IMPACTS OF URBANIZATION ON BASE FLOW AND RECHARGE RATES, NORTHEASTERN ILLINOIS: SUMMARY OF YEAR 1 ACTIVITIES

Scott C. Meyer and Steven D. Wilson[*]

Illinois State Water Survey, Champaign, Illinois

ABSTRACT

During year one of a two-year project to investigate the impacts of urbanization on base flow and ground-water recharge rates in northeastern Illinois, three gaged watersheds in urbanized areas of northeastern Illinois, and one watershed located in rural northwestern Illinois, have been selected for study. The gages have a common period of record extending from October 1952 through the present, a period during which the northeastern Illinois watersheds underwent substantial urbanization. Mean daily discharge data from the gages have been analyzed using an automated hydrograph separation technique, and monthly estimates of mean total discharge, base flow, and direct runoff have been calculated. Spearman rank correlation coefficients indicate a stronger correlation between precipitation and total discharge, base flow, and direct runoff in the northeastern Illinois watersheds than in the rural watershed. Smoothed time-series plots of total discharge, base flow, and direct runoff in the urban watersheds are less consistent with precipitation than similar plots constructed from the rural watershed data. The trends indicate that rates of direct runoff have overtaken rates of base flow in two of the three northeastern Illinois watersheds, but in one of these watersheds, this relationship probably reflects the cessation of effluent discharges to the stream. In general, double-mass curve analysis suggests that, relative to the rural watershed, base flow in the urban watersheds has proportionally decreased, and direct runoff has proportionally increased. The trends suggested by the smoothed time-series plots and the double-mass curves are consistent with a conceptual model of the northeastern Illinois watersheds in which sewering and impervious surfaces have reduced infiltration, and thence ground-water recharge and base flow, in the watersheds.

INTRODUCTION

The Northeastern Illinois Planning Commission (1999) has identified the adequacy of ground-water and surface-water supplies as a critical water resource issue facing northeastern Illinois. The Commission projects the population of the six northeastern Illinois counties (Cook, DuPage, Kane, Lake, McHenry, and Will) to grow by 25 per cent by 2020 and that of the outer collar counties (Kane, McHenry, and Will) to increase by 70 to 100 per cent by 2020. Moreover, two traditional sources of large water supplies for the region–the deep bedrock aquifer system and Lake Michigan–are at or near their sustainable and legally mandated limits, respectively, and cannot be relied upon as significant sources of additional water for the region. In 1994, withdrawals from the deep bedrock aquifer system in northeastern Illinois totaled about 67.1 million gallons per day (mgd) (Visocky, 1997), approximating the maximum practical sustained yield of the aquifer system for the region of 65 mgd (Suter et al., 1959). U.S. Supreme court decrees and other legal restrictions limit Illinois to diverting an average of 3200 cubic feet per second (cfs) from Lake Michigan, yet

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[*]Ground-Water Section, Illinois State Water Survey, 2204 Griffith Drive, Champaign, IL 61820. Correspondence should be addressed to Scott C. Meyer.

Illinois exceeded this limit during 11 of the 15 years from 1981 through 1995; the state diversion averaged 3197 cfs during 1995 (Daniel Injerd, personal communication).

In the absence of alternatives, most of the water which will satisfy future demands in the region will be obtained from the unconsolidated aquifer system and underlying shallow bedrock aquifer (referred to collectively as the shallow aquifers). Ground-water availability from these aquifers is, however, poorly understood (Northeastern Illinois Planning Commission, 1999). Critically important to understanding ground-water availability from the shallow aquifers is information on ground-water recharge rates and on the interaction between shallow ground water and surface water in the region. In the long term, ground-water withdrawals from a basin cannot exceed the rate of ground-water recharge to the basin. Ground-water withdrawals from shallow aquifers have the potential to reduce base flow in streams and water levels in lakes and wetlands. Therefore, public desires and legal mandates to maintain critical streamflows and water levels in surface-water bodies may impose constraints (in addition to those imposed by recharge rates) on acceptable ground-water withdrawals from the shallow aquifers. Presently, however, the degree to which such shallow ground-water withdrawals can affect surface waters in northeastern Illinois is poorly understood.

In urban areas, the problem of quantifying limitations on ground-water availability imposed by recharge rates is complicated by the fact that urbanization itself may reduce recharge rates. Infiltration capacity is reduced in urban areas by widespread impervious surfaces. Rather than being permitted to infiltrate, precipitation captured by rooftops and paved surfaces is channeled as direct runoff through storm sewers typically designed to convey it as rapidly as possible to nearby streams. Ground water withdrawn from wells is not returned to the saturated zone via on-site septic systems but is, rather, conveyed to treatment plants which typically discharge it to nearby streams. Although they may have consequences for ground-water quality, on-site septic systems function as artificial recharge systems and offset the impacts of ground-water withdrawals. Thus, the infrastructure associated with urbanization can reduce ground-water availability in the very areas where demand is greatest.

These features of the urban landscape, together with ground-water withdrawals from shallow aquifers, also reduce ground-water discharge to surface waters. This reduction has ramifications for shallow ground-water availability that are separate from the limitation imposed by reduced recharge rates. Lowering of the water table as a consequence of ground-water withdrawals, possibly augmented by diversion of ground water into breached sanitary sewers or other conduits constructed below the water table, may further reduce ground-water discharge. The increased volume of direct runoff captured by widespread impervious surfaces, and the rapid conveyance of this runoff to streams via storm sewers causes increased peak flows. Reduced base flow, together with increased volumes and rates of direct runoff, results in the highly variable, "flashy" flow typifying many urban streams.

The goals of this investigation are to (1) document temporal changes in base flow and ground-water recharge rates for selected drainage basins in northeastern Illinois; and (2) correlate significant temporal changes in these quantities with land-use changes and changes in water-resources management in the watersheds. The investigation will compare base flow and other flow data from urbanizing northeastern Illinois watersheds with contemporaneous data from a watershed in rural northwestern Illinois. Streamflow trends in the northeastern Illinois watersheds will be correlated with historical data on the timing and magnitude of changes in land cover and water-resources management strategies, and related to precipitation trends, within the watersheds. This report discusses project activities during year one of this two-year project.

PREVIOUS INVESTIGATIONS

Impacts of Urbanization on Base Flow and
Ground-Water Recharge on Long Island, New York

Several studies, authored primarily by United States Geological Survey (USGS) staff, documented the impacts on base flow and ground-water recharge rates of storm- and sanitary-sewerage systems, as well as impervious surfaces, in rapidly developing counties on the south shore of Long Island, New York. Most of these studies have focused on Nassau County, immediately east of New York City. Sawyer (1963) and Seaburn (1969) demonstrated the increase in direct runoff to East Meadow Brook, which drains a heavily urbanized portion of Nassau County, accompanying urbanization. Franke (1968), Garber and Sulam (1976), and Sulam (1979) quantified declines in ground-water levels resulting from sewering in Nassau County. Garber and Sulam (1976) documented an average water table decline of 6.9 feet in a sewer district encompassing southwestern Nassau County in relation to water levels in unsewered parts of Long Island. Sulam (1979) suggested that, since water levels in the urbanized sewered area had not declined significantly since the early 1970's, the water table had reached an equilibrium position with the decreased recharge rate resulting from urbanization. Pluhowski and Spinello (1978) analyzed the impacts of sewer development on base flow and ground-water recharge on Long Island. They showed that base flow in East Meadow Brook in the sewer district encompassing southwestern Long Island had declined from 91.2 per cent of total annual stream flow in 1949 to 64.8 per cent in 1974 as a consequence of interception of waste water by the sewer system. Koszalka (1975) showed that a general increase in ground-water levels on Long Island resulting from above-average precipitation in 1972 and 1973 was not evident in eastern Queens and southwestern Nassau Counties as a consequence of local ground-water development and sanitary sewer system development in southwestern Nassau County.

Simmons and Reynolds (1982) quantified reductions in base flow as a proportion of stream discharge through 1975 in streams draining urbanized areas on Long Island and related the reductions to impervious surfaces and storm- and sanitary-sewering. They concluded that these factors had reduced base flow from roughly 95 per cent to about 20 per cent of stream discharge in heavily urbanized parts of Nassau County. Spinello and Simmons (1992) corroborated and extended the research of Simmons and Reynolds (1982) by examining changes in base flow as a proportion of stream discharge through 1985; their analysis therefore examines the impacts of eastward urbanization of Long Island that occurred subsequent to the study period of Simmons and Reynolds (1982). In addition, Spinello and Simmons (1992) examined temporal changes in flow duration curves of Long Island streams resulting from urbanization. The flow duration curves showed that urbanization had resulted in decreased baseflow, increased high flows, and increased flow variability.

Impacts of Urbanization on Base Flow, Ground-Water Recharge,
and Leakage to Confined Aquifers in Northeastern Illinois

Studies of the impact of urbanization on base flow, ground-water recharge rates, and rates of leakage to confined aquifers in northeastern Illinois are limited in scope to investigations addressing the impacts of ground-water withdrawals. Most studies are limited to investigations of the capacity for inducing leakage into shallow, confined aquifers via heavy ground-water withdrawals. All of these studies are peripheral to other hydrologic investigations, and none of the studies addresses the potential for urban infrastructure to reduce base flow and ground-water recharge rates.

Zeizel et al. (1962) examined the relationship between ground-water recharge rates estimated from stream gage data and leakage to the shallow bedrock aquifer in diversion areas surrounding three centers of heavy shallow bedrock withdrawals in central and eastern DuPage County. Stream-gage data indicated that ground-

water runoff (i.e. ground-water discharge to streams) in the Salt Creek watershed, draining an area of DuPage County that is hydrogeologically comparable to the three diversion areas, averaged about 5.19 inches per year. Average leakage to the shallow bedrock aquifer in the three diversion areas, all of which were sites of heavy withdrawals from the shallow bedrock, was estimated at about 2.9 in/yr. Based on the quotient of the rate of leakage to the shallow bedrock and the average ground-water runoff rate, Zeizel et al. (1962) estimated that about 58 per cent of ground-water runoff can be diverted to confined sand and gravel aquifers and to the shallow bedrock aquifer under enhanced vertical hydraulic gradients in areas of large ground-water withdrawals from the confined aquifers.

Prickett et al. (1964) estimated leakage to a sand-and-gravel aquifer in Will County that had been developed by high-capacity wells as part of the public water system of Joliet. In addition, they quantified induced infiltration from an overlying stream, Spring Creek, to the aquifer. They concluded that the sand and gravel aquifer received about 6.3 in/yr of leakage, of which 2.1 in/yr was induced infiltration from Spring Creek. The aquifer is confined over most of its area, but is unconfined and hydraulically connected to Spring Creek by alluvium underlying the stream and associated valley.

Sasman et al. (1981) showed that heads in 1979 had declined considerably below stream water levels in much of DuPage County so that the streams were providing recharge to the shallow bedrock aquifer. They attributed the head declines to ground-water withdrawals. By comparing documented effluent inflows to Salt Creek (Cook and DuPage Counties) above a gaging station at Western Springs with annual 7-day low flows at the gaging station, Singh and Ramamurthy (1993) showed that streamflow in Salt Creek (Cook and DuPage Counties) was diverted into the subsurface in response to heavy pumping from shallow aquifers in the area. They concluded that the entire reach of Salt Creek downstream of Elmhurst was an area of potential recharge to the shallow aquifers, and their map shows declining 7-day, 10-year low flows in this reach in response to diversion of streamflow into the subsurface.

Roadcap et al. (1993) examined the effects of ground-water withdrawals on leakage to the shallow bedrock aquifer in DuPage, Will, and southern Cook Counties. They found that the best-fit trend on a plot of withdrawals versus 24 available leakage estimates in DuPage, Will, and southern Cook Counties is a third-power polynomial with a zero-withdrawal intercept of 0.6 in/yr. For withdrawals less than about 3.0 mgd, the curve essentially follows a linear trend. For withdrawals greater than 3.0 mgd, the curve falls progressively farther below the linear trend, approaching a limit of about 4.8 in/yr, the probable average maximum recharge rate. The analysis suggests that, for the average hydrogeological setting of the area, (1) leakage of about 0.6 in/yr is required to maintain natural steady-state flow in the shallow bedrock aquifer; (2) for withdrawals less than 3.0 mgd, each 1.0 mgd increase in pumping in a diversion area results in an average increase in leakage of about 0.6 in/yr across the diversion area; and (3) average leakage to the shallow bedrock in a diversion area cannot exceed about 4.8 in/yr. Leakage rates were higher than predicted by the best-fit line in diversion areas that were constricted by rivers or by adjacent diversion areas, the higher recharge rate compensating for decreased contributions of regional flow to the pumping centers. Conversely, recharge rates were lower than predicted by the best-fit line in diversion areas which were able to capture more water from the regional flow field. The data also suggested that recharge rates were higher in areas having thinner cover of clay-rich diamicton and/or a greater proportion of sand in within the glacial drift cover.

RELATIONSHIP BETWEEN BASE FLOW, GROUND-WATER RUNOFF, AND GROUND-WATER RECHARGE

Under natural conditions, ground water eventually discharges to surface-water bodies or is removed from the saturated zone by evapotranspiration in areas where the water table intersects the surface or the root zone of plants. Discharge by the process of seepage, often referred to as ground-water runoff, sustains flow from springs, maintains saturated conditions at wetlands, and provides the base flow of streams and rivers.

Ground-water runoff is only one component of the water which my enter a stream channel. The other components include surface runoff, interflow, and artificial discharges. For convenience, it is customary to divide streamflow into only two components: direct (or storm) runoff and base flow. Direct runoff is considered to be surface runoff and a substantial portion of interflow, whereas base flow is presumed to consist largely of ground water (Linsley et al., 1982). The two components are distinguished largely on the basis of their time of arrival in the stream rather than on a strict understanding of the path followed.

For a given time period, the hydrologic budget of an aquifer in a ground-water basin can be expressed by the following relationship (Holtschlag, 1997):

$$\Delta S = R - D_s - D_w - D_a - D_e$$

where:

ΔS = change in ground-water storage
R = ground-water recharge from precipitation, losing streams, and adjacent aquifers
D_s = aquifer discharge to streams
D_w = aquifer discharge to wells
D_a = leakage from the aquifer to underlying aquifers
D_e = aquifer discharge via evapotranspiration

Over a time interval selected so that changes in ground-water storage are negligible (such as one year), and in ground-water basins where withdrawals from wells and leakage to underlying aquifers are negligible, aquifer discharge to streams (D_s), or base flow, approximates net recharge, where net recharge is defined as total recharge minus ground-water evapotranspiration. Thus, under such conditions, the preceding equations reduces to the following:

$$D_s = R - D_e$$

METHODS AND DATABASE

Selection of Watersheds for Investigation in Northeastern Illinois

Three gaged watersheds in northeastern Illinois have been selected for analysis of the impacts of urbanization on base flow and ground-water recharge rates: (1) Tinley Creek near Palos Park (USGS Gage 05536500), (2) McDonald Creek near Mt. Prospect (USGS Gage 05529500), and (3) Weller Creek at Des Plaines (USGS Gage 05530000) (figure 1). The Tinley Creek watershed is located in southern Cook County and includes portions of the suburban Chicago communities of Crestwood, Oak Forest, Orland Hills, Orland Park, Palos Heights, and Tinley Park. Although much of the downstream portion of the Tinley Creek watershed is contained within a Cook County Forest Preserve, present land cover in the rest of the watershed is largely
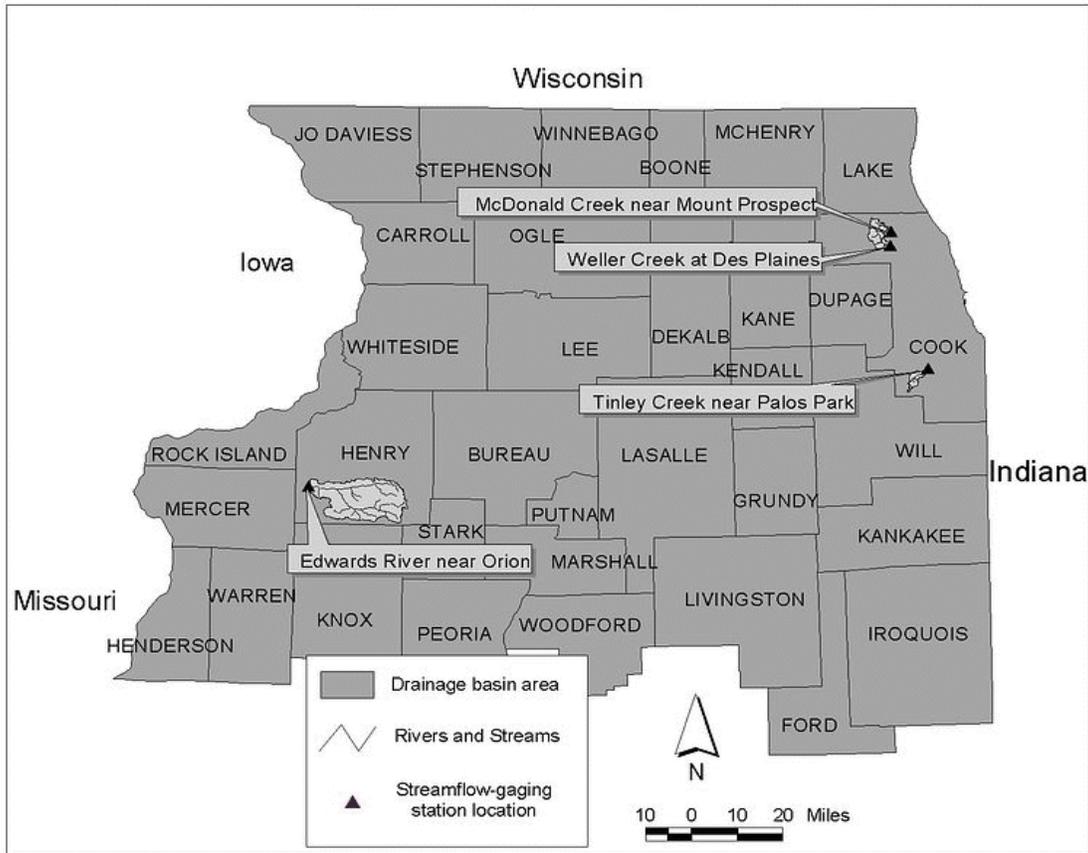
Figure 1. Map showing stream gages and watersheds mentioned in text.

urban. The watershed area is 11.2 square miles (sq mi) (Wicker et al., 1998). The McDonald and Weller Creek watersheds are located adjacent to one another in northern Cook County. The McDonald Creek watershed, with an area upstream of the gage of 7.93 sq mi (Wicker et al., 1998), includes portions of the suburban Chicago communities of Arlington Heights, Buffalo Grove, Mount Prospect, Palatine, Prospect Heights, and Wheeling. The Weller Creek watershed has an area of about 13.2 sq mi upstream of the gage (Wicker et al., 1998), the watershed includes portions of the suburban Chicago communities of Arlington Heights, Des Plaines, Mount Prospect, Palatine, and Rolling Meadows. The Tinley, McDonald, and Weller Creek gages have a common period of record extending from October 1952 to the present.

To provide useful data on recharge rates, discharges of effluent to the selected streams must ideally be zero. Artificial discharges would be interpreted as base flow by any manual or computerized hydrograph separation technique, and ground-water runoff estimates based on the base flow data from streams receiving artificial discharges would be erroneously high. Published references (Singh and Stall, 1973; Singh, 1983; Singh and Ramamurthy, 1993; and Wicker et al., 1998) indicate no documented artificial inflows to McDonald Creek upstream of the USGS gage. Wicker et al. (1998) indicates that Weller Creek received effluent from the Arlington Heights sewage treatment plant prior to November 15, 1958, so the data obtained prior to this date

may be of limited use in this study. Singh and Stall (1973), Singh (1983), Singh and Ramamurthy (1993), and Wicker et al., (1998) indicate that Weller Creek received no artificial discharges subsequent to November 15, 1958. Singh and Stall (1973) indicate that Tinley Creek received effluent from a small sewage treatment plant upstream of the USGS gage in 1970 at the rate of 0.31 cubic feet per second (cfs) in 1970, but Singh (1983) indicates that this discharge ceased before 1980. Records of discharges from this facility on file at IEPA show that the sewage treatment facility discharged effluent to Tinley Creek at rates approximating 0.31 cfs until some time between August and December 1973, when the plant became inactive. This effluent discharge comprised less than 3 per cent of mean total discharge in Tinley Creek, 11 cfs (Wicker et al., 1998), for the period of record of the gage. Owing to the absence of other suitable gage data sets for use in the project, we are including data from the Tinley Creek gage in the study with the awareness that the pre-1974 data from the gage might be influenced by the artificial discharge and may be of limited use in this study.

It is also critical that no diversions of water from the selected streams be present upstream of the gages. Such diversions would reduce base flow in downstream areas and would cause ground-water runoff estimates to be erroneously low. Published references (Singh and Stall, 1973; Singh, 1983; Singh and Ramamurthy, 1993; and Wicker et al., 1998) document no diversions upstream of the McDonald. Tinley, and Weller Creek gages. Pre-1970 data on diversions are not available.

Finally, large-scale control structures, which impound flow from upstream areas and release it slowly, would, if present, influence interpretations of base flow and ground-water runoff based on downstream gage data. USGS quadrangle maps covering the three selected watersheds, dating from the 1960's to the present, do not show significant control structures to be present. They do indicate, however, that some stormwater detention basins have been constructed within the watersheds. The effect of these basins, which slow down the movement of runoff through the watershed, will be considered as we analyze the hydrograph separation results. Gaged urban watersheds lacking these stormwater detention basins do not appear to be present in northeastern Illinois.

A stream gage data set from the Edwards River near Orion, in a rural setting, has been selected for comparison with the data from the northeastern Illinois stream gage data. The Edwards River gage has been in service for the entire common period of record of the three northeastern Illinois gages (October 1952-present). The Edwards River watershed, upstream of the gage, is 155 sq mi in area (LaTour et al., 1998) and is located in southern Henry County, Illinois. A small artificial discharge is documented by Singh and Stall (1973) and Singh et al. (1988)upstream of the gage, but the documented discharge rates of 0.20 and 0.24 cfs (in 1970 and 1984, respectively) suggest that the discharge to the stream has totaled less than 1 per cent of mean total discharge of 111 cfs reported by LaTour et al. (1998) for the period of record of the gage. Singh and Stall (1973), Singh et al. (1988), and LaTour et al. (1998) indicate no upstream diversions from the watershed. USGS quadrangle maps covering the three selected watersheds, dating from the 1960's to the present, do not show significant control structures to be present. The maps do show that small ponds are present in gullies and along intermittent streams within the dissected uplands of the watershed. These ponds would have the effect of slowing down the movement of runoff through the watershed and could potentially influence base flow estimates from the Edwards River gage data. However, owing to the lack of alternative rural gage data having both (1) the same period of record as the selected northeastern Illinois gages and (2) documented artificial discharges that total less than 1 per cent of mean total discharge, the Edwards River gage data has been selected for use in the study with the understanding that it might be influenced by the presence of mapped ponds within the watershed. During year 2 of the investigation, the northeastern Illinois data will be compared with gage data from other rural watersheds having shorter periods of record than the selected northeastern Illinois gages.

As discussed in the preceding section of this report, ground-water runoff approximates net recharge in watersheds in which both leakage to underlying aquifers and ground-water withdrawals may be considered negligible. Thus, it is critical that the effects of leakage to underlying aquifers and of ground-water withdrawals in the selected northeastern Illinois watersheds be considered.

In northeastern Illinois, the shallow aquifer system, consisting of the glacial drift together with the uppermost bedrock, can reasonably be considered to provide all of the ground-water runoff to the McDonald, Weller, and Tinley Creek watersheds. In response to a prevailing downward vertical hydraulic gradient, a small portion of ground-water recharge in the watersheds will leak across the underlying Maquoketa Confining Unit (a hydrostratigraphic unit consisting primarily of the Ordovician Maquoketa, Galena, and Platteville Groups) and into the underlying deep bedrock aquifer system. Walton (1962) estimated maximum leakage across the Maquoketa Group in northeastern Illinois at about 0.003 cubic feet per second per square mile (cfs/sq mi). Walton (1965) indicates that ground-water runoff during a year of near-normal precipitation in these areas is 0.1 to 0.2 cfs/sq mi. Comparison of these estimates of leakage and ground-water runoff suggests that leakage to underlying aquifers is about 1.5 to 3 per cent of ground-water runoff during a normal year of precipitation in the selected northeastern Illinois watersheds. This proportion is considered by the authors of the present report to be small enough to be dismissed as negligible with the understanding that estimates of recharge based on the base flow data may slightly underestimate actual ground-water recharge rates.

While the public water systems in and near the selected northeastern Illinois watersheds presently obtain water from Lake Michigan, this was not the case during the entire common period of record of the gages (which begins in October 1952). In fact, since October 1952, these public water systems have universally converted to Lake Michigan water from a locally-obtained ground-water source during the common period of record of the gages, which begins in October 1952. Records indicate that the majority of this ground water was withdrawn from the deep bedrock aquifer system, hydraulically separated from the shallow aquifer system by the Maquoketa Confining Unit. Several public water systems and other self-supplied commercial and industrial water users have, however, withdrawn water from the shallow aquifer system in the three watersheds (tables 1, 2, and 3). It is an inescapable conclusion that these withdrawals would have reduced ground-water runoff to some degree during the time of their occurrence. As a consequence, estimates of ground-water recharge rates based on base flow estimates from years during the periods of service of the wells will, to some degree, underestimate actual recharge. To determine whether shallow aquifer withdrawals in the watersheds could have significantly influenced base flow in McDonald, Tinley, and Weller Creeks, efforts are underway to obtain data on pumping rates and on drilling dates and dates of sealing, abandonment, disconnection, and disuse of the wells.

It is noteworthy that records show the presence of some domestic supply wells within the northeastern Illinois watersheds, although most residents of the region have, during the common period of record of the stream gages, obtained water from public water systems. Nevertheless, withdrawals from these domestic wells would have an effect, however incremental, on base flow that would cause estimates of ground-water recharge based on the base flow rates to underestimate actual recharge.

Efforts are underway to obtain data on public, industrial, and commercial withdrawals from the shallow aquifer system in the Edwards River watershed. Since it is not the authors' intention to employ the Edwards river data to estimate recharge rates, it is not as critical that base flow in the Edwards River be uninfluenced by ground-water withdrawals. It would be desirable, however, for shallow ground-water withdrawals to have remained more-or-less constant during the common period of record.

**Table 1. Public, Industrial, and Commercial Wells Withdrawing
Water From the Shallow Aquifer System in the McDonald Creek Watershed,
October 1952-September 1998**

| Owner | Well ID | Location[1] | | | Depth (ft) | Date Drilled | Date Unused[2] |
		T	R	Section			
Prospect Hgts Shopping Center	2	42N	11E	22	NR[3]	NR[3]	sealed, but date not reported
Prospect Hgts Shopping Center	3	42N	11E	22	111	NR[3]	1994
Prospect Hgts Shopping Center	1	42N	11E	22	128	1938	1991
Prospect Heights Pool	1	42N	11E	22	210	1958	

[1]All locations are within Cook County, Illinois.
[2]Sealing date, abandonment date, disconnection date, or first year of disuse. If blank, well is in use.
[3]Not Reported

Table 2. Public, Industrial, and Commercial Wells Withdrawing
Water From the Shallow Aquifer System in the Tinley Creek Watershed,
October 1952-September 1998

| Owner | Well ID | Location[1] | | | Depth (ft) | Date Drilled | Date Unused[2] |
		T	R	Section			
Silver Lake Country Club	1	36N	12E	11	260	1929	1981
Silver Lake Country Club	2	36N	12E	11	330	1929	1975
Silver Lake Country Club	3	36N	12E	11	500	1973	
Silver Lake Country Club	4	36N	12E	11	500	1974	
Silver Lake Country Club	5	36N	12E	11	198	NR[3]	1981
Silver Lake Country Club	6	36N	12E	11	450	1993	
Orland Park	4	36N	12E	10	408	1961	1986
Orland Park	5	36N	12E	13	517	1970	1986
Citizens Fernway Utility Div	1	36N	12E	23	125	1959	1988
Citizens Fernway Utility Div	4	36N	12E	23	420	1974	1974[4]

[1]All locations are within Cook County, Illinois.
[2]Sealing date, abandonment date, disconnection date, or first year of disuse. If blank, well is in use.
[3]Not Reported
[4]Well was never used and was eventually abandoned in 1988.

**Table 3. Public, Industrial, and Commercial Wells Withdrawing
Water From the Shallow Aquifer System in the Weller Creek Watershed,
October 1952-September 1998**

| Owner | Well ID | Location[1] | | | Depth (ft) | Date Drilled | Date Unused[2] |
		T	R	Section			
Mount Prospect	2	41N	11E	12	210	1927	1986
Mount Prospect	9	41N	11E	10	193	1955	1984
Mount Prospect	15	41N	11E	12	291	NR[3]	1983
Arlington Hgts	1	42N	11E	29	140	1909	1956
Arlington Hgts	4	42N	11E	30	1555[4]	1941	1981
Luther Village	1	42N	11E	19	251	1992	

[1]All locations are within Cook County, Illinois.
[2]Sealing date, abandonment date, disconnection date, or first year of disuse. If blank, well is in use.
[3]Not Reported
[4]Well finished in both the upper bedrock (the lowermost portion of the shallow aquifer system) and the deep bedrock aquifer system.

Precipitation Data

To account for the confounding effects of precipitation on base flow, a survey was made of weather observation stations having a period of record coincident with that of the four stream gages discussed above (i.e., October 1952 through September 1998). Monthly precipitation totals were obtained for the nearest of these stations to the Edwards River, McDonald Creek, Tinley Creek, and Weller Creek watersheds. These stations are located at Geneseo (near the Edwards River watershed) and at Chicago Midway Airport (near the McDonald Creek, Tinley Creek, and Weller Creek watersheds).

DATA ANALYSIS

Hydrograph Separation Procedure

The computer program HYSEP (Sloto and Crouse, 1996) was used to conduct hydrograph separations of streamflow data from the Edwards River, McDonald Creek, Tinley Creek, and Weller Creek gages for dates beginning October 1, 1952 and ending September 30, 1996. HYSEP permits the user to conduct hydrograph separations using any of three methods discussed by Pettyjohn and Henning (1979). These methods are based on empirical, manual methodologies employed by researchers rather than on the physics of streamflow hydrology. Use of a computer to conduct the hydrograph separations saves significant resources and eliminates the inconsistencies accompanying manual hydrograph separation. Of the three methods offered by HYSEP, we employed the *local minimum method* of hydrograph separation. This is the method

recommended for use by Pettyjohn and Henning (1979) for use when little is known about the physical conditions governing streamflow in a watershed. The output of the hydrograph separation procedure consists of values of daily mean base flow and direct runoff.

The daily mean total discharge, base flow, and direct runoff values were normalized by dividing by watershed area. From the resulting normalized values, monthly mean values of total discharge, base flow, direct runoff per unit of watershed area were calculated. In addition, the ratio of monthly mean base flow to monthly mean direct runoff was calculated.

Testing to Determine the Appropriate Test of Correlation of Precipitation and Streamflow Data

Non-normality of data can affect the commonly-employed Pearson product-moment correlation coefficient. Thus, the distributions of total monthly precipitation and of mean monthly total discharge, base flow, and direct runoff were tested for normality using the probability plot correlation coefficient (PPCC) method of Looney and Gulledge (1985) and discussed by Helsel and Hirsch (1995). The null hypothesis in the PPCC test, H_0, is that the data are normally distributed.

To conduct the test, the correlation coefficient between the observed data and their normal quantiles (or normal scores) is calculated as a test statistic. A plot of the data versus their normal quantiles will approximate a straight line is the data are normally distributed, and the linear correlation coefficient, r, between the data and their normal quantiles will be very close to 1.0.

Looney and Gulledge (1985a) calculated critical values of r for various sample sizes and for selected significance levels that can be used to test the hypothesis that a data distribution is normal. The significance level, α, is the probability that H_0 will be rejected when it is, in fact, true. If the calculated correlation coefficient is less than the critical value of r from Looney and Gulledge's (1985) table, then H_0 is rejected.

An α of 0.05 (or 5%) was selected for the PPCC test, and the test statistic was calculated for a random sample of 100 values selected from the populations shown in table 4. For a sample size of 100 and an α of 0.05, the null hypothesis H_0 is rejected when r is less than 0.987. Since the correlation coefficients are universally less than 0.987, the hypothesis that the populations are normally distributed is rejected in all cases.

Analysis of Correlation Between Precipitation and Streamflow Data

The degree of correlation between monthly total precipitation and monthly mean total discharge, base flow, direct runoff, and base flow/direct runoff ratio was evaluated using the Spearman rho rank-order correlation coefficient, a nonparametric analog to the Pearson product-moment correlation coefficient. The square of the correlation coefficient is a measure of the total variance accounted for by the relation (Barringer et al., 1994). Thus, the magnitude of the Spearman rank-order correlation coefficients reflect the degree to which variability in precipitation, rather than other factors such as land cover and basin geometry, account for variability in total discharge, base flow, direct runoff, and base flow/direct runoff ratio.

Trend Identification

Two techniques were employed to explore the data for trends. The first technique was the weighted low-regression filter LOWESS (LOcally WEigthed Scatterplot Smoothing) (Cleveland, 1979), which was applied to time-series plots of monthly total precipitation, mean total discharge, mean base flow, and mean direct

**Table 4. Probability Plot Correlation Coefficients for Flow and
Precipitation Data, October 1952-September 1996**

Population	Location					
	Edwards River near Orion	McDonald Creek near Mt. Prospect	Tinley Creek near Palos Park	Weller Creek at Des Plaines	Chicago Midway Airport	Geneseo
Monthly Mean Total Discharge	0.900	0.892	0.874	0.875	-	-
Monthly Mean Base Flow	0.915	0.862	0.759	0.885	-	-
Monthly Mean Direct Runoff	0.769	0.854	0.895	0.826	-	-
Monthly Mean BR Ratio	0.760	0.610	0.636	0.665	-	-
Monthly Precipitation	-	-	-	-	0.962	0.950

[1]Monthly Mean Base Flow / Monthly Mean Direct Runoff

runoff. LOWESS is a computationally intensive smoothing methodology that involves fitting at least 2^n weighted least squares equations, where n = sample size. A smoothness factor between 0 and 1 is selected subjectively by the analyst. A larger smoothness factor leads to greater smoothing of the data set.

The second technique was to construct double-mass curves for several measures of precipitation, total discharge, base flow, and direct runoff in the rural Edwards River watershed versus each of the three urban watersheds. The graphical-statistical method of double-mass-curve analysis (Searcy and Hardison, 1960) is based on the fact that a plot of the cumulation of one property against the cumulation of another property during the same time period will plot as a straight line if the sums are proportional. Slope changes in double-mass curves may indicate the timing and magnitude of changes that affect only one of the two variables or changes that affect both variables unequally. In the present investigation, slope changes in double-mass curves of the hydrograph separation series of the rural Edwards River versus those of urban McDonald, Tinley, and Weller Creeks may indicate the timing of land cover, land use, and other changes within the watersheds which affect flow in the streams. In addition, total monthly precipitation at Geneseo and Chicago Midway Airport are compared to explore for trends in monthly precipitation rates affecting one watershed independent of the other.

DISCUSSION

Correlation Between Precipitation and Flow Data

Spearman rho rank-order correlation coefficients between monthly total precipitation and monthly mean total discharge, base flow, direct runoff, and base flow/direct runoff ratio are shown in table 5. Correlations of mean monthly total discharge with precipitation are 0.42 for Edwards River and range from 0.54 to 0.65 for the urban watersheds, suggesting that precipitation accounts for about 18 per cent of the total variance of mean monthly total discharge observed at Edwards River and about 29 to 42 per cent of the total variance observed at the urban streams. Correlations of mean monthly base flow with precipitation are 0.30 for Edwards River and range from 0.33 to 0.39 for the urban watersheds, suggesting that precipitation accounts for about 9 per cent of the total variance of mean monthly base flow observed at Edwards River and about 11 to 15 per cent of the total variance observed at the urban streams. Correlations of mean monthly direct runoff with precipitation are 0.53 for Edwards River and range from 0.58 to 0.69 for the urban watersheds, suggesting that precipitation accounts for about 28 per cent of the total variance of mean monthly direct runoff observed at Edwards River and about 34 to 48 per cent of the total variance observed at the urban streams. Correlations of mean monthly base flow / direct runoff ratio with precipitation are -0.51 for Edwards River and range from -0.23 to -0.47 for the urban watersheds, suggesting that precipitation accounts for about 26 per cent of the total variance of mean monthly base flow / direct runoff ratio observed at Edwards River and about 5 to 22 per cent of the total variance observed at the urban streams.

The correlation of precipitation with the hydrograph-separation series can be expected to be highest with direct runoff, lowest with base flow, and intermediate between direct runoff and base flow for total discharge. The weaker correlation with base flow relative to that with direct runoff reflects the delayed response of ground-water flow to precipitation events. The correlation with the base flow / direct runoff ratio is expected to be negative because base flow will increase at the same time that runoff and precipitation are decreasing,

Table 5. Spearman Rho Rank-Order Correlation Coefficients Between Monthly Total Precipitation[1] and Monthly Mean Total Discharge, Base Flow, Direct Runoff, and Base Flow/Direct Runoff Ratio, October 1952-September 1996

Gaging Station	Correlation Coefficient			
	Total Discharge	Base Flow	Direct Runoff	BR Ratio[2]
Edwards River near Orion	0.42	0.30	0.53	-0.51
McDonald Creek at Mt. Prospect	0.54	0.39	0.60	-0.23
Tinley Creek near Palos Park	0.51	0.33	0.58	-0.47
Weller Creek at Des Plaines	0.65	0.33	0.69	-0.37

[1]Correlations for Edwards River at Orion are with precipitation at Geneseo, Illinois, and correlations for McDonald Creek, Tinley Creek, and Weller Creek are with precipitation at Chicago Midway Airport, Illinois.
[2]Base flow/Direct Runoff Ratio

and vice versa (Barringer et al., 1995). The correlations of precipitation with total discharge and direct runoff are greater for the urban watersheds than the rural Edwards River watershed, suggesting that the addition of more impervious surface and sewering in the urbanized basins has caused the correlation of runoff with precipitation to increase. As proposed by Barringer et al. (1995) in regard to an urbanized watershed in New Jersey, the increased correlation of precipitation with base flow might reflect leakage from storm sewers and recharge from detention basins. It is noteworthy that the absolute values of the negative correlation coefficients between precipitation and the base flow / direct runoff ratio are smaller for the urban watersheds than for the rural Edwards River watershed. These correlation coefficients might reflect the decreased response time of the base flow system to precipitation events in the urbanized watersheds mentioned previously.

During year 2 of the project, similar correlation coefficients will be calculated for one or more other rural watersheds. This will permit an assessment of whether the differences between the coefficients for the Edwards River and those for the urban watersheds, discussed above, are a function of differences in urban versus rural land cover or whether other watershed features could account for the differences in the coefficients.

Trend Identification

LOWESS-Smoothed Time-Series Plots

Smoothed time-series plots of monthly mean total discharge, base flow, and direct runoff for each of the four watersheds are shown in figures 2 through 5. A smoothed time-series plot of monthly precipitation is included in each figure for comparison with the flow trends. Discussion of these trends in the present report is primarily descriptive, and research to be completed during year 2 of the project is directed toward relating the trends to land cover and other changes in the watersheds.

Figure 3 shows LOWESS trends in precipitation in the McDonald Creek watershed, as indicated by precipitation at Chicago Midway Airport, and LOWESS trends in total discharge, base flow, and direct runoff of McDonald Creek. The LOWESS trend in precipitation suggests that precipitation generally declined from 1952 until about 1960. From 1960 through the early 1980's precipitation generally increased, though this trend is interrupted by a downward trend in precipitation during the mid-1970's. From the early 1980's until about 1990, the trend in precipitation at Chicago Midway was downward, and the LOWESS trend suggests that precipitation at Chicago Midway has been relatively constant since 1990. In contrast to precipitation, total discharge of McDonald Creek increased during the 1950's, as indicated by the LOWESS trend, as did base flow and direct runoff. From about 1960 through the early 1970's, the upward precipitation trend is accompanied by a similar upward trend in direct runoff, but during the early 1960's the trends in total discharge and base flow were relatively flat, or even slightly downward. From about 1965 through the early 1970's, trends of total discharge and base flow in McDonald Creek were upward, like that of direct runoff. Perhaps significantly, the trend lines indicate that direct runoff rates, which were generally less than those of base flow before 1965, began to exceed the base flow rates in about 1965 and continued to exceed base flow rates through the end of the study period in 1996. Such a relationship between base flow and direct runoff trends is consistent with a conceptual model of the urbanizing McDonald Creek watershed in which sewer development and expanding impervious surfaces have the effect of reducing infiltration, ground-water recharge, and base flow, and increasing direct runoff. The downward trend in precipitation during the 1970's is accompanied by downward trends in total discharge and base flow and a more subtle downward trend in direct runoff. The upward trend in precipitation during the late 1970's and early 1980's is accompanied by a upward trends in total discharge, base flow, and direct runoff. The downward precipitation trend between the early 1980's and about 1990 is accompanied by slight downward trends in total discharge and direct
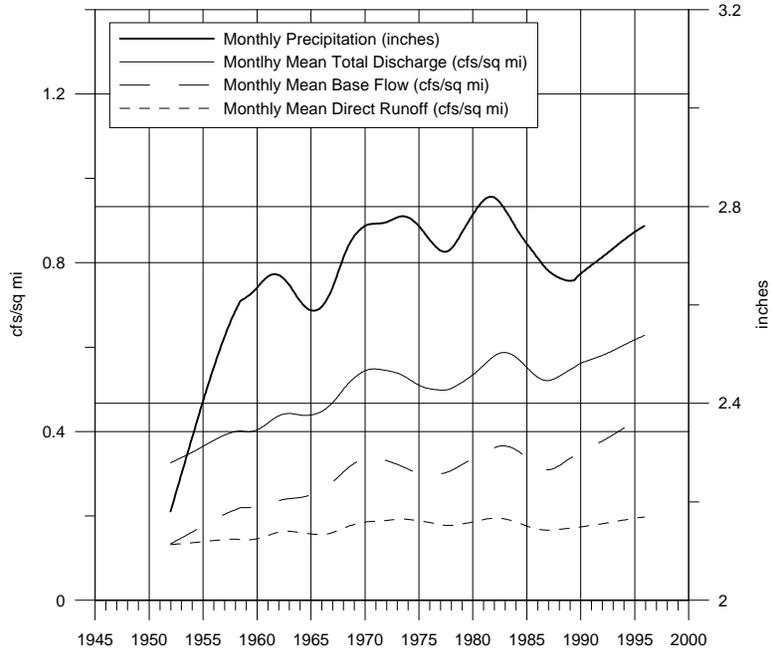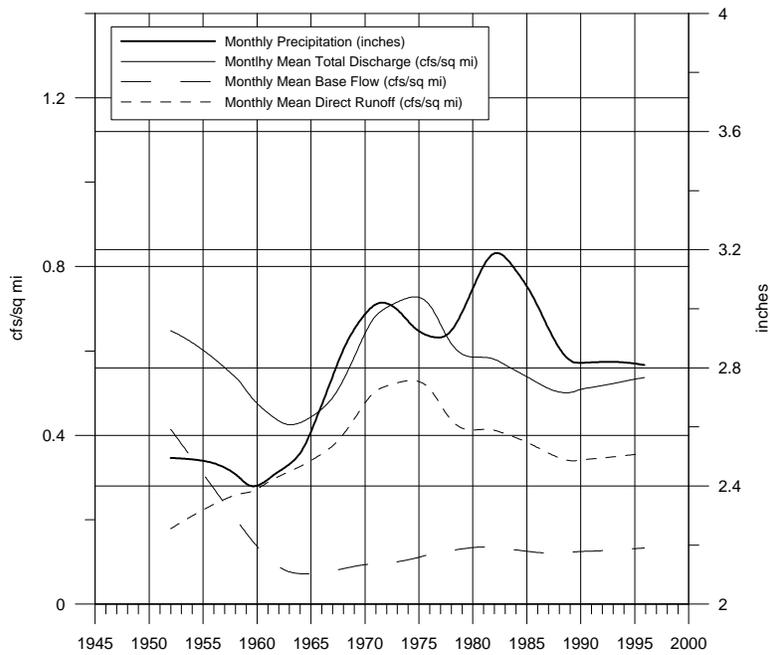
Figure 2. Smoothed time-series plot of precipitation and streamflow data, Edwards River near Orion.
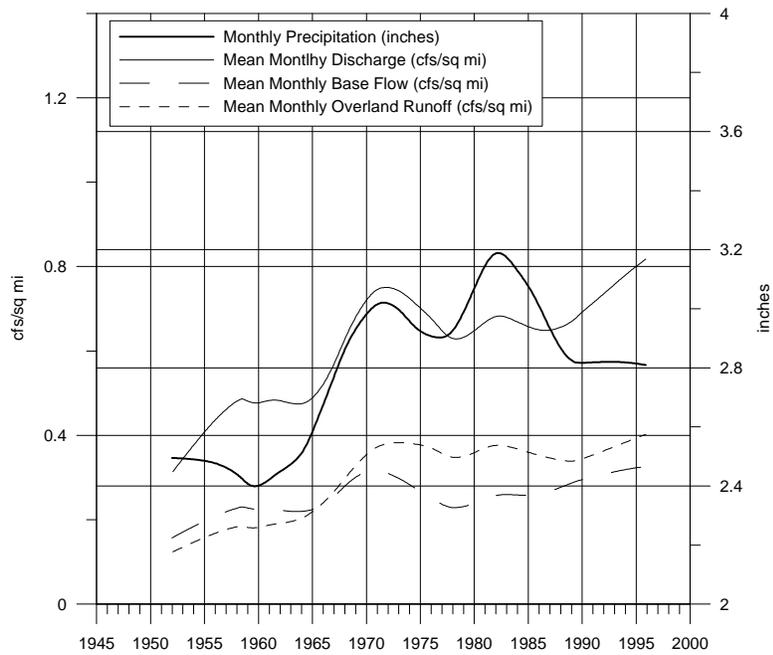
Figure 3. Smoothed time-series plots of precipitation and streamflow data, McDonald Creek near Mt. Prospect.
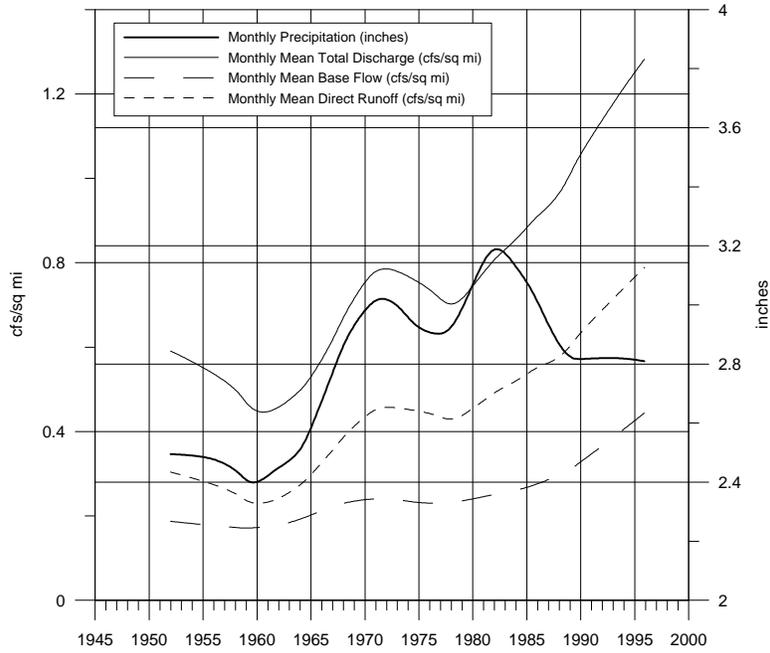
Figure 4. Smoothed time-series plots of precipitation and streamflow data, Tinley Park near Palos Park.

Figure 5. Smoothed time-series plots of precipitation and streamflow data, Weller Creek at Des Plaines.

runoff, but the base flow trend during this period is level to slightly upward. During the 1990's, when the precipitation trend is more-or-less level, the trends in total discharge, base flow, and direct runoff are all upward.

LOWESS trends in total discharge, base flow, and direct runoff of Tinley Creek are similar to the Chicago Midway precipitation trend through the early 1980's (figure 4). In contrast to the downward precipitation trend between the early 1980's and about 1990, however, trends in total discharge, base flow, and direct runoff were all upward. These upward trends continued from 1990 through the end of the study period in 1996, when the precipitation trend is more-or-less level. Pre-1974 effluent discharges to Tinley Creek from a small sewage treatment plant, mentioned previously, are not clearly indicated in figure 4. A slight downward turn of the base flow trend line in the early 1970's may in part reflect the cessation of this discharge, but this correlation is confounded by the fact that the decline in the base flow trend during the early 1970's is contemporaneous with declines in the precipitation, total discharge, and direct runoff trends.

During the 1950's until about 1960, when the trend in precipitation at Chicago Midway was downward, trends in total discharge and base flow of Weller Creek were also downward (figure 5). The trend in direct runoff during this period is upward, however. Furthermore, the trend lines suggest that rates of direct runoff overtook rates of base flow in Weller Creek during the late 1950's, and rates of direct runoff remained higher than those of base flow through the end of the study period in 1996. The downward trend in base flow that concludes about 1960, together with the observation that direct runoff rates overtook base flow rates during the late 1950's, probably reflect the discharge of effluent to Weller Creek in the 1950's from the Arlington Heights sewage-treatment plant, with this artificial discharge ceasing in November 1958. HYSEP, the computer program used for hydrograph separation employed in this study, would have recognized the effluent discharge as base flow. Between the early 1960's and the end of the study period in 1996, the trends in total discharge and direct runoff of Weller Creek are closely similar. These trends are roughly similar to the precipitation trend through the early 1970's, but the similarity disappears between the early 1970's and early 1980's. During the early part of the generally downward precipitation trend of the mid-1970's, the trends of total discharge and direct runoff are upward, continuing the trend begun in the early 1960's. Generally downward trends in total discharge and direct runoff prevailed from about 1975 through 1990, and trends in total discharge and direct runoff were slightly upward during the 1990's. The downward trends in total discharge and direct runoff are in contrast to the upward precipitation trend the prevailed from the late 1970's through the early 1980's. The trend in base flow is level to slightly increasing between the early 1960's and the end of the study period in 1996.
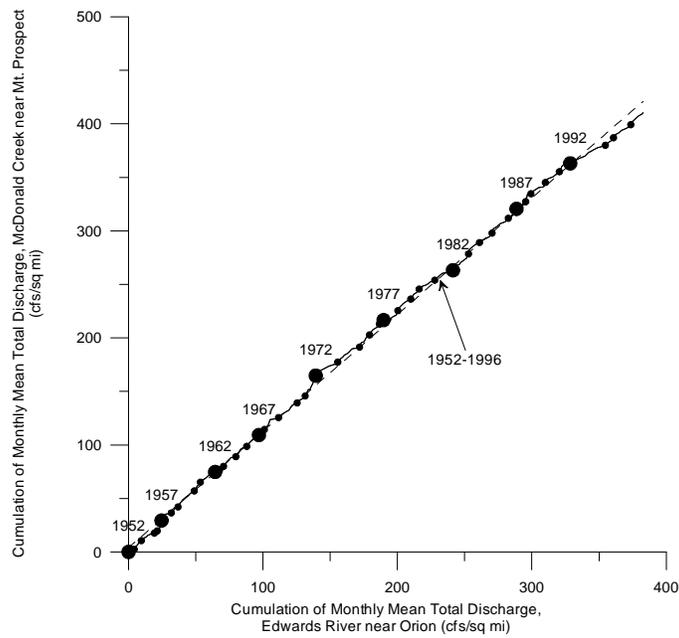
Double-Mass Curve Analysis

Figure 6 is a double-mass curve of the cumulation of precipitation at Geneseo versus that of precipitation at Chicago Midway Airport. On this and the other double-mass curves included in this report, circular symbols superimposed on the double-mass curve correspond to October data points and hence mark increments of one year. Every fifth data point is marked with a slightly larger circular symbol and annotated with the year corresponding to the data point. For example, *1967* indicates that the relatively large circular symbol directly below the annotation corresponds to the October 1967 data point. The relatively linear plot indicates that precipitation at the two locations has remained essentially proportional over the study period.

The double-mass curves shown in figures 7 through 9 illustrate the cumulation of monthly mean total discharge at the rural Edwards River gages versus those of monthly mean total discharge at the three urban gages. Linear trends which we have identified subjectively in each double-mass curve (and in the double-mass curves showing base flow and direct runoff, discussed in the following paragraphs) are indicated by superimposed dashed lines annotated with the approximate dates of the data on which each linear trend is based. Figure 7 suggests that monthly mean total discharge at McDonald Creek and Edwards River have
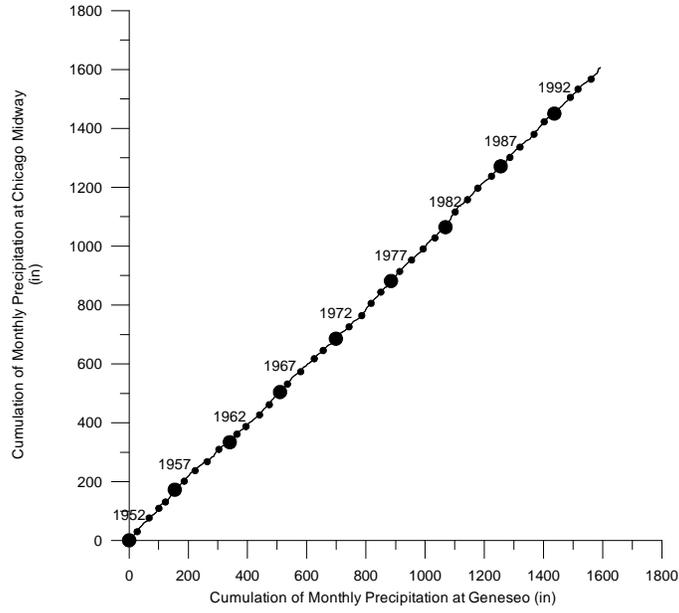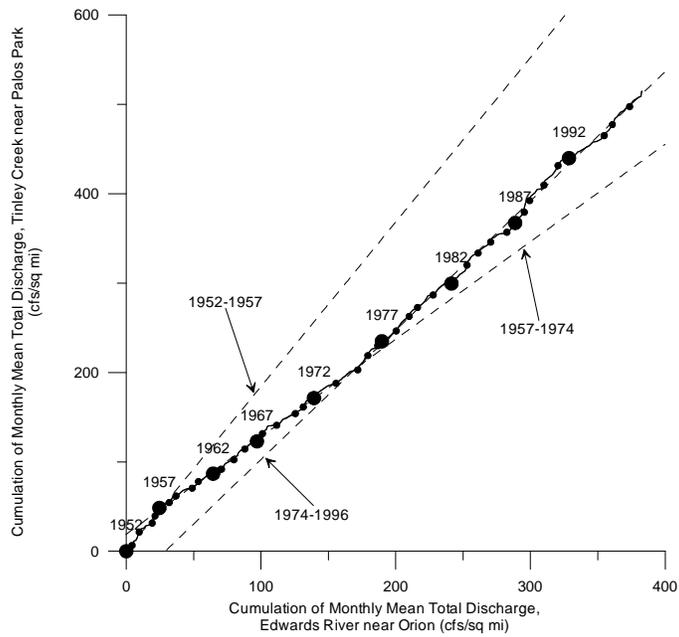
Figure 6. Double-mass curve showing cumulative monthly precipitation at Geneseo, Illinois, versus Chicago Midway Airport.

Figure 7. Double-mass curve showing cumulative monthly mean total discharge at Edwards River versus McDonald Creek.
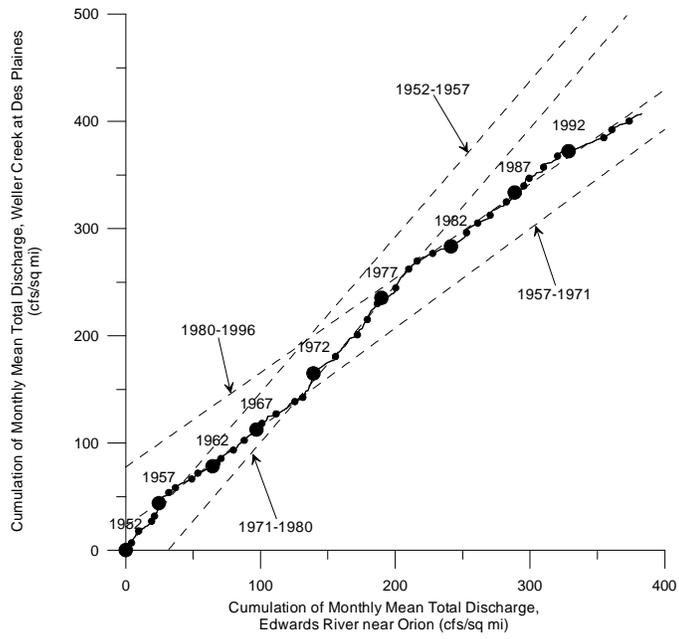
Figure 8. Double-mass curve showing cumulative monthly mean total discharge at Edwards River versus Weller Creek.
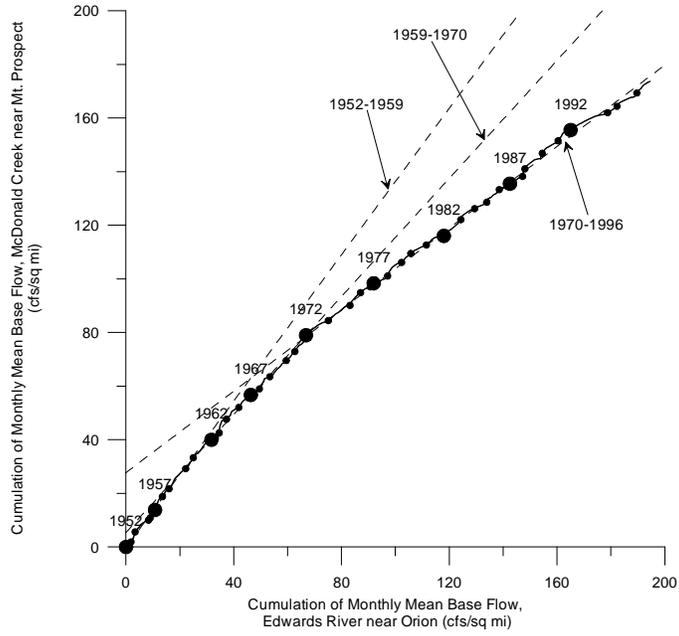

Figure 9. Double-mass curve showing cumulative monthly mean total discharge at Edwards River versus Tinley Creek.

remained more-or-less proportional during the study period, although a slight deviation of the post-1992 data points from the linear trend based on the complete, 1952-1996, data set may indicate a reduction in monthly mean total discharge during these later years. Figures 8 and 9 suggest three and four changes of monthly mean total discharge rates in Tinley and Weller Creeks. In both cases, the steep slope of the early data suggest that total discharge in the streams was high, and possibly at its highest, during the earliest part of the study period, from 1952 to about 1957. High total discharge rates in Weller Creek during this period probably reflect the discharge of effluent to the stream from the Arlington Heights sewage-treatment plant. This artificial discharge ceased in November 1958. Total discharge then occurred at a lower rate until about 1974 in Tinley Creek and until 1971 in Weller Creek, at which time total discharge increased. Figure 8 suggest that total discharge of Tinley Creek during the period 1974 through 1996, while generally higher than the 1957-1974 period, did not attained the rates of the 1952-1957 period. Figure 9 suggests that total discharge during the 1971-1980 period increased to approximately the rate of the 1952-1957 period. It then decreased during the period 1980-1996 to about its 1957-1971 rate.

The double-mass curves shown in figures 10-12 show the cumulation of monthly mean base flow at the rural Edwards River gage versus those of monthly mean base flow at the three urban gages. The plots suggest that base flow in the streams has, overall, decreased since the earliest portion of the common period of record in the 1950's. Although the lack of obvious breaks in slope in the double-mass curve in figure 10 suggests that base flow in McDonald Creek has decreased gradually since the 1950's, it is possible to superimpose subjective linear trends on the data suggestive of stepwise decreases in base flow in about 1959 and 1970. Figures 11 and 12 suggest overall high rates of base flow in Tinley and Weller Creeks prior to 1959 and 1958, respectively, that have not been attained since. Possible linear trends in the data, indicated in figures 11 and 12, suggest alterations of the base flow system in Tinley Creek in 1959, 1974, and 1979 and in Weller Creek in 1958, 1971, and 1980. It is likely that the high rates of base flow in Weller Creek from 1952 to 1958 (figure 12) reflect effluent discharges from the Arlington Heights sewage treatment plant. Ironically, figure 13 suggests that base flow rates in Tinley Creek increased in about 1974, almost precisely when effluent discharges to the stream ended.

Double-mass curves illustrating the cumulation of monthly mean direct runoff at the Edwards River gage versus those of monthly mean direct runoff at the three urban gages are shown in figures 13-15. Overall, the plots show that direct runoff has increased in two of the three urban watersheds. Figure 13 shows that direct runoff increased in McDonald Creek, possibly gradually, although linear trends, identified subjectively in the data, suggest that direct runoff increased to a generally higher rate in about 1967 and remained at that rate through the end of the study period in 1996. Figure 14 suggests that overall rates of direct runoff in Tinley Creek from 1974-1996 are similar to those of 1952-1957. The plot suggests that rates of direct runoff in Tinley Creek were generally lower from 1957-1974. Figure 15 suggests that direct runoff in Weller Creek increased after 1966 to rates higher than those prevailing during the period 1952-1966. Prevailing rates of direct runoff in Weller Creek appear to have returned to lower values from 1980-1996, but these rates were still higher than those suggested by the 1952-1957 data.


SUMMARY

Stream discharge measurements from USGS stream gages in three watersheds in northeastern Illinois (McDonald Creek near Mt. Prospect, Tinley Creek near Palos Park, and Weller Creek at Des Plaines) and one water shed in rural northwestern Illinois (Edwards River near Orion) have been selected for study of the impacts of urbanization on base flow and ground-water recharge rates in northeastern Illinois. These gages have a common period of record extending from October 1, 1952 through the present, a period during which the three northeastern Illinois watersheds underwent substantial urbanization. The northwestern Illinois
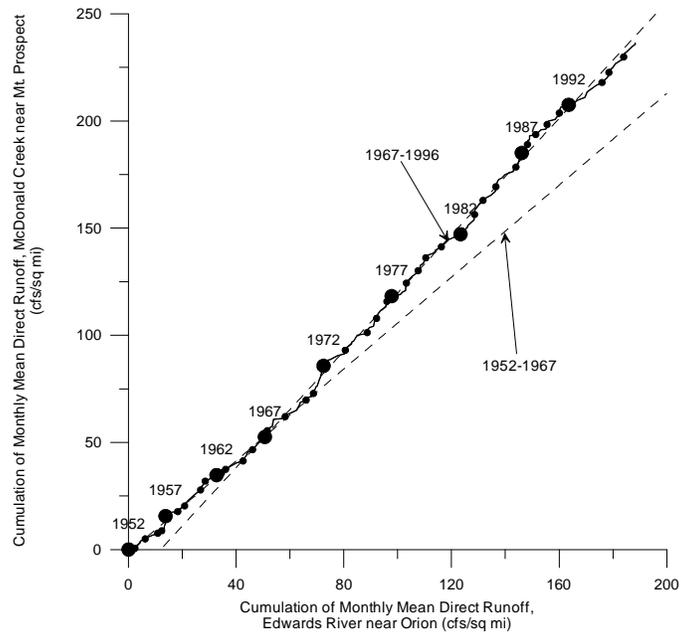
**Figure 10. Double-mass curve showing cumulative
monthly mean base flow at Edwards River
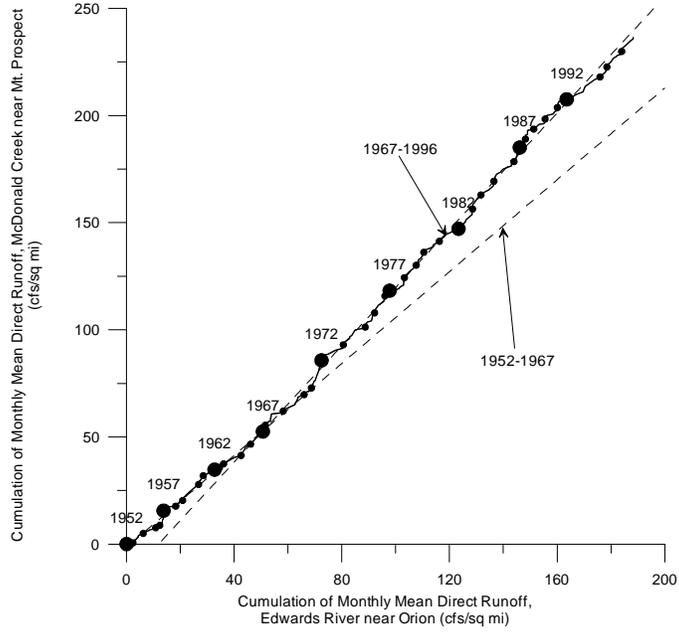versus McDonald Creek.**
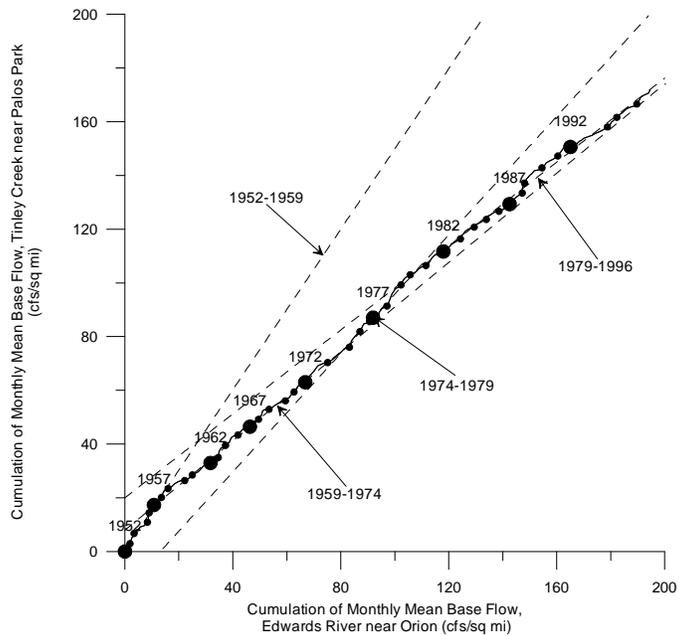
**Figure 11. Double-mass curve showing cumulative
monthly mean base flow at Edwards River
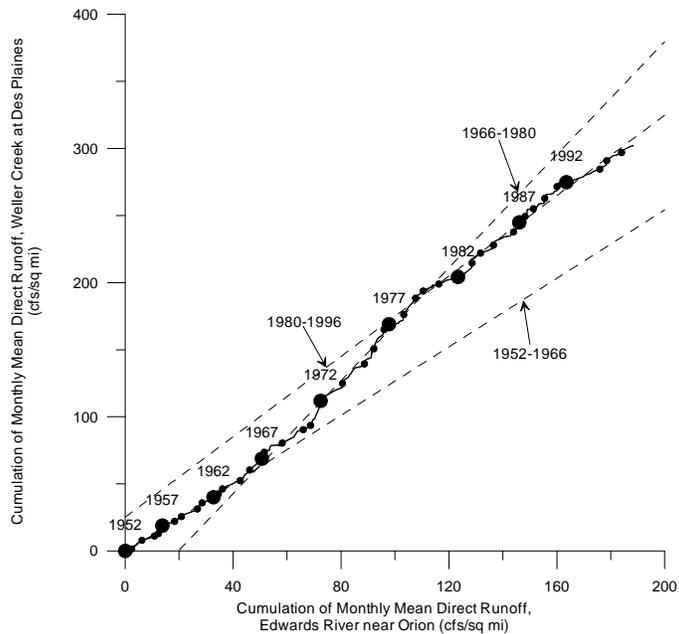versus Tinley Creek.**
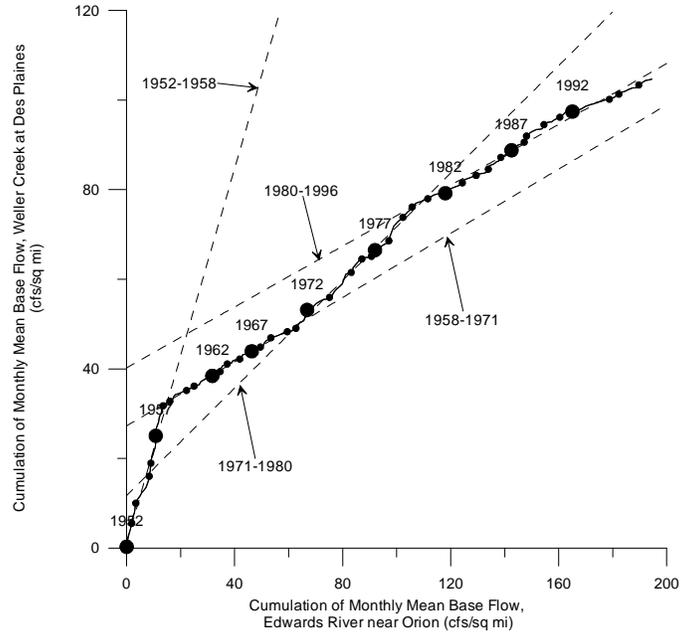
Figure 12. Double-mass curve showing cumulative monthly mean base flow at Edwards River versus Weller Creek.

Figure 13. Double-mass curve showing cumulative monthly mean direct runoff at Edwards River versus McDonald Creek.

Figure 14. Double-mass curve showing cumulative monthly mean direct runoff at Edwards River versus Tinley Creek.

Figure 15. Double-mass curve showing cumulative monthly mean direct runoff at Edwards River versus Weller Creek.

watershed has remained largely rural during this time period. Available documentation indicates that the selected northeastern Illinois streams have received no artificial discharges during the common period of record, and the Edwards River has received discharges at a rate that is less than 1 per cent of mean discharge. Available mapping indicates that large control structures are absent from all four of the watersheds, although stormwater detention basins and small ponds are present.

Based on mean daily discharge measurements from the four gages for the period October 1, 1952 through September 30, 1996, estimates of mean daily base flow and direct runoff were developed using the computer program HYSEP (Sloto and Crouse, 1996). Monthly mean base flow and direct runoff were calculated from these daily estimates. In addition, estimates of monthly mean total discharge were calculated from the raw mean daily discharge data from the gages. Trends were estimated from these monthly estimates of mean total discharge, base flow, and direct runoff using the weighted low-regression filter LOWESS (Cleveland, 1979).

Estimates of monthly precipitation for the common period of record were obtained for stations at Geneseo, Illinois (near the Edwards River watershed) and Chicago Midway Airport (near the McDonald, Tinley, and Weller Creek watersheds).

Spearman rho rank correlation coefficients between precipitation and mean monthly total discharge, base flow, direct runoff, and base flow / direct runoff ratio (BR ratio) at each of the selected gages were calculated. The correlation coefficients indicate a stronger correlation between precipitation and total discharge, base flow, and direct runoff in the northeastern Illinois watersheds than in the Edwards River watershed. The correlation coefficient between precipitation and the BR ratio is negative for all of the watersheds, but the absolute value of the correlation coefficient is less for the northeastern Illinois watersheds than for the Edwards River watershed. The correlation coefficients are consistent with a conceptual model in which the process of urbanization has increased the responsiveness to precipitation events of total discharge, direct runoff, and base flow in the northeastern Illinois watersheds.

Trends were estimated from these monthly estimates of mean total discharge, base flow, and direct runoff using the weighted low-regression filter LOWESS (Cleveland, 1979) and the graphical-statistical method of double-mass analysis (Searcy and Hardison, 1960). These trends suggest the timing and magnitude of alterations in land cover and water resources management strategies in the northeastern Illinois watersheds which have affected total discharge, base flow, and direct runoff in the watersheds. The smoothed time-series data suggest that base flow rates in the rural Edwards River watershed are more responsive to precipitation than are the direct runoff rates. This responsiveness of base flow to precipitation (and the lack of responsiveness of direct runoff rates to precipitation) is perhaps a reflection of the Cahokia Alluvium bordering the stream and its tributaries in many areas upstream of the gage near Orion. In general, trends in total discharge, base flow, and direct runoff in McDonald, Tinley, and Weller Creeks are less consistent with precipitation trends than are those in the rural Edwards River. The trends indicate that rates of direct runoff have overtaken rates of base flow in the McDonald and Weller Creek watersheds, but in Weller Creek, this relationship probably reflects the cessation of effluent discharges to the stream.

Double-mass curves are plots of cumulation of one quantity versus that of another quantity. As long as the proportionality of the plotted quantities does not change, the double-mass curve will be linear. Changes in slope indicate that the proportionality of the plotted quantities has changed. In general, the double-mass curves developed for this project show that, relative to the rural Edwards River watershed, base flow rates in the urban watersheds were proportionally less during the final portion of a study period October 1, 1952- September 30, 1996 than during the initial portion of the period. Relative to the Edwards River watershed, rates of direct runoff in the urban watersheds during the final portion of the period were proportionally greater in two of the three urban watersheds (McDonald and Weller Creeks) at the end of the study period than at the beginning; the rate of direct runoff in the other urban watershed (Tinley Creek) was proportionally

about the same relative to the Edwards River at the end of the study period as the beginning. The double-mass curves suggest that total discharge in two of the three urban watersheds (Tinley and Weller Creeks), relative to the Edwards River, was proportionally less during the final portion of the study period than during the beginning; total discharge in the other urban watershed (McDonald Creek) was proportionally about the same relative to the Edwards River at the end of the study period as the beginning. In general, the results of the double-mass curve analysis are consistent with a conceptual model of the northeastern Illinois watersheds in which sewering and impervious surfaces have reduced infiltration, and thence ground-water recharge and base flow in McDonald, Tinley, and Weller Creeks.

ACKNOWLEDGMENTS

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