage (2 percent) and USACE-determined domestic pumpage (3 percent), the Fifth Technical Committee's analysis indicates that the combined uncertainty in the direct diversion flow record is only double the uncertainties associated with measurements of consumptive use and domestic pumpage.

22. The comparison of the Lakefront Accounting concept using the model error and the Romeoville Accounting shows that the Romeoville Accounting System has slightly less uncertainty (about 10 percent smaller total COV) than the Lakefront Accounting System because of the low uncertainty of the Romeoville Acoustic Velocity Meter. The comparison of the Lakefront Accounting System considering the runoff and consumptive use as deterministic shows that the two systems have similar uncertainty (i.e. differences equal to ±10 percent). The relatively small difference in uncertainty between the two Accounting Systems indicates that for practical purposes they have equivalent uncertainty, and, thus, neither of these Accounting Systems can be rejected on the basis of unacceptable uncertainty.

23. An independent backup flow-measurement method must be maintained for each AVM gage. This is of critical importance to stations such as the Romeoville AVM gage where the uncertainty in gage record comprises a relatively large portion of the overall uncertainty in the reported diversion. The current method used by the USGS is a regression equation that relates daily discharge at an AVM station with daily discharge reported by MWRDGC on LMO-6 reports for the nearby flow-regulation structure. The Fifth Technical Committee suggests that the appropriateness of each estimating equation be documented through a more formal comparative analysis of AVM and LMO-6 records to identify any trends in differences between the records that would suggest one method or the other is providing potentially inaccurate record. The results of the analysis should be summarized, similar to rating shifts, in the annual station analysis.

24. Several actions are recommended as quality assurance practices in support of the LMO-6 reporting for the various controlling works and the analysis of independent flow measurement methods suggested previously. Check measurements of gate-opening indicators at the controlling works should be made annually in addition to the periodic inspection of stage sensors maintained by the MWRDGC and USACE. A field survey should be performed to verify the elevations of reference points and/or staff gages located on the upstream and downstream sides of controlling works in the vicinity of the primary stage sensors. A reference point, or staff gage, should be established on the upstream side of the O'Brien Lock and Dam. Check measurements of stage should be made at the outside gage or reference point and compared with concurrent readings of the primary stage sensor to verify the sensor calibration.

25. Uncertainty of water-supply records varies between ±0.04 and ±32.1 percent, and suitable backup measurement systems exist. The uncertainty in annual volumes reported for 16 of 18 lake withdrawal stations was typically less than 2 percent.

26. The City of Chicago Lakeview Pumping Station's east and west venturi meters are oversized, and the range of pressure sensors at the Highland Park Water Treatment Plant are greater than needed. These factors contribute to an estimated uncertainty in annual flow records of ± 27 percent and ±32 percent, respectively.

27. Independent flow-measurement systems are lacking for 35 percent of WY 2000 annual Lake Michigan withdrawal.

28. The Fifth Technical Committee concurs with and reiterates the recommendations of the Fourth Technical Committee and the contractor who evaluated the pumping stations and water treatment plants that the venturi meters (a) should be calibrated to establish if manufacturers' rating curves are correct and (b) should be physically removed so that inlet and throat dimensions can be measured and inspected for physical deterioration. This might be done by partitioning the facilities into three groups based on annual pumping and then randomly sampling 5 to 10 percent of the meters associated with the pumping reported within each group.

29. The Fifth Technical Committee recommends that the USACE provide a copy of the technical review to each municipality evaluated by Mead & Hunt. The findings and recommendation documented by these reviews should be shared with those responsible for maintaining the facilities.

30. Northeastern Illinois Planning Commission (1985) advised that additional attempts at calibration should be made in the future as additional experience with the new accounting procedure is gained and as sources of discrepancies in other flow components are determined. Now, nearly 20 years since this statement was made, a recalibration of the models is needed. The current procedure for computing infiltration into the sewer system combines with 90 percent of the water supply in the WRP drainage basin as return flow/wastewater and yields a reasonable estimate of dry weather flows to the WRPs. However, the Fifth Technical Committee's review of water withdrawal and delivery data indicates that a 10 percent consumptive use factor is substantially smaller than the losses from the withdrawal point to households. Thus, if consumptive use increases in future modeling, infiltration must increase to maintain a good flow balance during dry weather flow at the WRPs. Thus, the ground-water flow and interflow portions of HSPF will need to be adjusted in future modeling. The porous nature of the sewer systems and the efficiency and density of the drainage networks make such an increase in sewer system infiltration reasonable. The re-calibration of sewer infiltration should be examined through several years of comparison of simulated and measured flows at the North Side, Stickney, and Calumet WRPs.

31. One way to independently evaluate the possible adjustment of subsurface flow might be to utilize combined sewer flow data collected by Waite et al. (2002). The potential areas where sewer infiltration could be studied using this data are the Gage Street Pipe in Riverside with a drainage area of 210 ac. (0.33 mi^2) and the Lake Street Pipe in Evanston with a drainage area of 1,738 ac. (2.72 mi^2). If household water meter data are available for these drainage areas, only household consumptive use would need to be approximated. Thus, infiltration during low flow periods could be more accurately determined and compared to simulation results.

32. The comparisons of simulated and measured flows at the WRPs are not sufficiently precise to evaluate the accuracy of the rainfall-runoff simulation. Wastewater flow comprises more than 80 percent of the WRP flows. With a revision to the consumptive use the percentage may drop below 80 but wastewater still will dominate the WRP flows. Thus, substantial errors in the rainfall-runoff simulation could be hidden in a 5 percent difference in simulated and measured WRP flows. Thus, three new checks of rainfall-runoff simulation are recommended.

    A. Midlothian Creek is a 20 mi^2 watershed (12.6 mi^2 of it gaged at Oak Forest, Ill.) that drains to the Calumet-Sag Channel just downstream from the confluence of the Calumet-Sag Channel and the Little Calumet River at River Mile 31.0 from Lockport. Tinley Creek is a 13.6 mi^2 watershed (11.2 mi^2 of it gaged at Palos Park, Ill.) that drains to the Calumet-Sag Channel near the center of this channel at River Mile 23.1 from Lockport. The ungaged Calumet, lower Des Plaines, and Summit Conduit watersheds would not be simulated with the recalibrated models because they are not drained with combined sewers. Thus, this would be an evaluation of the accuracy of the current model parameters and of the parameter transfer. This comparison of simulated and measured flows for these gages in the "ungaged" Calumet watershed would greatly increase confidence that the HSPF model parameters are valid for the watersheds to which they are applied in the diversion accounting.

B. The North Branch of the Chicago River also is gaged at Albany Avenue at Chicago, Ill. This gage is 7.5 mi downstream from the Touhy Avenue at Niles, Ill. gage and measures the flow from an additional 13 mi^2 of drainage area that is within the combined sewer drainage area. Thus, comparison of simulated and measured flow at this gage would provide insight on the quality of the HSPF and SCALP model parameters. For the comparison, it would only be necessary to simulate the runoff from the additional 13 mi^2 of drainage area and combine this with the measured flow at Touhy Avenue.

C. A comparison should be made for annual flows at the North Branch, Racine Avenue, and 125th Street Pump Stations of the MWRDGC. Combined sewer overflow volumes from large areas (15.82, 32.39, and 5.96 mi^2 for North Branch, Racine Avenue, and 125th Street, respectively) may be approximated at these locations from pump operation records. Previous studies have indicated difficulties in making comparisons at these sites on a storm by storm basis. However, some of the previous difficulties may be eliminated by TARP operation and comparisons on an annual basis may reduce others. Thus, comparison of simulated and measured flows at the pump stations on an annual basis may be a good check of the CSO flows estimated with SCALP and TNET.

33. The performance of the WY 1997 modifications to land use should be monitored as additional years of diversion calculations are completed. If the CSO flows still seem to be overestimated, the DuPage County (1993) values for medium and low density residential development should be applied for the H&H modeling in the diversion accounting.

34. The comparisons at the Upper Des Plaines Pump Station and for the lower Des Plaines River watershed by area ratio indicate potential underestimation of Des Plaines River watershed runoff. This requires further evaluation.

A. The increased values of LZSN, LZETP (grassland only), and UZSN relative to the originally calibrated values result in increased water in storage and increased evapotranspiration, and, thus, decreased runoff. Therefore, the adjusted parameter values could contribute to the under-simulation of flow from the Des Plaines River watershed. This question could be addressed by comparing observed and simulated flows for Tinley and Midlothian Creeks as previously suggested. If these flows are not consistently under-simulated, then the parameter changes probably are not adversely affecting the simulation of flows for the Des Plaines River watershed.

B. Distribution system losses in suburban areas have been found to be less than for the City of Chicago (see Section 4.6). Thus, perhaps the consumptive losses for the Des Plaines River watershed could stay closer to their current 10 percent, whereas the infiltration to the combined sewers could increase similar to the increases in infiltration applied in the City of Chicago to compensate for increased consumptive loss (and decreased water supply return flow as wastewater) determined in the recalibration. This would result in increased dry weather flow and total flow at the Upper Des Plaines Pump Station.

C. If Romeoville Accounting is to be used in the future, gaging at the Upper Des Plaines Pump Station must be improved so that meaningful comparisons can be made at this station and the Des Plaines River watershed flows can be properly tested and adjusted. In 1993, the U.S. Geological Survey (USGS) proposed using dye dilution to check the rating of the orifice plates (Kevin Oberg, Steve Melching, and Art Schmidt, 1993, written commun.). Given the advances in non-invasive flow measurement methods since 1993, it seems the USGS should be able to propose additional means to rate the orifice plates and to measure the by pass flows. Further, installation of a data logger to replace the strip charts could virtually end the problems of lost data.

35. Since a recently revised TNET model (Burke, 1999) is using a base groundwater inflow of 32.5 cfs at the pump station and the average annual shortfall in Calumet TARP flows is 14 cfs from 1989-1999, a review of the groundwater inflow for the Calumet TARP system used in the diversion accounting modeling is needed since current estimates are more than 20 cfs less than the value used by Burke (1999).

36. The quality of the stage agreement during UNET calibration for the Grand Calumet River often is very poor and the USACE original evaluation indicates too much flow may be directed East in the model resulting in an underestimate of the Indiana Water Supply pumpage deduction (Column 5 in the Diversion Accounting Table). The UNET model should be revised using more recent data and accounting for changes in roughness during the growing season for aquatic vegetation. Once better agreement between measured and simulated stages are obtained or the errors in stage and discharge are consistent, new equations for estimating Indiana water supply pumpage reaching the CWS can be derived from the revised UNET model. The derivation of new equations should be completely detailed for review by a future Technical Committee for Review of Diversion Flow Measurements and Accounting Procedures.

37. In the application of the TNET model for diversion accounting, the measured stage at the TARP pumping stations should be used as the downstream boundary condition and the outflow, i.e. pumpage, should be computed. If the computed outflow exceeds the actual pumpage, decrease TARP inflow and increase CSOs. Conversely, if the computed outflow is less than the actual pumpage, increase TARP inflow and decrease CSOs. Water-surface elevations measured throughout the TARP system could be used to ensure that adjustments in TARP inflows and CSOs are properly distributed throughout the system. In this way inflow gate operations can be indirectly considered and CSOs can be more correctly estimated. At this present time, this recommendation can only be applied for the Calumet TARP system. Once the MWRDGC has established stage sensors in the other TARP tunnels, this recommendation can be tried on the other TARP tunnels, if the application to the Calumet TARP tunnels is successful.

38. If Lakefront Accounting is selected, the period of record runoff analysis should be redone using the recalibrated models for the WRP drainage areas. The WY 1997 H&H model adjustments of impervious area should be used in the new analysis. Also, rather than estimating the O'Hare Airport precipitation data prior to June 1, 1962 using the Midway Airport and University of Chicago gages, the Arlington Heights precipitation data should be used. The runoff resulting from the increase in sewer infiltration during recalibration should cancel the effect of the increase in consumptive use on the Lakefront Accounting System, but the adjustments would make the revised Lakefront Accounting conform with the Supreme Court's requirement that the diversion accounting be done according to the "best current engineering practice and scientific knowledge."

39. The streamflow separation in the period of record runoff analysis should be revised as follows to more correctly adjust earlier runoff for 1990 land use conditions using the double mass curve method proposed by Riggins and Yen (1995). The annual runoff after streamflow separation should be summed and plotted versus the sum of representative precipitation from gages in or near the Little Calumet River above South Holland or the North Branch Chicago River above Touhy Avenue watersheds. Riggins and Yen (1995) should be consulted for additional ideas on the double mass curve approach to estimating urbanization effects on runoff.

40. Once the diversion accounting procedure is selected (Lakefront or Romeoville) and the models have been recalibrated, the diversion accounting manual of procedures should be completed.

41. The flow at the North Side and Calumet WRPs is measured by a series of Venturi meters, and, thus, the accuracy of these flows should be similar to the accuracy of the measured water supply withdrawals. The flow for the West Side portion of the Stickney WRP, also is measured by Venturi meters. However, the flow for the Southwest Side portion of the Stickney WRP is determined on the basis of the rated maximum flow for the pumps on this side of the plant. The West Side accounts for about 40 percent of the flow at Stickney and the Southwest Side accounts for about 60 percent of the flow at Stickney. Thus, for a typical year the Southwest Side of Stickney accounts for 35-40 percent of the total WRP flow to the CWS, and this value is biased high. The USACE should work with the MWRDGC to improve the flow rating for the Southwest Side of the Stickney WRP. Improved flow measurements at Stickney would improve the calibration/testing of the H&H models used in the diversion accounting.

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-----, 2003g, Technical Review of Lake Michigan Withdrawals, City of Chicago, Roseland Pumping Station: Contract Report to the U.S. Army Corps of Engineers, Chicago District, Chicago, Illinois, August 2003, 42 p.

-----, 2003h, Technical Review of Lake Michigan Withdrawals, City of Chicago, Southwest Pumping Station: Contract Report to the U.S. Army Corps of Engineers, Chicago District, Chicago, Illinois, August 2003, 41 p.

-----, 2003i, Technical Review of Lake Michigan Withdrawals, City of Chicago, 68th Street Pumping Station: Contract Report to the U.S. Army Corps of Engineers, Chicago District, Chicago, Illinois, June 2003, 42 p.

-----, 2003j, Technical Review of Lake Michigan Withdrawals, City of Chicago, Springfield Avenue Pumping Station: Contract Report to the U.S. Army Corps of Engineers, Chicago District, Chicago, Illinois, August 2003, 40 p.

-----, 2003k, Technical Review of Lake Michigan Withdrawals, City of Chicago, Thomas Jefferson Pumping Station: Contract Report to the U.S. Army Corps of Engineers, Chicago District, Chicago, Illinois, August 2003, 37 p.

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9.0 APPENDICES

APPENDIX A

HISTORICAL SUMMARY OF HYDROLOGICAL SIMULATION PROGRAM – FORTRAN PARAMETERS USED FOR SNOWMELT AND FOR IMPERVIOUS AREAS

Table A-1: Snowmelt parameters for grassland in the Hydrological Simulation Program-Fortran model used in the current diversion accounting, found by calibration in neighboring watersheds, applied in the original models of the Chicago Sanitary and Ship Canal (CSSC), and applied for 10 of 13 raingages in the diversion accounting models developed by the Northeastern Illinois Planning Commission (NIPC) for Water Year 1989.

Parameter	North Branch	Little Calumet	Des Plaines	Hickory Creek	CSSC	NIPC	Current
CCFACT	1.0	1.0	0.8-1.0	1.0	1.0	1.0	1.0
SNOWCF	1.3	1.55	1.3-1.4	1.3	1.3-1.55	1.4	1.4
RDCSN	0.15	0.15	0.1-0.18	0.15	0.15	0.12	0.12
SHADE	0.25	0.1-0.15	0.01-0.25	0.25	0.1-0.25	0.2	0.2
MGMELT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MWATER	0.03	0.02	0.03	0.03	0.02-0.03	0.2	0.2
COVIND	1.0	0.2	0.2-1.5	0.25	0.2-1.0	0.5	0.5
SNOEVP	0.1	0.1	0.1-1.0	0.1	0.1	0.2	0.2
MELEV	675	700-750	650-750	665-680	590-700	610	610
TSNOW	31	32-33	31-33	33	31-33	32	32

References: North Branch = Hydrocomp (1977d)
Little Calumet = Hydrocomp (1977c)
Des Plaines = Hydrocomp (1977a)
Hickory Creek = Hydrocomp (1977b)
CSSC = Hydrocomp (1979)
NIPC = Rust Environment and Infrastructure (1993b)

Table A-2: Snowmelt parameters for forest in the Hydrological Simulation Program-Fortran model used in the current diversion accounting, found by calibration in neighboring watersheds, and applied in the diversion accounting models developed by the Northeastern Illinois Planning Commission (NIPC) for Water Year 1989.

Parameter	North Branch	Little Calumet	Des Plaines	Hickory Creek	NIPC	Current
CCFACT	1.0	1.0	0.8-1.0	1.0	1.0	1.0
SNOWCF	1.3	1.4-1.55	1.3-1.4	1.3	1.4	1.4
RDCSN	0.15	0.15	0.1-0.18	0.15	0.12	0.12
SHADE	0.9	0.8	0.8-0.9	0.8	0.2	0.3
MGMELT	0.0	0.0	0.0	0.0	0.0	0.0
MWATER	0.03	0.02	0.03	0.03	0.2	0.2
COVIND	1.0	0.2	0.2-1.0	0.25	0.5	0.5
SNOEVP	0.1	0.1	0.1-1.0	0.1	0.2	0.2
MELEV	675	700-750	650-750	665-680	610	610
TSNOW	31	32-33	31-33	33	32	32

References: North Branch = Hydrocomp (1977d)
Little Calumet = Hydrocomp (1977c)
Des Plaines = Hydrocomp (1977a)
Hickory Creek = Hydrocomp (1977b)
NIPC = Rust Environment and Infrastructure (1993b)

Table A-3: Snowmelt parameters for impervious areas in the Hydrological Simulation Program-Fortran model used in the current diversion accounting, found by calibration in neighboring watersheds, applied in the original models of the Chicago Sanitary and Ship Canal (CSSC), and applied for 10 of 13 raingages in the diversion accounting models developed by the Northeastern Illinois Planning Commission (NIPC) for Water Year 1989.

Parameter	North Branch	Little Calumet	Des Plaines	Hickory Creek	CSSC	NIPC	Current
CCFACT	1.0	1.0	0.8-1.2	1.0	1.0	1.2	1.0
SNOWCF	1.3	1.4	1.3-1.4	1.3	1.3-1.4	1.9	1.4
RDCSN	0.15	0.15	0.1-0.18	0.15	0.15	0.12	0.12
SHADE	0.1-0.25	0.05-0.25	0.001-0.25	0.1-0.25	0.05-0.25	0.1	0.2
MGMELT	0.001	0.001	0.0-0.005	0.0-0.001	0.001	0.0	0.0
MWATER	0.03	0.02	0.03	0.03	0.02-0.03	0.2	0.2
COVIND	1.0	0.2	0.2-1.5	0.25	0.2-1.0	0.5	0.5
SNOEVP	0.1	0.1	0.1-1.0	0.1	0.1	0.2	0.2
MELEV	675	700-750	650-750	665-680	590-700	730	610
TSNOW	31	32-33	31-33	33	31-33	32	32

References: North Branch = Hydrocomp (1977d)
Little Calumet = Hydrocomp (1977c)
Des Plaines = Hydrocomp (1977a)
Hickory Creek = Hydrocomp (1977b)
CSSC = Hydrocomp (1979)
NIPC = Rust Environment and Infrastructure (1993b)

Table A-4: Rainfall-runoff parameters for impervious areas in the Hydrological Simulation Program-Fortran used in the current diversion accounting model and applied for 10 of 13 raingages in the diversion accounting models developed by the Northeastern Illinois Planning Commission (NIPC) for Water Year 1989.

Parameter	NIPC	Current
LSUR	100	50
SLSUR	0.015	0.01
NSUR	0.2	0.2
RETSC	0.3	0.25

Reference: NIPC = Rust Environment and Infrastructure (1993b)

Note: In HSP, which was used in the initial calibrations on neighboring watersheds (Hydrocomp, 1977a-d) and the initial application to the Chicago Sanitary and Ship Canal watershed (Hydrocomp, 1979), impervious areas were treated as a special type of pervious area. Thus, the parameters from the earlier models are not directly comparable in the HSPF models that have been used for the diversion accounting.

APPENDIX B

WORKSHOP AGENDA

LAKE MICHIGAN DIVERSION ACCOUNTING
5TH TECHNICAL COMMITTEE - WORKSHOP # 1

USACE - Chicago District
111 North Canal - 6th Floor
Chicago, IL 60606

Monday Jan 6, 2003
- Friday Jan 10, 2003

TOPIC	PRESENTER	TIME
Monday: January 6, 2003 (session for USACE and Technical Committee members)		
1. Overview of Workshop	USACE	1:00 - 1:20
2. Review of Scope of Work and Expected Products Goals of Workshops and Technical Committee	USACE	1:20 - 4:00
Tuesday: January 7, 2003 (session for USACE and Technical Committee members)		
1. General Discussion	USACE	8:00 - 12:00
2. Lunch		12:00 - 1:00
3. Discussion with 5th Technical Committee	USACE	1:00 - 3:30
4. Scheduling of Upcoming Workshops / Meetings	USACE	3:30 - 4:00
Wednesday: January 8, 2003 (session open to all interested parties)		
1. Welcome / Introductions	USACE	8:00 - 8:15
2. Overview of Diversion Accounting	USACE	8:15 - 9:00
3. Break		9:00 - 9:10
4. Data Sources / Measurement Locations	USACE	9:10 - 10:00
5. Break		10:00 - 10:10
6. Modeling Procedures and Concerns	USACE	10:10 - 11:00
7. Break		11:00 - 11:15
8. Status of Diversion Numbers	USACE	11:15 - 11:30
9. Status Since Last Technical Committee	USACE	11:30 - 12:00
10. Lunch		12:00 - 1:00
11. Mediation Process / Lakefront Accounting	USACE	1:00 - 2:00
12. Break		2:00 - 2:15
13. Briefings by Interested Parties (States, MWRD..)	To Be Scheduled	2:15 - 4:30
Thursday: January 9, 2003 (session open to all interested parties)		
1. Field Trip w/ USGS (Romeoville, Lockport, O'Brien, CRCW...)		* 8:00 - 5:00
** Plan to arrive at the Chicago District office 5 to 10 minutes before 8:00 a.m. so we can leave at 8:00.*		
Friday: January 10, 2003 (morning session open to all interested parties) (afternoon session for USACE and Technical Committee members)		
1. Presentation by the USGS	USGS	8:00 - 10:45
2. Break		10:45 - 11:00
3. Presentation by the State of Illinois	IDNR	11:00 - 12:00
** Remainder of Friday Session for USACE and Technical Committee Members **		
4. De-Briefings by Corps / General Discussion	USACE	12:00 - 1:00

CELRC-TS-H 28 February 2003

MEMORANDUM FOR RECORD

SUBJECT: First Workshop Meeting with the 5th Technical Committee For Review of Lake Michigan Diversion at Chicago, IL

The first workshop meeting was held in Chicago from 6 January 2003 to 10 January 2003. A letter dated 17 December 2002 was sent to all of the parties concerning the details of the workshop. A copy of the letter sent to the parties is included as enclosure 1. A copy of the meeting agenda for the workshop is included as enclosure 2. Participating in the workshop were the following individuals:

Committee Members	USACE
Dr. William Espey	Mr. Thomas Fogarty
Mr. Dean Mades	Ms. Susanne Davis
Dr. Charles Melching	Dr. Tzuoh-ying Su
Mr. Arthur Schmidt	
USGS	IDNR
Mr. James Duncker	Mr. Daniel Injerd
Mr. Kevin Oberg	Mr. Robert Mool
Dr. Thomas Over	Mr. James Casey
MWRDGC	City of Chicago – Dept. of Water
Mr. Sergio Serafino	Mr. Michael Sturtevant
USDOJ	New York Attorney General's Office
Ms. Robin Lawrence	Mr. Peter Skinner
Michigan Department of Attorney General	Indiana Attorney General's Office
Ms. Sharon Feldman	Mr. Steven Griffin

1. General discussions were held in the afternoon on 6 January between the committee members, Mr. Thomas Fogarty, Ms. Susanne Davis and Dr. Tzuoh-ying Su. The committee members received a briefing on contracting responsibilities, focal areas of technical reviews, communication protocol and the deliverable products.

2. In the morning on 7 January 2003, Mr. Thomas Fogarty led the discussion of the suggestions and recommendations proposed by the previous Technical Committee. In the afternoon, Mr. James Duncker hosted the discussions of AVM flow measurements and index velocity and ratings development with the technical committee members. The second workshop meeting, which is mostly consisted of Committee member working sessions, has been scheduled for

the week of 24 February 2003 and the third workshop meeting would be held in the week of 14 April 2003.

3. In the morning on 8 January 2003, Dr. Tzuoh-ying Su presented the Lake Michigan diversion accounting overview (enclosure 3), data sources (enclosure 4) and modeling process (enclosure 5). In the early afternoon, Dr. Su completed the current status of diversion accounting followed by Mr. Thomas Fogarty's presentation on the Great Lakes mediation process and lakefront accounting (enclosure 6). Mr. Fogarty concluded USACE's presentation by going through the current status and action plans in response to the recommendations made by the previous technical committee (enclosure 7).

4. In the later afternoon of 8 January 2003, Mr. Daniel Injerd gave a briefing to the audience with Illinois water allocation process and water demand forecast (enclosure 8). Having completed the Chicago harbor lock and inner harbor wall repairs, direction diversion has significantly reduced as a result of reduced leakage. In addition unaccounted-for-flow for water supply pumpage has reduced as a result of city of Chicago's continued effort of replacing old water mains.

5. On 9 January 2003, Mr. James Duncker guided the field trip; Mr. Duncker and Dr. Thomas Over provided transportation. Participants included committee members, Ms. Susanne Davis, Dr. Tzuoh-ying Su, Ms. Robin Lawrence and Mr. Peter Skinner (afternoon). In the morning the group toured the Lockport power house and Romeville AVM gaging site. In the afternoon the group visited O'Brien AVM site, O'Brien Lock and Dam, Wilmette AVM site, Wilmette controlling works, Chicago River Controlling Works and Columbus Drive AVM site. Photos were taken at Lockport and various diversion locations (enclosure 9).

6. On 10 January 2003, Mr. James Duncker presented the AVM flow measurements at Romeoville and lakefront sites (enclosure 10) and addressed the preliminary error analysis results for the Columbus Drive AVM data. A draft copy of "Computation of Discharge and Error Analysis for the Lake Michigan Diversion Project – Lakefront Accounting Streamflow-Gaging Stations" was provied to Committee members (enclosure 11). Finally, Mr. Duncker reported the corresponding actions to the previous Committee's recommendations that pertain to the flow measurements (enclosure 12).

7. Mr. Thomas Fogarty announced that the next open-session meeting would be scheduled for 17-18 April 2003. The meeting was adjourned at noon.

FOR THE COMMITTEE:

____
Dr. Willim H. Espey
Chairperson

FOR THE USACE:

____
TZUOH-YING SU
Hydraulic Engineer,
Hydraulic Engineering Section

____
THOMAS J. FOGARTY
Chief, Hydraulic and Environmental Engineering Branch

12 Enclosures
As stated

U.S. Army Corps of Engineers Chicago District

MEETING TOPIC Diversion Accounting 5th Technical Committee Date 1/8/03

SIGN – IN SHEET

	NAME	OFFICE/COMPANY	TELEPHONE NUMBER	E-MAIL ADDRESS
1.	Tom Fogarty	USACE	312-353-6400 x3100	thomas.j.fogarty@usace.army.mil
2.	Daniel Injerd	IDNR	312-793-3123	dinjerd@dnrmail.state.il.us
3.	Jim Casey	IDNR/OWR	(312) 793-5947	Jcasey@dnrmail.state.il.us
4.	Jim Duncker	USGS	(217) 344-0037	jduncker@usgs.gov
5.	Tom Over	USGS	(217) 344-0037 x3038	tmover@usgs.gov
6.	Dean Mades	5th Tech Comm.	941-739-3903	dmades@ebaenviron.com
7.	Pete Skinner	NY AG.	518-474-2432	Peter.Skinner@oag.state.ny.us
8.	W H Espey Jr.	Tech Committee	512 326-5659	wespey@espeyconsultants.com
9.	Tzuoh-ying Su	USACE	630 357-6105	tzuoh-ying.su@usace.army.mil
10.				

LRC Form 1-1 Apr02

U.S. Army Corps of Engineers Chicago District

MEETING TOPIC Diversion Accounting 5th Technical Committee Date 1/8/03

SIGN - IN SHEET

	NAME	OFFICE/COMPANY	TELEPHONE NUMBER	E-MAIL ADDRESS
1.	CHARLES MELCHING	5TH TECH. COMM.	414-288-6080	charles.melching@marquette.edu
2.	Kevin Oberg	USGS	217-344-0037 x3014	kaoberg@usgs.gov
3.	Tom Over	USGS	217-344-0037 x 3037	tmover@usgs.gov
4.	Jim Duncker	USGS	217-344-0037 x 3023	jduncker@usgs.gov
5.	Susanne Davis	USACOE	312-353-6400 x3114	susanne.j.davis@usace.army.mil
6.	MICHAEL STURTEVANT	CHICAGO DEPT OF WATER	312 742 4281	MSTURTEVANT@CITYOFCHICAGO.ORG
7.	SERGIO SERAFINO	MWRD	312 751 5107	Sergio.Serafino@mwrd.org
8.	Steve Griffin	Indiana AG	317-232-6226	sgriffin@atg.state.in.us
9.	ROBIN LAWRENCE	U.S. DOJ	202-514-4112	ROBIN.LAWRENCE@USDOJ.GOV
10.	Sharon Feldman	Michigan AG	(517) 335 1471	feldmans@michigan.gov

LRC Form 1-1 Apr02

LAKE MICHIGAN DIVERSION ACCOUNTING
5TH TECHNICAL COMMITTEE - WORKSHOP # 2

USACE - Chicago District	USGS – Illinois District	Monday Feb. 24, 2003 -
111 North Canal - 6th Floor	221 North Broadway Ave. Suite 101	Friday Feb. 28, 2003
Chicago, IL	Urbana, IL	

TOPIC	PARTICIPANT	TIME
Monday: February 24, 2003 (Working Sessions)		
1a Review flow measurement records	Espey/Mades/USGS	Full Day
1b Review Modeling	Melching	Full Day
Tuesday: February 25, 2003 (Working Sessions)		
2a Review flow measurement records (Continued)	Espey/Mades/USGS	Full Day
2b Review Modeling (Continued)	Melching	Full Day
Wednesday: February 26, 2003 (Working sessions)		
3a Review flow measurement records (Continued)	Espey/Mades/USGS	Full Day
3b Review Modeling (Continued)	Melching	Full Day
Thursday: February 27, 2003 (Field Trip/Working Session/Discussion)		
4a Field Trip (Pumping stations/ADCP flow measurements??)	Espey/Mades/USGS	Morning
4b Discuss Modeling with USACE staff	Melching/USACE	Morning
4c Discussions	All	Afternoon
Friday: February 28, 2003 (Discussion)		
5 Discussions	All	Morning

Sessions 1a, 2a and 3a: held in USGS – Illinois District office in Urbana, IL

TECHNICAL REVIEW COMMITTEE MEETING FOR LAKE MICHIGAN DIVERSION ACCOUNTING

FEB. 24-28, 2003
URBANA, IL

Monday, Feb. 24, 2003

- Welcome to office.
- General overview of how discharge records are computed at acoustic velocity meter gaging stations.

--CSSC at Romeoville

- Review of discharge records at the Chicago Sanitary and Ship Canal at Romeoville gage.
- Discussion of index-velocity ratings for the AVM and Sontek velocity meter.
- Detailed discussion of different methods of analyzing the Sontek velocity meter data to evaluate the index-velocity rating.

Tuesday, Feb. 25, 2003
--Chicago River at Columbus Drive

- Review of discharge records at the Chicago River at Columbus Drive at Chicago gage.
- Discussion of bi-directional flow periods.
- Review of ADCP discharge measurements showing bi-directional flow.

--Calumet River at O'Brien

- Review of discharge records at the Calumet River at O'Brien Lock and Dam at Chicago gage.
- Review of ADCP discharge measurements showing large eddy circulation.
- Review of index-velocity rating plots.
- Discussion of methodology for discharge records computation and methods used by the Metropolitan Water Reclamation District (MWRD) for their flow records.
- Detailed discussion of the leakage-only ADCP discharge measurements and overall leakage at the O'Brien Lock and Dam.
- Detailed discussion of ADCP discharge measurement analysis to evaluate specific sections of an ADCP discharge measurement with respect to the installation of a horizontal profiler.
- Brief discussion of siting considerations for a horizontal profiler on the headwater (lake) side of the sluice-gates.

Wednesday, Feb. 26, 2003
--North Shore Channel at Wilmette

- General discussion of the methods used to compute discharge at the North Shore Channel at Wilmette gage. Index-velocity rating from the 2000 WY used to compute discharge and then develop a regression with the MWRD discharge records. Regression used to back-calculate the 1997-1999 WY records (prior to installation of the USGS gage).

--Uncertainty Analysis

- A detailed discussion of the uncertainty analysis. Tom Over described in detail both methods used in the analysis, the first-order variance method and the regression method. A decision was made to include both methodologies in the uncertainty analysis report to provide a range of uncertainty. A target date for completion of the provisional analysis is April 1, 2003.

--University of Illinois, Hydrosystems Lab tour.

The workgroup met with Dr. Marcello Garcia and Fabian Bombardelli to discuss progress in the three-dimensional computer modeling of the density current in the Chicago River. Fabian Bombardelli gave a presentation on the work-to-date. Following the presentation, Dr. Garcia gave a brief tour of the Hydrosystems Lab and the physical model of the Chicago River. Dr. Garcia stressed the need for data from the new USGS streamflow gage on the North Branch of the Chicago River at Grand Avenue as soon as possible, so that the modeling can proceed.

Thursday, Feb. 27, 2003

The workgroup traveled to Chicago and met with engineers at the Metropolitan Water Reclamation District to discuss the methods used by MWRD for computing discharge in the canal system. The MWRD records are used by USGS for comparison purposes and as a back-up during periods of missing USGS gage record. Sergio Serafino and Jim Vey gave an outline on how the MWRD discharge records are computed. Discussion focused on leakage calculations through the lakefront control structures and a recent decrease in lake level and the operation of the canal system when the lake drops below river level. A tour of the real-time control room and a conversation with the system dispatcher concluded the visit to the MWRD office.

The committee met with the Corps of Engineers on Thursday afternoon, while USGS staff made ADCP discharge measurements at the North Branch Chicago River at Grand Avenue gage.

Friday, Feb. 28, 2003

The workgroup met with the Corps of Engineers at the Corps office in Chicago. A quick summary of the activities during the week was given by Jim Duncker. Discussion then focused on details of the uncertainty analysis. Following the meeting, USGS staff made ADCP discharge measurements on the Chicago River at Columbus Drive. The discharge measurements were observed by committee member Dean Mades.

LAKE MICHIGAN DIVERSION ACCOUNTING
5TH TECHNICAL COMMITTEE - WORKSHOP # 3

USACE - Chicago District
111 North Canal - 6th Floor
Chicago, IL

Monday Aug. 4, 2003 -
Friday Aug. 8, 2003

Topic	Presenter	Time (Room)
Monday: August 4, 2003		
1. Agenda, Status, Scheduling of Technical Committee Activities and Upcoming Meetings and General Discussion	Technical Committee USACE/USGS	1:00 – 3:00 (CO Conf)
Tuesday: August 5, 2003		
1. Potential Relocation of AVM Gage at Romeoville	Technical Committee USACE/USGS/MWRD	8:00 – 9:30 (ED Conf)
2. Field Trip (Romeoville AVM Site)	Technical Committee USACE/USGS/MWRD	9:30 – 1:00 (N/A)
3. Lunch		
4. Field Trip (Evanston Water Treatment Plant) - Appointment at 2:00PM	Technical Committee USACE/USGS/Evanston Water Treatment Plant	2:00 – 4:00 (N/A)
Wednesday: August 6, 2003		
1. Updates on CRCW/O'Brien AVM/ADCP Flow Measurements	Technical Committee USACE/USGS	8:00 – 10:00 (ED Conf)
2. Field Trip (Raingage Sites)	Technical Committee USACE/USGS/ISWS	10:00 – 1:00 (N/A)
3. Lunch		
4. Water Supply Metering and Measurements	Technical Committee USACE/USGS	2:00 – 3:00 (ED Conf)
Thursday: August 7, 2003		
1. Methodology of Uncertainty Analysis for Romeoville vs. Lakefront Annual Diversion	Technical Committee USACE/USGS	8:00 – 11:30 (ED Conf)
2. De-briefing by USACE	USACE	11:30 – 12:00 (ED Conf)
3. Lunch		
4. Consumptive Use Measurement and Methodology Discussion	Technical Committee USACE	1:00 - 2:00 (CO Conf)
5. HSPF Modeling Status and Discussion	Technical Committee USACE (As Requested)	2:00 – 4:00 (CO Conf)
Friday: August 8, 2003		
1. Discussion and Review of Future Work Assignment	Technical Committee	8:00 – 12:00 (VTC Conf)

LAKE MICHIGAN DIVERSION ACCOUNTING
5TH TECHNICAL COMMITTEE – WORKSHOP #4

USACE - Chicago District
111 North Canal - 6th Floor
Chicago, IL

Wed. Oct. 15, 2003 -
Friday Oct. 17, 2003

Topic	**PRESENTER**	**TIME (ROOM)**
Wednesday: October 15, 2003 (session for USACE, USGS, and Technical Committee members; 2 and 3 are concurrent sessions)		
1. Overview of Meeting and Scheduling of Technical Committee Activities and Upcoming Meetings	USACE/USGS/Technical Committee	1:00 – 1:30 (CONF-CO)
2. Discussion of Technical Committee Review and Data Collected To Date	USACE/USGS	1:30 – 4:00 (CONF-ED)
3. Preparation of Review Findings	Technical Committee	1:30 – 4:00 (CONF-CO)
Thursday: October 16, 2003 (session open to all interested parties)		
1. Presentation of Overall Findings Relating to Romeoville and Lakefront Accounting Procedures	Espey, Technical Committee Chairperson	9:00 – 9:40 (VTC)
2. Presentation of Findings Relating to Flow Measurements	Mades, Technical Committee Member	9:40 – 10:20 (VTC)
3. Break		10:20 – 10:40
4. Presentation of Findings Relating to Modeling	Melching, Technical Committee Member	10:40 – 11:20 (VTC)
5. Relocation of Romeoville AVM	USGS	11:20 – 12:00 (VTC)
6. Lunch		12:00 – 1:00
7. Open Discussion (Q/A)	USACE/USGS/Technical Committee/States	1:00 – 3:00 (VTC)
Friday: October 17, 2003 (session for USACE and States)		
1. Discussion and Summary of Outstanding Issues Relating to Accounting Procedures with USACE and States	USACE/States	9:00 – 12:00 (VTC)

Lake Michigan Diversion Accounting Technical Committee
Visitors on Thursday, October 16

Technical Committee	Position
Dr. Bill Espey	Chairman
Dr. Steve Melching	Modeling Expert
Mr. Dean Mades	Measurement Expert

USGS	Position
Mr. James Duncker	Measurements
Dr. Tom Over	Error Analysis

US Dept of Justice	Position
Ms. Robin Lawrence	Attorney

State of Illinois	Position
Mr. Dan Injerd	Natural Resources
Mr. Jim Casey	Natural Resources

MWRD	Position
Ms. Manju Sharma	Engineering
Mr. Sergio Serafino	Operations

State of ~~Illinois~~ Michigan	Position
Ms. Sharon Feldman	Attorney
Mr. David Hamilton	Natural Resources

Canada – Natural Resources	Position
Mr. Ian Cameron	Natural Resources

Rock Island District	Position
Mr. Frank Monfeli	Operations
Mr. Rick Granados	Operations
Mr. Jim Stiman	Hydraulics

Probable

State of New York	Position
Pete Skinner	Engineer

APPENDIX C

1980 DECREE AND MOU

101 S.Ct. 557 (Mem)

66 L.Ed.2d 253

(Cite as: 449 U.S. 48, 101 S.Ct. 557)

State of WISCONSIN et al., Complainants,

v.

State of ILLINOIS and the Metropolitan Sanitary District of Greater Chicago et al., Defendant, United States, Intervenor.

State of MICHIGAN, Complainant,

v.

State of ILLINOIS and the Metropolitan Sanitary District of Greater Chicago et al., Defendant, United States, Intervenor.

State of NEW YORK, Complainant,

v.

State of ILLINOIS and the Metropolitan Sanitary District of Greater Chicago et al., Defendant, United States, Intervenor

No. 1 Orig

Supreme Court of the United States

December 1, 1980

Former decision, 441 U.S. 921, 99 S.Ct. 2027; 441 U.S. 921, 99 S.Ct. 2028; 449 U.S. 812, 101 S.Ct. 60.

ORDER

*48 Ordered:

A. Paragraph 3 of the Decree entered by the Court herein on June 12, 1967, 388 U.S. 426, 87 S.Ct. 1774, 18 L.Ed.2d 1290, 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 *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 **558 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 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

10

members shall be employees of the Corps of Engineers or employees or paid consultants of any of the parties to these proceedings other than *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.

***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 ****559** of the existing Decree that prevent Illinois from effectively utilizing and managing the 3200 cubic feet per second (cfs) 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 cfs 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 cfs limit by 2000 cfs-years in the aggregate (one cfs-year is the volume of water resulting from an average flow of one cfs for a period of one year); ***52** 3. Limits the average diversion in any one accounting period to 115% of 3200 cfs, but in two years of any forty year period permits the average diversion to reach 120% of 3200 cfs, 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, ***53** that the mean annual stormwater flow is 683 cfs, the maximum departure is 405 cfs. This could result in a diversion of 13% above the allowable 3200 cfs 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 cfs, 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 cfs, to accommodate extraordinary hydrologic conditions.

**560 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 cfs for best management, and some years when the diversion will be less than the 3200 cfs average. Calculations of the cumulative sum of the annual departures show that the maximum cumulative exceedance of 3200 cfs would be slightly below 1500 cfs-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 cfs-years. Since the record used is relatively short and urbanization is likely to increase runoff, the maximum cumulative exceedance has been established at 2000 cfs-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 cfs.

THE GREAT LAKES MEDIATION
MEMORANDUM OF UNDERSTANDING
July 29, 1996

The terms that follow set forth the principles of a Memorandum of Understanding ("MOU") that would address the dispute over the alleged violation by the State of Illinois of the diversion limits set forth in the 1967 and 1980 Supreme Court Consent Decree in *Wisconsin v. Illinois*, 388 U.S. 426 (1967), *as modified*, 449 U.S. 48 (1980) ("Decree"). The principles are the product of voluntary negotiations among the State of Illinois, the other seven Great Lakes states, the Metropolitan Water Reclamation District of Greater Chicago and the United States during a mediation that began in December 1995. Representatives from Canada and the Province of Ontario observed the negotiations and participated in the discussions.

The final acceptance of these terms may require ratification by principals not present at the mediation. Moreover, certain terms will not become final and binding unless and until the Decree is amended. Thus, the terms represent the principles that the negotiators believe will resolve the dispute. The negotiators will use their best efforts toward obtaining final approval of the principles and implementing the Memorandum of Understanding ("MOU"), provided, however, that there shall be a transition period described in paragraph 4 below.

1. Lakefront Diversion Measurement System -- The "lakefront diversion measurement system" shall refer to measurement of waters diverted from Lake Michigan or its watershed by the State of Illinois, and municipalities, political subdivisions, agencies and instrumentalities, and shall include measurement of the "direct diversion" (as used in the Decree) to the Sanitary and Ship canal system by acoustic velocity meters ("AVMs"), and also include measurement of "domestic pumpage" (as defined and used in the Decree). AVMs shall be installed at the lakefront near the Chicago River Controlling Works and the O'Brien lock. The State of Illinois shall bear the non-federal cost of installing the AVMs. Subject to Congressional direction and funding, the U.S. Geological Survey and the U.S. Army Corps of Engineers ("Army Corps") shall be responsible for overseeing the installation and calibration of the AVMs.

2. Stormwater Runoff -- In order to make lakefront diversion measurement feasible, a value for stormwater runoff shall be fixed. Based on analysis performed by the Army Corps, stormwater runoff shall be set at 800 c.f.s. through the year 2020, subject to the conditions of paragraph 4.

3. Consumptive Use Credit -- There shall be a credit in the lakefront diversion measurement system of 168 c.f.s. for consumptive use, subject to the conditions in paragraph 4. In 2010, any party can request that the

Doc #12138354.DC

consumptive use credit be reevaluated based on more recent scientific evidence.

4. Transition Period -- During a three-water-year transition period beginning after the installation and initial calibration of the AVMs at the lakefront (WY 1997), the Army Corps shall, subject to Congressional direction and funding, maintain a dual reporting system (i.e. the diversion accounting system established pursuant to the Decree and the lakefront diversion measurement system) for the purpose of: (1) assessing the technical acceptability of moving the diversion measurement system to the lakefront and (2) completing the QA/QC program for the lakefront diversion measurement system and domestic pumping meters. In addition, subject to Congressional direction and funding, the Army Corps shall initiate a technical review of the accuracy of the reported domestic and industrial withdrawals from Lake Michigan or its watershed that are part of the State of Illinois' allocation program. The Army Corps shall also undertake a technical review of the accuracy of the sluice gate rating curve at Wilmette lock. The parties understand that there might not necessarily be a "one-for-one" correspondence between the diversion accounting system established pursuant to the Decree and the lakefront diversion measurement system.

In the event that: (1) the lakefront diversion measurement system is shown to be technically acceptable to the satisfaction of the Parties and a Technical Committee appointed pursuant to the Decree; and (2) the State of Illinois is making demonstrable progress toward compliance with this MOU and toward compliance with the Decree, including reduction and extinguishment of the cumulative excess average c.f.s.-water-years as defined in the Decree ("Overage")(approximately 3,500 c.f.s-water-years in WY 1995), then the lakefront diversion measurement system will be accepted by the parties hereto.

In the event that the parties accept the lakefront diversion measurement system, then during the transition period the parties understand that (1) 800 c.f.s. for stormwater runoff and a 168 c.f.s. credit for consumptive use will be used for calculating the annual diversion limit and the annual diversion, and (2) Illinois shall adhere to the lakefront diversion method equivalent of 2,568 c.f.s. annual diversion limit. In the event that the Decree is amended, the certified flows as measured during the transition period by the lakefront diversion measurement system shall replace flows of the diversion accounting system established pursuant to the Decree as the flows of record.

In the event that the lakefront diversion measurement system is rejected for any of the above reasons, then the diversion measurement system required by the Decree shall continue to be the measurement system of record and the State of Illinois shall adhere to the 3,200 c.f.s. annual diversion limit as set forth in the Decree.

5. Undertakings by the State of Illinois -- The State of Illinois will (1) with the concurrence of the Illinois legislature, when necessary, reduce discretionary diversion to a maximum annual average of 240 c.f.s. in WY 1996 and WY 1997 as long as the reduction in discretionary flows does not result in significant exceedances of water quality standards, and to 270 c.f.s. in WY 1998 through 2010, as long as the reduction in discretionary flows does not result in significant exceedances of water quality standards; (2) initiate leakage repairs at the Chicago River Controlling Works in WY 1996; (3) initiate allocation proceedings by the start of WY 1998 regarding all domestic and industrial Illinois Lake Michigan water users; (4) install AVMs in WY 1996, subject to appropriations from the Illinois General Assembly; (5) subject to appropriations from the Illinois General Assembly, initiate construction of a wall across the mouth of the Chicago River Turning Basin by December 1, 1998; (6) promptly initiate steps to reduce navigation makeup to the Metropolitan Water Reclamation District below 50 c.f.s., subject to maintaining navigation depths in accordance with the Code of Federal Regulations, 33 C.F.R. 207.420; and (7) subject to appropriations from the Illinois General Assembly, install by WY 1999 one or more pumps at the lakefront for the purpose of returning water to Lake Michigan. By WY 2000, and subject to water quality and navigation regulations, the State of Illinois will pump back to Lake Michigan not less than an annual average of 50 c.f.s., or an amount equal to the total leakage and navigational waters at Chicago for the months in which there is no discretionary flow.

6. Undertakings by the Army Corps -- Subject to Congressional direction and funding, the Army Corps will repair the lock systems at the Chicago River Controlling Works beginning in WY 1996 and continuing through WY 1999.

7. Compliance with 3,200 c.f.s Diversion Limit -- The State of Illinois accepts the diversion limit of 3,200 c.f.s. as measured by the terms set forth in the Decree.

8. Approval and Availability of Funds -- The parties recognize that completion of the undertakings described in paragraphs 5 and 6, the lakefront pump and other tasks outlined herein are subject to legislative and Congressional approvals and appropriations of funds. However, the parties need not take into account the lack of such approvals or the availability of such funds when determining, pursuant to paragraphs 4 and 5, whether Illinois has made demonstrable progress during the transition period toward compliance with this MOU and the Decree.

9. Reduction of Overage to 2,000 c.f.s.-water years by WY 2010 -- The State of Illinois shall reduce its Overage to less than 2,000 c.f.s.-water-years no later than the end of WY 2010.

10. Reduction of Overage to 1,000 c.f.s.-water-years by WY 2015 -- The State of Illinois shall reduce its Overage to less than 1,000 c.f.s.-water-years no later than the end of WY 2015.

11. Reduction of Overage to Zero by the end of WY 2019 -- The State of Illinois shall reduce its Overage to 0 c.f.s.-water-years no later than the end of WY 2019.

12. Running Average -- Subject to adoption of the lakefront diversion measurement system and amending the Decree, the parties understand that in lieu of the 40-year running average set forth in the Decree there shall be a five-year running average of diversion that shall apply prospectively from the beginning of the transition period. The parties may study the reasonableness of, and recommend the use of, a running average for periods other than five years. Notwithstanding this paragraph and anything else in this MOU, the parties understand that any Overage existing under the Decree when the transition period begins will not be recalculated but will instead be carried forward as already accumulated under the Decree and will be first reduced and then extinguished in accordance with the preceding three paragraphs.

13. Enforcement of Water Use and Conservation Measures -- The State of Illinois shall use its regulatory and statutory powers to ensure that municipalities using water from Lake Michigan, including the City of Chicago, comply with allocation limits, unaccounted for flow requirements and conservation measures required by state law, regulation, court order, consent decree or settlement agreement.

14. Funding for Army Corps -- The parties recognize the additional financial burden that the Army Corps will assume for administering a dual measurement system during the transition period, or longer if the parties seek modification of the decree, and that the Army Corps' administration of a dual measurement system is dependent upon Congressional direction and funding. The State of Illinois will request assistance from appropriate state officials to consult with their federal representatives to assure the availability of the necessary funds.

15. No Litigation During Transition Period -- During the three-water-year transition period, no party shall commence a legal action respecting this dispute in the absence of material non-compliance with the foregoing commitments. Furthermore, this MOU does not create a right of action against any party in any forum for failure to comply with any of those commitments.

Title

State

Date

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