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Pilot Study: Riffle-Pool Geometry below Algonquin and Aquatic Habitat Assessment

by Sally A. McConkey, Robert S. Larson, and Krishan P. Singh
Office of Surface Water Resources & Systems Analysis

Prepared for the
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Illinois State Water Survey
Hydrology Division
Champaign, Illinois

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Notations

A = cross-section area of flow

Avg = average

CV = coefficient of variation

D = hydraulic depth

P = pool

R = riffle

R/D = riffle/divided flow

Std = standard deviation

V = velocity

W = width

INTRODUCTION

The Fox River flows through northeastern Illinois. Urban areas are expanding rapidly in this region. However, many of the communities located along the Fox River were established before 1900. The Fox River has unique geologic and hydrologic features and has also been extensively modified by human activities. The steamflow characteristics of this river and the aquatic habitat availability were investigated. An extensive program of field measurements was conducted along the segment of the Fox River from Algonquin to Serena (above the Dayton Dam pool). Hydraulic parameters, depth, velocity, and flow width, were measured and bed materials were inspected. Historical steamflow data were reviewed. The availability of suitable habitat was assessed for measured flow conditions. The Instream Flow Incremental Methodology (IFIM) developed by the U.S. Fish and Wildlife Service was used to evaluate the habitat in terms of the measured flow parameters. This study provides basic information on the channel forms and flow parameters of a river that has been subjected to extensive modification of discharges, channel form, and surrounding land use.

Purpose and Scope

The purpose of this study was to provide basic information needed to define the nature of the bed and channel forms, which have evolved along the Fox River, and the habitat provided in terms of the flow parameters. The investigation focused on the collection of field-measured widths, depths, and velocities along selected reaches of the Fox River between Algonquin and Serena. Of particular interest was the study of naturally forming shallow and deep areas (riffles and pools), both in backwater pool areas above in-channel dams and in areas not affected by the backwater. The study provides a comparison of channel forms and flow characteristics in segments of the river subject to differing controls, both natural and artificial. The availability of suitable aquatic habitat provided by these diverse conditions was determined for measured flows using the IFTM.

In the interest of clarity a distinction must be drawn between the pools created by the in-channel dams and the deeper areas of the river (pools) that form naturally, alternating with shallows (riffles). The pools created by the dams are referred to as backwater pools. The naturally formed deep and shallow segments in the river are referred to as pools and riffles, respectively. The undulating profile of the bed surface creates riffles and pools.

Acknowledgments

This study was jointly supported by the Division of Water Resources, Illinois Department of Transportation, and the Illinois State Water Survey (ISWS). Gary R. Clark, Division of Water Resources, served in a liaison capacity during the course of this study. Particular recognition goes to Elizabeth Esseks who supervised the field work, performed data entry, and made calculations and graphics for report preparation. Kathleen J. Brown typed and formatted the final report, which Eva Kingston edited. Linda Hascall finalized the illustrations.

DESCRIPTION OF BASIN

The Fox River has its headwaters in Waukesha County, Wisconsin, and enters the state of Illinois at the northern border of McHenry County. At the Wisconsin-Illinois border the Fox River has a drainage area of 870 square miles (sq mi). The river continues in a southerly direction, flowing through a series of lakes, the Fox Chain of Lakes, in McHenry and Lake Counties. The river flows south through Kane County then turns southwest. It flows through Kendall County and then LaSalle County where it joins the Illinois River at Ottawa. The Fox River is a major tributary of the Illinois River with a drainage area of 2658 sq mi at its mouth. The basin area includes all or part of Waukesha, Racine, Walworth, and Kenosha Counties in Wisconsin, and McHenry, Lake, Cook, Kane, DuPage, Kendall, DeKalb, Grundy, Lee, Will, and LaSalle Counties in Illinois. The study area extends from the Algonquin Dam in McHenry County to just above the pool created by the Dayton Dam in LaSalle County. A map of the basin is shown in Figure 1.

The flat, marshy basin area above Algonquin gives way to a relatively steep and narrow segment from below Algonquin to Geneva in Kane County. Downstream of Algonquin the terrain is more hilly with bluffs encroaching on the floodplains. The basin is approximately 28 miles wide at the Wisconsin-Illinois border, near Algonquin it is 17 miles wide. It narrows to a minimum width of 10 miles near Geneva in Kane County. The basin terrain becomes less steep below Geneva, and the basin widens again.

In Illinois the Fox River is unique in that it has a less steep slope in upstream reaches compared to the downstream reaches as shown in Figure 2. The total length of the river is about 187 miles with a total fall of about 460 feet and an average slope of about 2.5 feet per mile. However, from Algonquin to South Elgin (segment 3 on Figure 2) the slope is about 2 feet per mile, between South Elgin and Yorkville (segment 2 on Figure 2) it is steepest with a slope of about 4.5 feet per mile, becoming less steep below Yorkville to above Dayton (segment 1 on Figure 2) with a slope of about 2.7 feet per mile.

The Fox River is dotted with well established, vegetated islands and sand-and-gravel bars. Over 230 islands were identified between Algonquin and Dayton in a 1947 survey of the river for the Illinois Division of Waterways (1962). Between Algonquin and Dayton, fairly straight channel reaches alternate with braided segments. The braided segments have a sinuous channel interspersed with islands. Above Algonquin the watershed is characterized by a series of lakes and a dredged navigation channel with few islands. Between Algonquin and the mouth at the Illinois River near Ottawa the sinuosity (ratio of channel length to valley length) is about 1.2. A value of 1.5 or greater is indicative of a meandering channel and for a value below 1.5 the river may be classified as

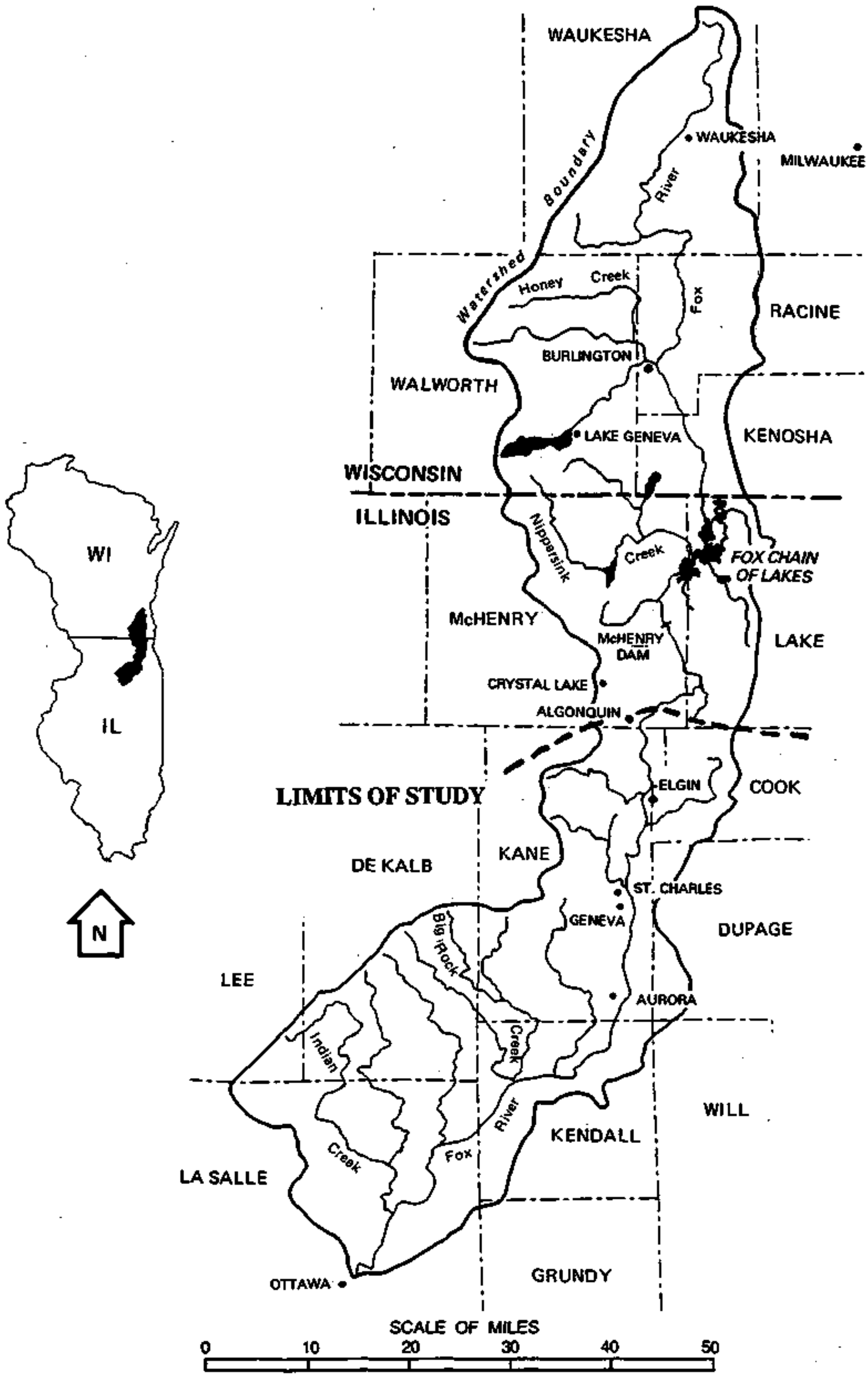

Figure 1. Fox River Basin in Illinois and Wisconsin (after Knapp, 1988)

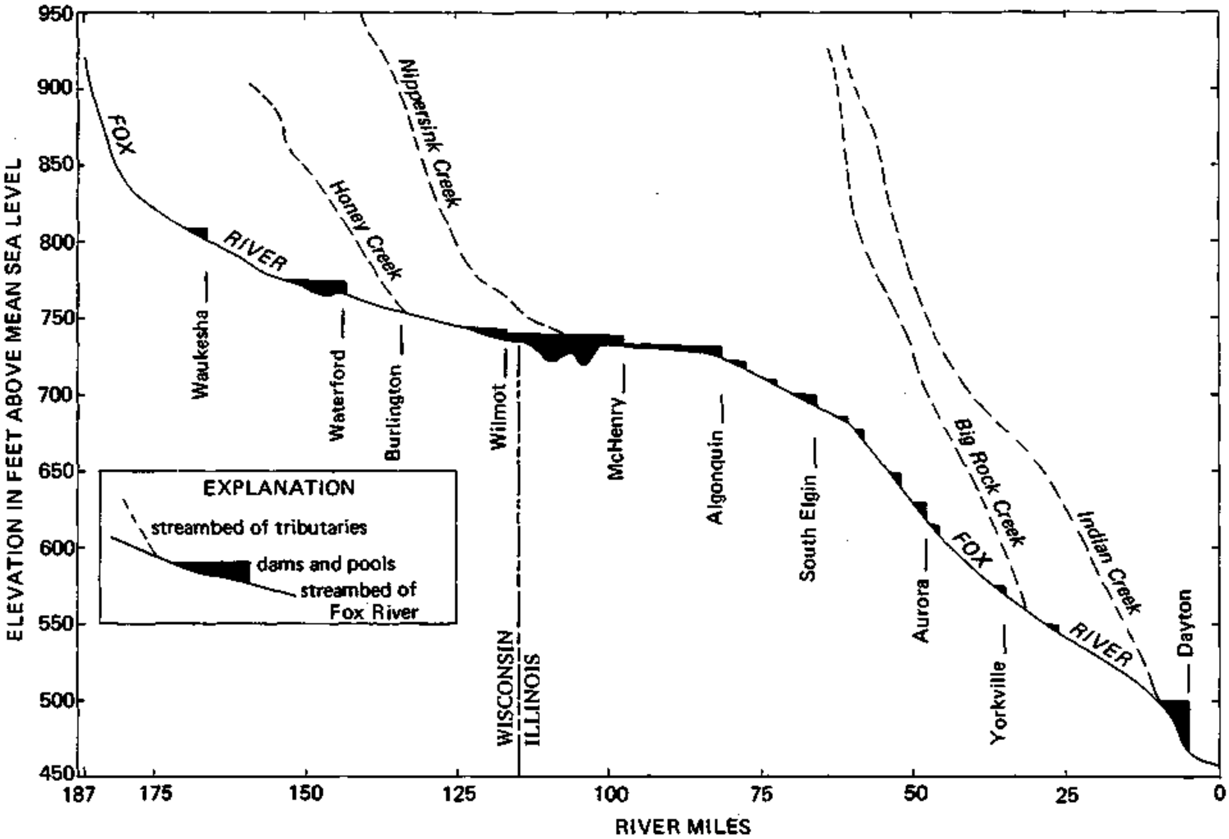

Figure 2. Riverbed profile of the Fox River and major tributaries
and location of major dams (after Knapp, 1988)

straight or sinuous (Leopold, Wolman, and Miller, 1964). Braided channels often have reaches that meander, but they are usually less sinuous than meandering channels.

Human Modifications

The Fox River has been extensively modified by the construction of 19 in-channel dams, of which 15 are located in Illinois. The dam at Wilmot, Wisconsin, was breached by floodwater in 1992 and no longer exists. Thus the current number of dams is 18. Their names and locations are listed in Table 1 along with other pertinent and descriptive information. As can be observed from the data presented in Table 1, most of the dams have been in place in one form or another for over 100 years. This provides an excellent opportunity to observe the channel form that evolves in a controlled river system.

These dams form backwater pools, which extend approximately 0.5 to 16.3 miles upstream from the dams. With the exception of the Dayton Dam, the dams located along the Fox River in Illinois are less than 15 feet high; many are less than 10 feet high. The pool lengths reported in Table 1 represent the distance from the dam crest elevation to the location on the stream where the elevation is approximately that of the dam crest. There are about 76.2 river miles between the Algonquin Dam and the Dayton Dam; on the basis of the data in Table 1 (from the Illinois Department of Transportation), approximately 35 of these miles are within the backwater pools at crest elevation.

Flows in the Fox River have changed over time as a consequence of area development. Flows are directly regulated, and are also modified by various uses of the river and river water.

Discharges in the Fox River are regulated by the operation of the gates at Wilmot Dam in Wisconsin and Stratton Dam (formerly McHenry Dam) above Algonquin. The Wilmot Dam is above the Chain of Lakes. Flows in the study area are primarily affected by the gate operation policy at Stratton Dam. Discharges are manipulated to minimize flooding, maintain lake levels in the Chain of Lakes for navigation and recreation, and maintain desirable minimum flows downstream. Other in-channel dams do not have operable gates. However, the backwater pools have greater width than the original river and hence greater water surface area. This increases evaporation losses. Singh (1983) estimates a loss of 3 cubic feet per second (cfs) per square mile of surface area for instream pools on the Fox River during dry periods, typically late August through September, under 7-day, 10-year low flow conditions.

The flow regimen of the Fox River has been changed by urban development, particularly in Kane County. Peak discharges are typically increased with urbanization, and this may result in channel enlargement (Hammer, 1972). The communities along the

Table 1. Fox River Dams

Name	*Yr. orig. constr.*	*Yr. pres. constr.*	*River mile(1)*	*Pool length (mile)*	*Pool area (acre)*	*Dam height (2) (feet)*	*Crest storage (acre-ft)*	*Drainage area (1) (so mi)*
Dayton	1830	1925	5.4	4.1	199	38	605	2631
Yorkville	1838	1961	36.08	2.2	111	7		
Montgomery	1916	1967	46.3	1.4	48	8	131	
Aurora (west)	1841	1937	47.8	. 0.5	67	15	80	
Aurora (east)	1834	1936	48.35	1.0	33	11.5		
North Aurora	1834	1964	51.9	2.3	133	9	159	
Batavia	1844	1962	54.8	1.5	74	5		1658
Batavia	1834	1964	55.5	1.1	68	12	169	
Geneva	1916	1961	57.9	2.0	89	13		1652
St. Charles	1916	1939	59.9	5.2	295	10.3	143	1646
South Elgin	1836	1973	67.3	3.7	192	8.3		1555
Elgin	1837	1916	71	6.3	314	13		
Carpentersville	1838	1916	77.2	4.5	140	9		
Algonquin	1854	1947	81.6	16.3	849	10.5		1399
McHenry	1907	1939	97.7	6.8	6850	7	37000	1249
Wilmont (3)	1852	1992	116.6		135			868
Rochester, WI					46			
Waterford, WI					1240			
Waukesha					23			

Notes:

Tabular information from "Fox River Dams Study Report", 1974 Revised 1976, Illinois Department of Transportation, Division of Water Resources , unless otherwise noted.

(1) River miles from the mouth and drainage area from Knapp (1988).
River miles agree with data published by the USGS (Healy, 1979), but there are some differences between reported drainage areas.

(2) Butts and Evans, 1978

(3) Removed after flood breech.

Fox River for the most part use ground water from both deep and shallow aquifers not connected to the river. The treated wastewater from these communities is discharged to the Fox River, which increases the river flow. Increases in effluent discharges over the years have also caused river flow to increase (Singh and Stall, 1973; Singh, 1983). This is most dramatic during low flows, when the accumulated effluent discharges may represent as much as 50 percent of the total flow (Broeren and Singh, 1987).

The Fox River is also used as a source of water supply for the cities of Elgin and Aurora. Water withdrawn from the river is returned as treated wastewater with an estimated 10 percent or less consumptive loss.

Recreation

The Fox River provides considerable recreational opportunity. It is a popular area for fishing, boating, and canoeing. There are numerous game fish in the Fox River. The tailgates of the dams are the most popular for fishing (Brown, 1989). Power boats operate in the backwater pool areas above the dams. Canoeing is popular in the meandering reaches above the pools. There are numerous access areas and parks. Outside of the urban areas there are also camping facilities.

HYDROLOGY

An extensive hydrologic analysis of the Fox River performed by H. V. Knapp is reported in *Fox River Basin Streamflow Assessment Model: Hydrologic Analysis* (1988). The results of the study are incorporated in an interactive computer model, ILSAM. ILSAM produces estimates of long-term streamflow conditions for any location in a watershed. The model provides algorithms necessary to estimate the impacts of potential changes in water use and sources for water supply, and translates the effects of these modifications to other sites along the stream. The model may be used to estimate flows for virgin conditions, natural flow conditions not affected by discharges and withdrawals; "present" (1983 in the model) conditions of effluent discharges and withdrawals; and simulated flows for proposed discharges or withdrawals.

ILSAM was used exclusively in this study. Discharges corresponding to desired annual flow durations were computed for locations along the river. Flow durations of measured discharges were computed from model results by interpolation. The discharges and flow durations were determined under the option of "present conditions" specified in the model.

Hydraulic Geometry Relationships

In natural streams and rivers, average width (W), depth (D), velocity (V), and cross-sectional area (A) of flow vary in a consistent and predictable way with discharge. The power function relationship between stage (S) and discharge (Q), $S = aQ^b$, is well documented and widely used at streamgaging stations. Leopold and Maddock (1953) proposed power functions to mathematically define similar relationships for W, D, V, and A at a stream cross section as a function of Q. They further demonstrated that when compared at discharges having the same frequency of occurrence, W, D, V, and A typically vary systematically along the stream network, increasing with increasing drainage area in a hydrologically homogeneous basin. Various formulations for the mathematical expressions approximating the variation of these flow parameters along the stream network have been proposed (Stall and Fok, 1968; Singh et al., 1986; Broeren and Singh, 1990). The collection of relationships, for a single cross section and for the basin stream network, are referred to as hydraulic geometry relationships. The mathematical expressions defining the variation of flow parameters both at a station and along the stream network hold for natural streams where the channel and flows have not been significantly altered artificially. Stall and Yang (1970) demonstrated the applicability of these relationships to stream networks throughout the United States. The ability or inability of the standard relationships to approximate the variation of W, D, V, and A with

Q at locations along the Fox River serves as an indicator of the deviation of the Fox River evolution from that of other streams.

Station Relationships

Hydraulic geometry relationships are usually developed from data collected during routine discharge measurements made by the U.S. Geological Survey (USGS) for gaging station calibrations. Flow width, cross-sectional area, and average depth and velocity are available for a wide range of discharges. Discharge measurements near a gaging station are typically made at locations where conditions are optimal for an accurate discharge determination. Cross sections at a control such as a riffle or constriction, where the flow is shallow and fast moving, are usually selected. Discharge measurements made at bridge cross sections or upstream of in-channel dams are not representative of natural reaches.

Data from USGS calibration measurements were obtained for the four gaging stations on the main stem of the Fox River. The four gages, their locations, drainage area and river mile are listed in Table 2. Plots of flow width, average depth and velocity, and cross-sectional area versus discharge from measurements made near these four gages along the Fox are shown in Figures 3-6. The plots of W, D, V, and A versus discharge for each station are commonly referred to as station relationships. A sample of the discharge measurement sheets completed over approximately the last 20 years were reviewed to determine the actual locations along the river where the discharge measurements were made.

The Dayton gage is located about 0.1 miles downstream of Dayton Dam. Discharge measurements are routinely made within 500 feet upstream or downstream of the gage. The data shown in the station plots, Figure 3, for this site show a consistent increase of W, D, V, and A with Q.

The Montgomery gage is downstream of the Montgomery Dam. Discharge measurements are typically made within about 1000 feet on either side of the gage. There are several locations where measurements are made, two of these sites are at constricted cross sections, where the channel width is notably less than in most of the reach. Data from measurements made near these constrictions are plotted with open circles in Figure 4. The plots of W versus Q, and D versus Q show a clear difference between the flow conditions measured at constricted sections compared to other measurement locations in the vicinity of the gage. The V versus Q, and A versus Q plots for this station do not show the same divergence between the two sets of data that is apparent with the other parameters. In general, for any stream, the variation of A with Q tends to be the most consistent relationship, with the least data scatter.

Table 2. Fox River USGS Gaging Stations

Station	*Number*	*Drainage area (sq mi)*	*River mile from mouth*	*Location description*
Dayton	5552500	2,642	5.3	at upstream side of county road, bridge, Dayton Hydro-Electric Co.
Montgomery	5551540	1,732	45.9	at bridge on Mill Street
South Elgin	5551000	1,556	67.2	at bridge on State Street
Algonquin	5550000	1,403	81.6	140 feet upstream from Algonquin Dam

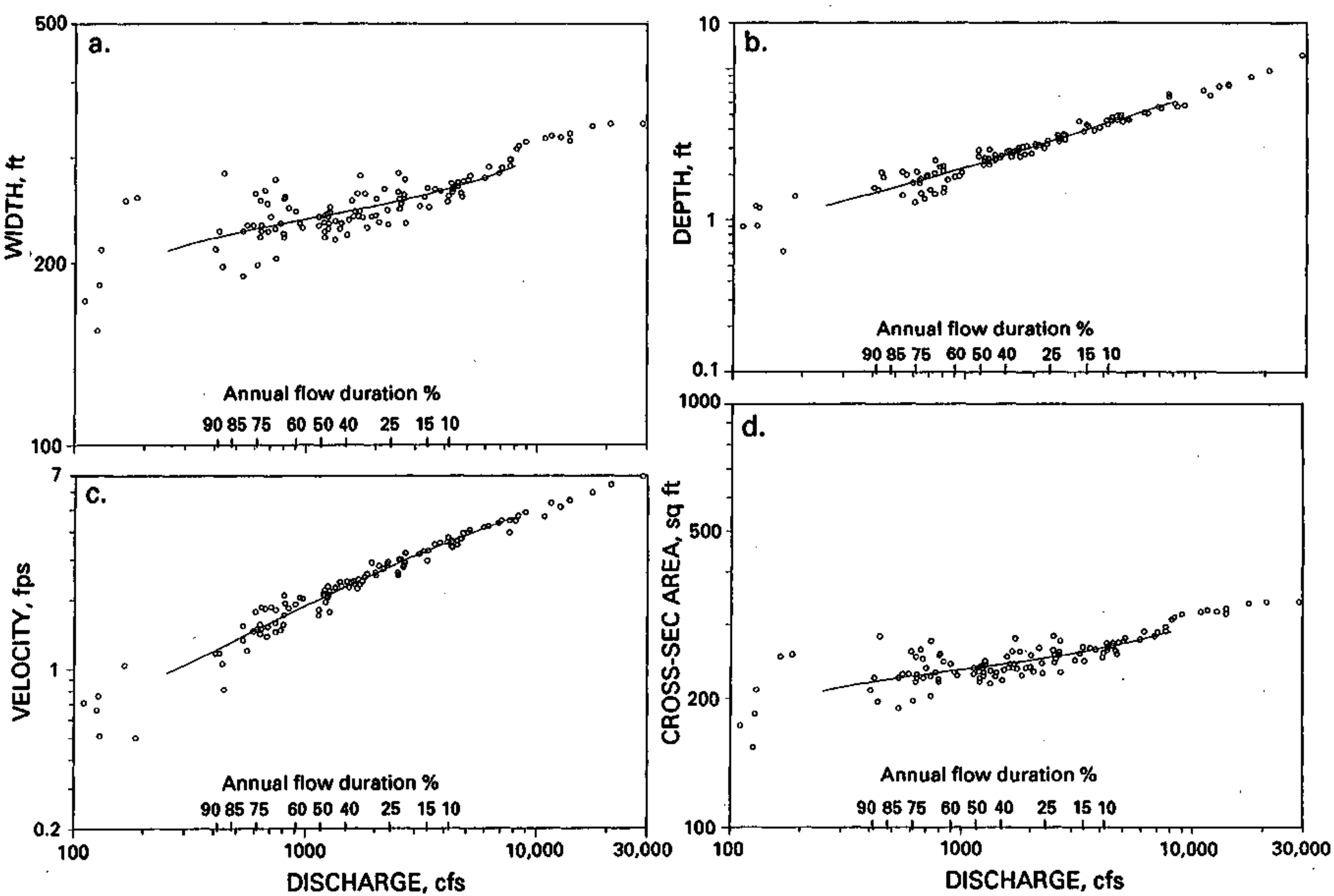

Figure 3. Station hydraulic geometry, USGS gage at Dayton

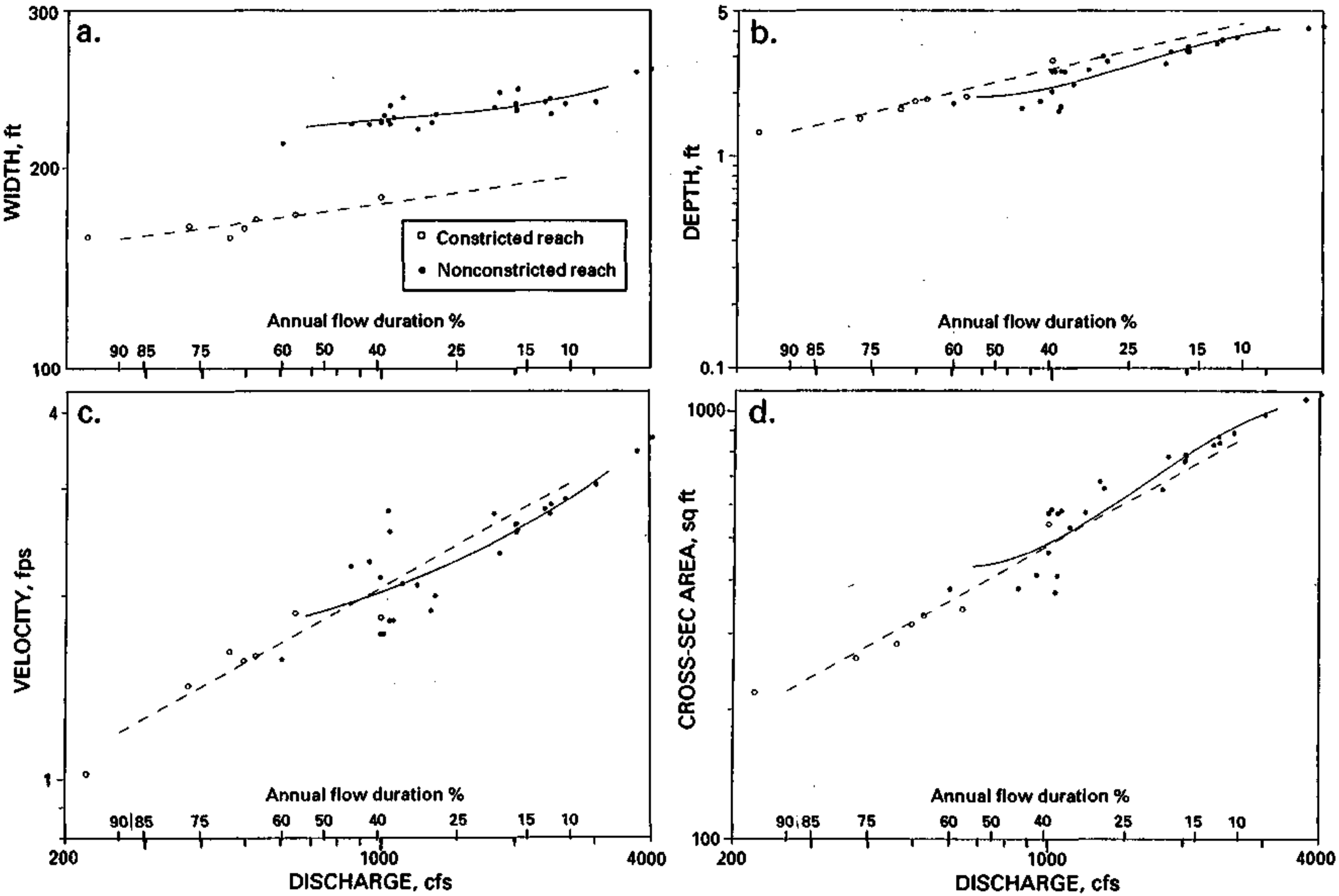

Figure 4. Station hydraulic geometry, USGS gage at Montgomery

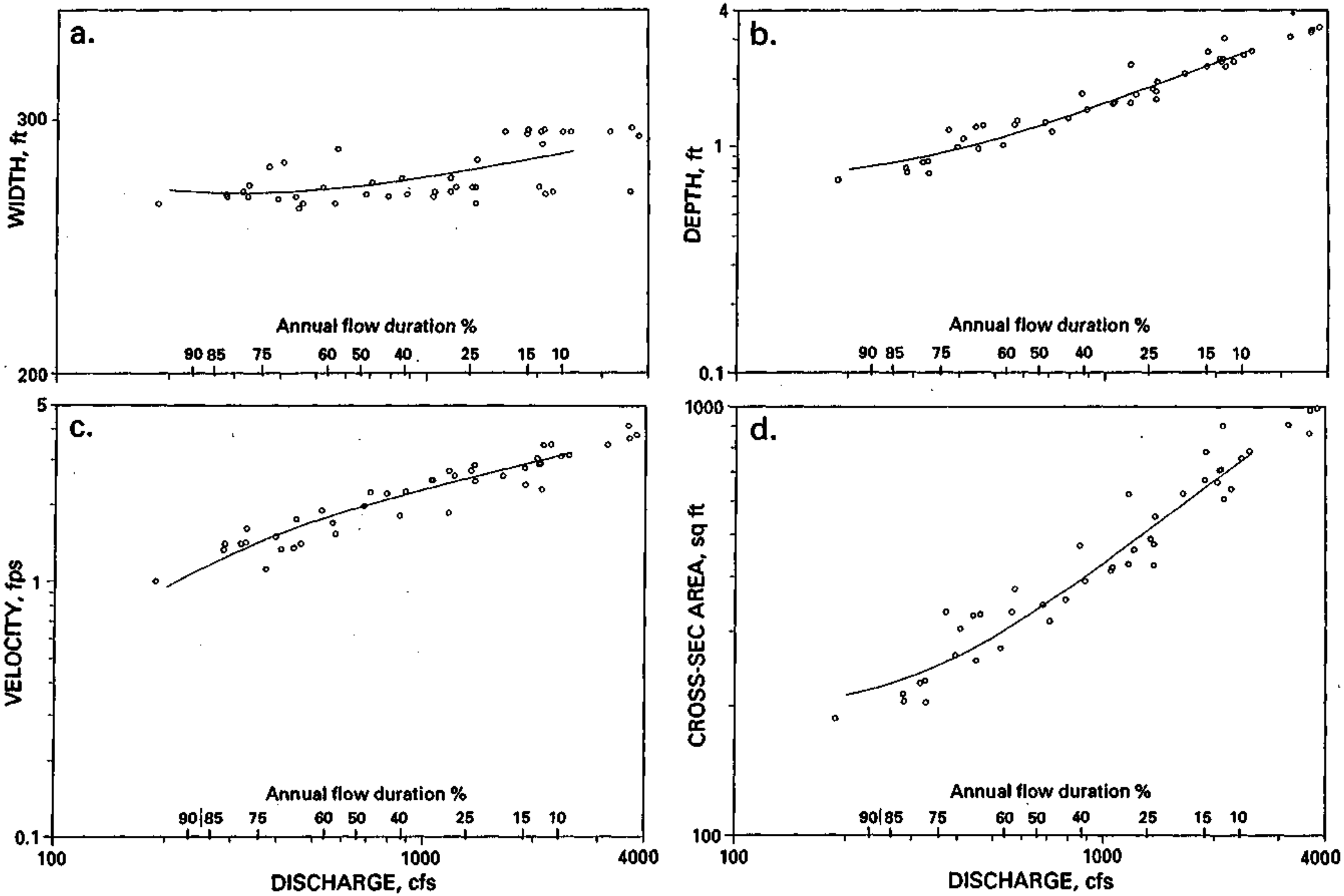

Figure 5. Station hydraulic geometry, USGS gage at South Elgin

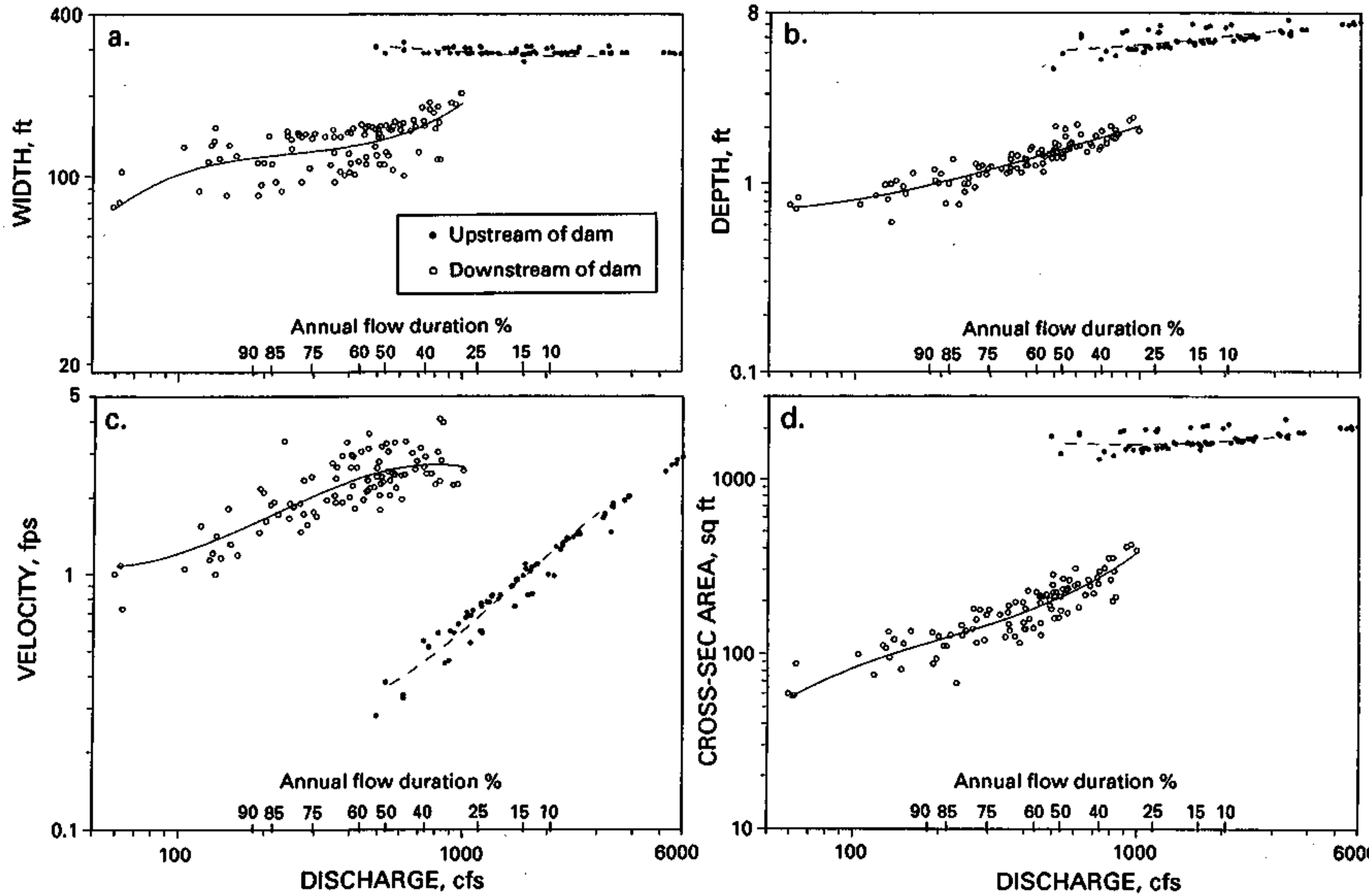

Figure 6. Station hydraulic geometry, USGS gage at Algonquin

The South Elgin gage is about 0.1 mile downstream of the South Elgin Dam. Discharges are usually measured within 500 feet of the gage. The plotted data in Figure 5 show a consistent increase in parameter values with increasing Q.

The station plots in Figure 6, developed from data collected near the Algonquin gage show the dramatic difference between flow conditions upstream and downstream of an in-channel dam. The Algonquin gage is located about 140 feet upstream of the dam. Discharge measurements are made both upstream and downstream of the dam. Data from cross sections upstream of the dam are plotted with closed circles and data from cross sections downstream of the dam are plotted with open circles in Figure 6. The data plotted in Figure 6 are from cross sections located within about 600 feet of each other, from about 150 feet upstream of the dam to about 450 feet downstream of the dam. The data collected from above the dam actually show decreasing width with increasing discharge. This seems to be a consequence of the measurement being taken further upstream, away from the dam, to obtain a discharge measurement during high flows.

Data from measurements made both upstream and downstream of the dam are available for discharges corresponding to annual flow durations between 60 and 25 percent. Inspection of the data plotted in Figure 6 shows that for this range of flows, widths above the dam are on the order of twice those measured downstream of the dam, depths are on the order of 3 feet greater, velocities are as much as 2 feet per second (fps) less and not as variable as measured below the dam, and cross-sectional area of flow is about three times greater above the dam than below it.

The lines plotted on Figures 3-6 represent a best-fit, third-order polynomial approximation of the relationships; except that the dashed line shown on the Montgomery station plots is a linear approximation. There were insufficient data to develop a third-order equation. The coefficients of the polynomials for each parameter at each station are given in Table 3. Two sets of equations were developed for Montgomery and for Algonquin. The correlation coefficients for the equations developed for the Dayton and South Elgin stations are higher overall than those for the other two stations. The correlation coefficients for width tend to be low at all the stations. This arises because the channel has fairly steep banks, and width does not vary significantly over the range of flows investigated as illustrated in the plots of W versus Q (Figures 3 - 6). The equations developed from data taken in the backwater pool, upstream of the Algonquin Dam, show very low correlation coefficients.

To satisfy the condition of continuity, the product of W, D, and V computed for a given Q must equal that Q. The ratio (Q=WxDxV)/Q, multiplied by 100 serves as a measure of the combined error of the equations as a percentage of the discharge. The

Table 3. Fox River Station Hydraulic Geometry Coefficients

$$\log(VAR) = C + C1 \times (\log Q) + C2 \times (\log Q)^2 + C3 \times (\log Q)^3$$

VAR = W, D,V, or A

Dayton station, USGS gage 05552500, drainage area 2,642 sq mi

	C	C1	C2	C3	R2	RMSE
W	1.1367	1.0824	-0.3335	0.0367	0.718	0.032
D	-0.2659	-0.1745	0.1702	-0.0145	0.951	0.051
V	-0.7602	-0.0214	0.2004	-0.0260	0.966	0.040
A	0.9084	0.8738	-0.1532	0.0212	0.978	0.041

South Elgin station, USGS gage 05551000, drainage area 1,556 sq mi

	C	C1	C2	C3	R2	RMSE
W	3.0799	-0.6540	0.2086	-0.0210	0.339	0.016
D	4.2602	-4.9480	1.7494	-0.1840	0.925	0.056
V	-7.4630	6.7576	-2.0210	0.2127	0.902	0.057
A	7.2691	-5.5260	1.9314	-0.2010	0.927	0.059

Montgomery station, USGS gage 05551540, drainage area 1,732 sq mi

Relationships for flows >650 cfs

	C	C1	C2	C3	R2	RMSE
W	-2.2651	4.4614	-1.4483	0.1582	0.711	0.011
D	53.7612	-51.4032	16.2967	-1.6996	0.829	0.055
V	-2.5578	2.8684	-1.0458	0.1360	0.748	0.050
A	51.0737	-46.5366	14.7195	-1.5278	0.863	0.054

Relationships for flows <1000 cfs at constricted sections

	C	C1	C2	C3	R2	RMSE
W	2.0612	0.0671	0.0000	0.0000	0.747	0.009
D	-1.1429	0.5218	0.0000	0.0000	0.934	0.030
V	-0.9145	0.4097	0.0000	0.0000	0.861	0.036
A	0.9222	0.5875	0.0000	0.0000	0.928	0.036

Algonquin station, USGS gage 05550000, drainage area 1,403 sq mi

Relationships upstream of dam, flows >500 cfs, D> 3 feet

	C	C1	C2	C3	R2	RMSE
W	0.5158	2.1805	-0.7802	0.0899	0.026	0.066
D	4.1217	-3.3605	1.0694	-0.1084	0.454	0.039
V	17.0475	-18.1088	6.0024	-0.6282	0.920	0.069
A	3.2818	0.3144	-0.2380	0.0417	0.156	0.067

Relationships downstream of dam, flows <1000 cfs, D< 3 feet

	C	C1	C2	C3	R2	RMSE
W	-6.2257	10.1915	-4.2064	0.5844	0.438	0.075
D	1.1360	-1.8428	0.8013	-0.0931	0.778	0.058
V	5.3637	-7.6927	3.5481	-0.5110	0.601	0.090
A	-5.0514	8.3022	-3.3864	0.4888	0.785	0.090

Notes: C, C1, C2, and C3 regression coefficients
R2= adjusted multiple regression coeffcient
RMSE= root mean square error

ratio was computed for discharges corresponding to ten selected annual flow durations between 10 and 90 percent. The percent error was less than 0.5 for the Dayton station, the constricted section equations from the Mongomery data, the South Elgin station, and equations developed from measurements taken downstream of the Algonquin Dam. The percent error of the remaining equations was less than 3 percent, with the majority of the ratio values less than 1 percent. Therefore, the equations may be used to predict the values of hydraulic parameters at the stations.

Basin Relationships

Basinwide empirical relationships for W, D, V, and A may be developed for hydrologically homogenous basins with natural channel configurations. Basins such as the Sangamon (Broeren and Singh, 1990) and the Vermilion (Singh et al., 1987) show a consistent and predictable increase of W, D, V, and A with increasing drainage area (DA) when compared at discharges having the same frequency of occurrence. The Sangamon and Vermilion River Basins are located in central Illinois. The Sangamon River is tributary to the Illinois River and the Vermilion River is tributary to the Wabash River. The trends of increasing parameter values with increasing DA may be observed by plotting each station value of a parameter, such as W, determined for a selected flow duration discharge, versus DA on log-log paper. Figure 7 illustrates the relationships between DA and W, D, and V for the main stem of the Sangamon River, Illinois. The plotted points are the station values of the parameters at discharges corresponding to selected annual flow durations. The lines plotted are a best-fit linear approximation of the data trends for the annual flow durations noted on the plots.

In contrast to the fairly uniform progression of increasing parameter values shown for the Sangamon Basin, similar plots of data from the main Fox River are provided in Figure 8. Two sets of points are given for Montgomery and Algonquin corresponding to the two sets of equations derived. The data points computed for "unconstricted sections" at Mongomery are plotted at a DA of 1700 sq mi (instead of 1732 sq mi), and the data points computed for "upstream of Algonquin Dam" are plotted at 1450 sq mi (instead of 1403 sq mi). The offset eliminates overlapping of the points to improve visual interpretation of the plots. The values plotted (Figure 8) for the reach in the backwater pool at Algonquin Dam represent conditions clearly different from those at the other stations.

In conclusion, inspection of the plots shown in Figure 8 shows, that on the basis of the gaging station data (excluding data from above the Algonquin Dam), the hydraulic parameters, W, D, and V, do not vary in a predictable along the course of the river. The

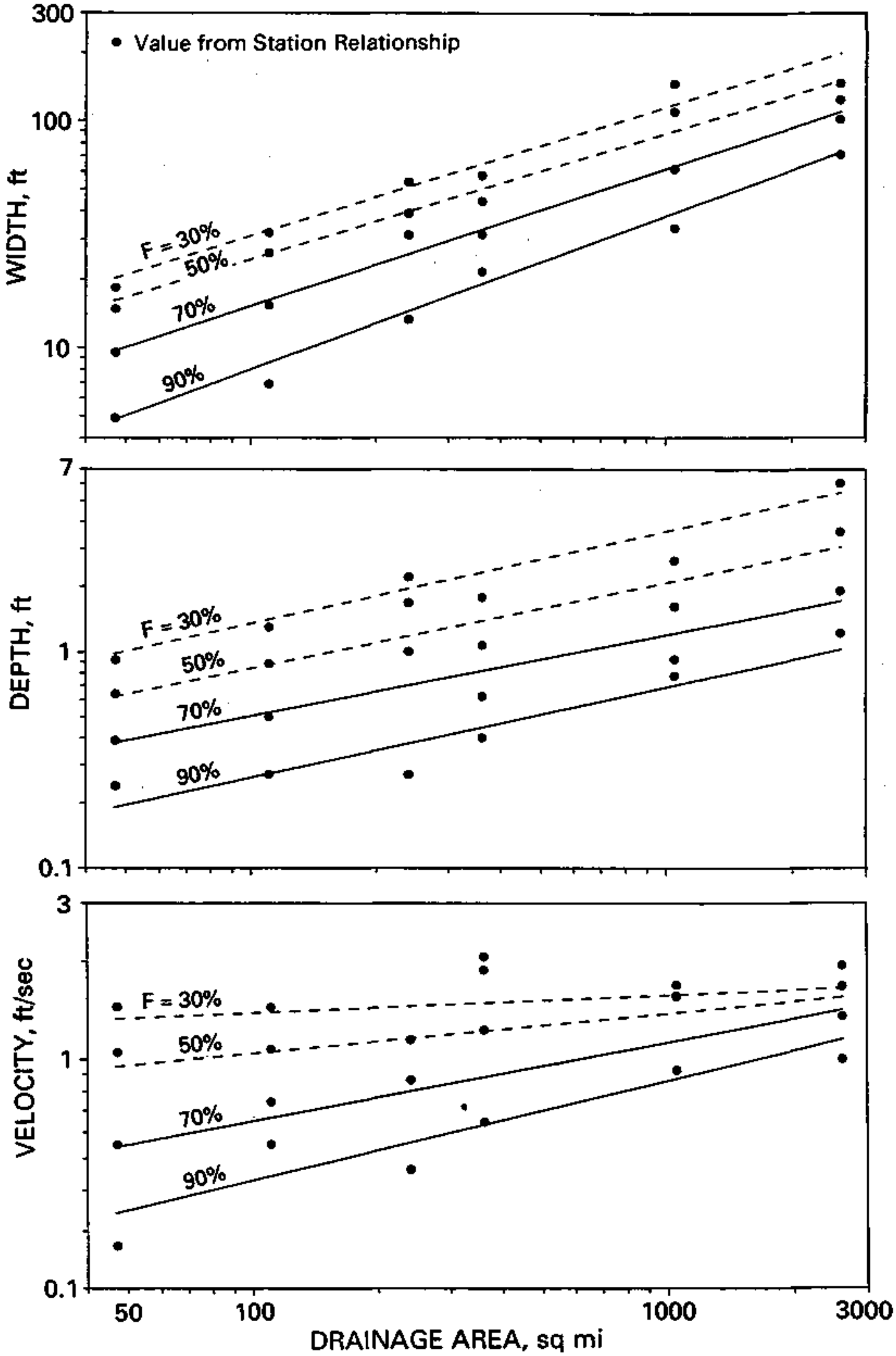

Figure 7. Sangamon Basin hydraulic geometry relations

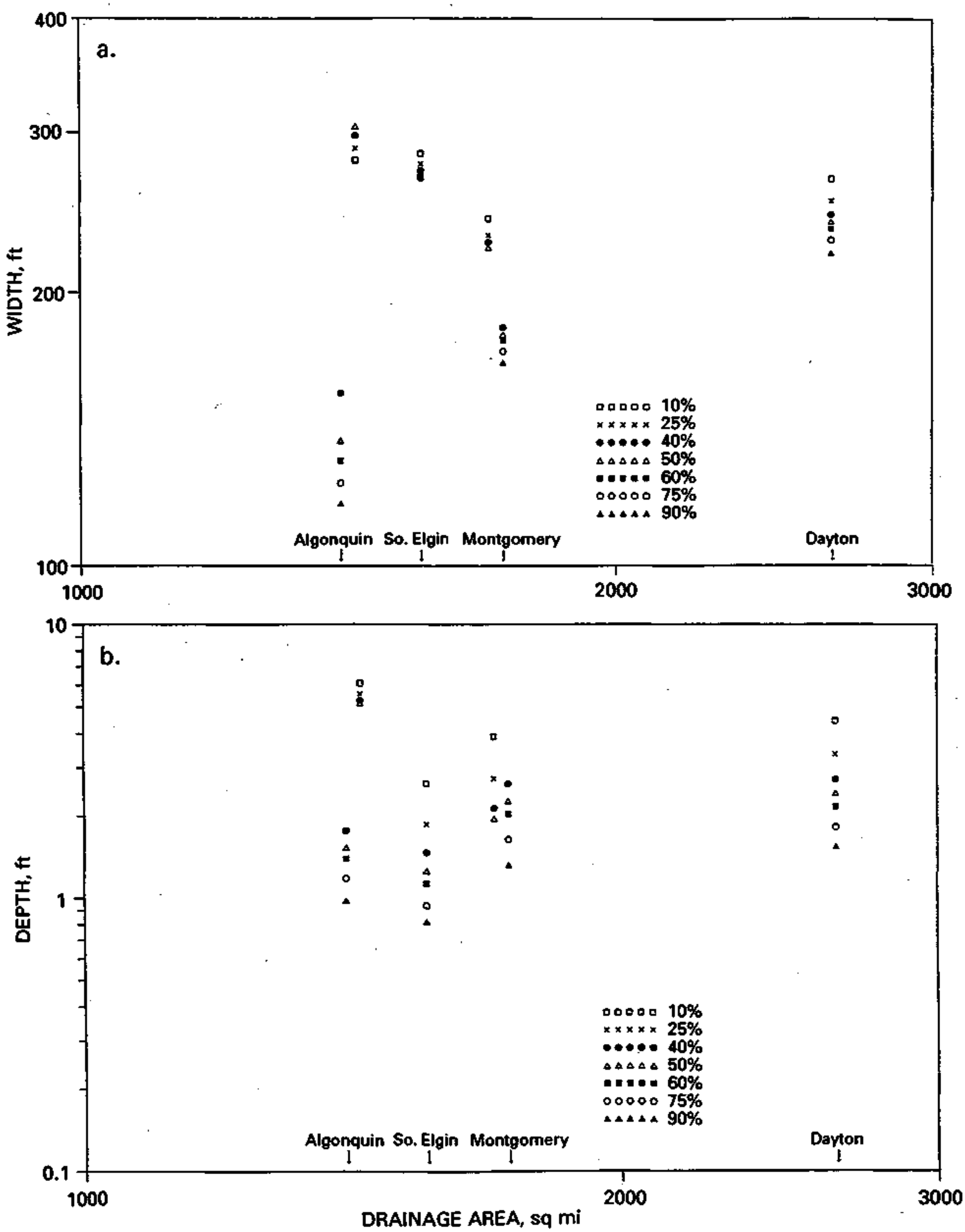

Figure 8. Fox River station values of (a) width, (b) depth, (c) velocity, and (d) area plotted vs. drainage area

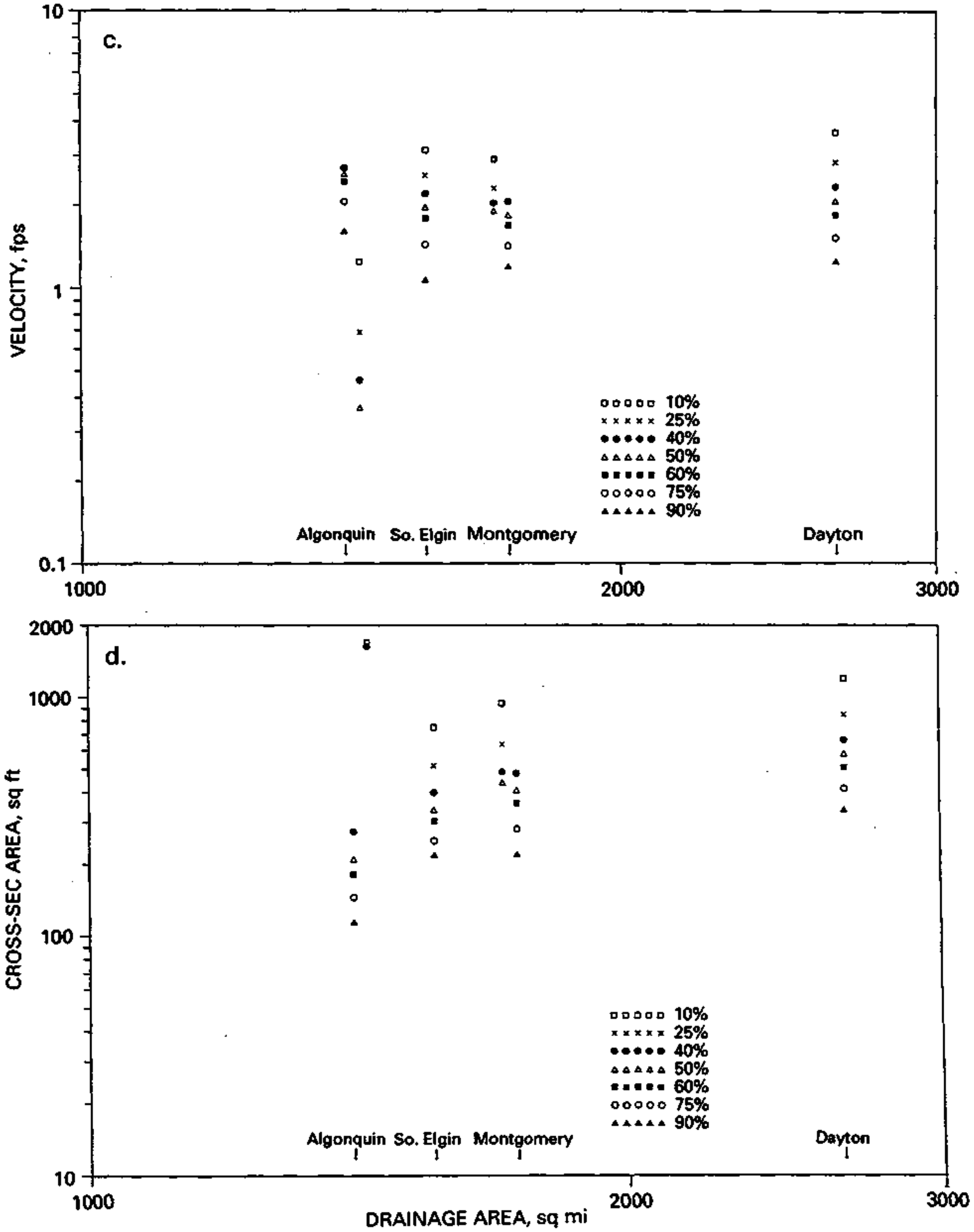

Figure 8. Concluded

parameter values do not follow the same patterns as observed for other major drainage basins in the Midwest and the United States (Leopold and Maddock, 1953; Stall and Yang, 1970; Singh et al, 1987; Broeren and Singh, 1990). The A (cross-sectional area) values at the stations, for the selected flow durations, tend to increase with DA. The widths computed for South Elgin and shown on the plot of W versus DA are considerably greater than at other sections, and this is echoed in the D versus DA plot where the depths computed for South Elgin are less than would be interpolated between Algonquin and Mongomery. Depth values for "constricted " sections at Montgomery are nearly the same as predicted at Dayton, which has about 1.5 times the DA Velocities decrease from Algonquin to South Elgin, velocities at Montgomery and Dayton are comparable to those at South Elgin. These results are not consistent with the results of hydraulic geometry studies for other basins.

FIELD STUDY

Selection of Field Study Reaches

Five reaches were selected for detailed field measurements. Three of the reaches are located along sections of the river that are above the backwater pools. These three reaches are each located in one of the three segments shown on Figure 2 and thus represent each of the major slopes found along the river course below Algonquin. The other two study reaches are located within the backwater pools created by in-channel dams. The study reaches were selected to represent a variety of channel characteristics. Transect locations, for depth and velocity measurements, were established so as to include riffles, pools, and flow areas divided by sandbars and islands. The general goal for establishing study reaches was for each reach to include three riffle areas separated by two pools.

A well-established riffle and pool sequence was identified along the river near East Dundee and West Dundee. This reach is identified as the Dundee Reach. Similarly, a reach upstream of the town of Yorkville was found that has well-established riffle and pool areas, as well as areas of divided flow. This reach is identified as the Yorkville Reach. The area along the river below Yorkville is not developed and access is limited. Field personnel examined the river from Silver Springs State Park (approximately river mile 31) to the town of Wedron (approximately river mile 9). Between these points numerous islands were found that divided the river channel and multiple thalwegs were identified. Variations in water depth were erratic, not patterned. Thus riffle and pool sequences were not readily identifiable. At the canoe launch near Wedron, a rock outcrop forms the left bank; in this area a deep pool with water depth on the order of 20 feet was observed. An alternate approach was adopted to establish a study reach in the river segment between Dayton and Yorkville. Two reaches were established by setting equally spaced transects starting 500 feet above and below the Illinois Route 52 bridge near Serena. This study area is identified as the Serena Reach. The backwater pool study reaches are located above the Elgin Dam and the Yorkville Dam. The Elgin Dam reach is in two approximately equal length segments, divided by a natural constriction. The Yorkville Dam reach has numerous islands, and the upstream end of the reach terminates near the most downstream transect of the Yorkville riffle-pool reach providing a continuous picture of the river in its transition from backwater pool. The river mile, DA, location, distance to the nearest downstream dam, and length of each study are listed in Table 4.

Table 4. Fox River Study Reaches

Reach name	*River mile **	*Drainage area (sq mi)*	*First downstream dam*	*Distance from dam (mi)*	*Location (S, T,R,3rd PM)*	*Reach length (ft)*
Serena	14.97	2273.5	Dayton	9.6	S29 T35N R5E	4000
Yorkville Dam (backwater pool)	36.17	1788.7	Yorkville	0.09	S33 T37N R7E	5813
Yorkville	37.76	1783	Yorkville	1.7	S27 R37N R7E	3712
Elgin Dam (backwater pool)	71.06	1507.2	Elgin	0.06	S11 T41N R8E	10226 7616"
Dundee	74.80	1451.1	Elgin	3.8	S27 T42N R8E	2766

Notes:

* River mile from mouth at Ottawa of downstream transect.

** Does not include stream length along unmeasured constriction.

S, T, R = section, township, and range from the 3rd Principal Meridian

reach length = distance between upstream and downstream transects

Field Procedures and Flow Conditions Measured

Transects were established along each study reach. A minimum of 10 transects were located in each study reach, with most reaches having 12 or more transects. The farthest downstream transect is identified as number 1, with transect numbers increasing in the upstream direction. Transects were equally spaced between riffles when possible. However, the position of transects was adjusted to include locations where flow conditions or channel characteristics changed, e.g., islands and sandbars. Measurements of width, depth, and velocity were made at the transect locations at two different discharges. Six or more depths and velocities were measured at points across each transect. Depth and velocity measurements represent the incremental changes in flow conditions along the stream reach and across each transect. Two sets of field data were collected at each of the five study reaches. Most field measurements were conducted during low flow conditions as these are typically most critical for aquatic life, and variations in hydraulic parameters due to channel form are most pronounced during low flow conditions. One set of field measurements at each of the backwater pool sites was conducted during relatively high flows. A summary of the dates of the field work, discharges measured, and their corresponding annual flow duration are presented in Table 5.

Analysis of Field Data

Field data were analyzed statistically and graphically. Each transect was identified as representing one of three classifications of channel form and flow conditions: *riffle* — relatively shallow and fast flowing and typically having coarser bed materials; *pool* — relatively deeper and slower flowing and having finer bed materials; *divided* — two or more distinct channels separated by a vegetated island or sandbar. Areas of divided flow were further noted as having flow conditions similar to riffle or pool areas in the reach.

Two different approaches were used to statistically analyze measured widths, depths, and velocities. One approach was to calculate the arithmetic average depth and velocity at each transect, then compare transect values of water width, depth, and velocity representative of riffle, pool, and divided flow conditions, respectively. Average width, depth, and velocity values for riffle, pool, and divided flow conditions were computed as the arithmetic average of transect values designated as representing one of those conditions. For comparison, the average width, depth, and velocity of all transects where the flow forms a single channel (i.e., no sandbars or islands) were computed and are referred to as undivided flow averages.

Table 5. Annual Flow Durations and Discharges Measured at Field Sites

Reach name	*Letter identifier*	*Date*	*Discharge (cfs)*	*Annual flow duration (percent)*
Serena	A	9/29/90	603	72.6
	B	9/29/90	691	67.6
Yorkville Dam (backwater pool)	A	10/15/91	636	61.6
	B	2/27/92	2016	18.5
Yorkville	A	8/16/90	507	70.4
	B	9/15/90	574	65.8
Elgin Dam (backwater pool)	A	7/9/91	259	84.3
	B	3/18/92	1808	15.2
Dundee	A	8/15/90	354	72.4
	B	9/9/90	472	61.1

The second approach to evaluating the measured data was to calculate a weighted average value of depth and velocity for the entire reach at each measured discharge. Each pair of depth and velocity measured at a point were assumed to represent an incremental segment of the stream. The weight factors were determined on the basis of the water surface area represented by each pair measured. In the streamwise direction the transect and points along the transect were assumed to represent a length of stream equal to the sum of half the distance to the adjacent upstream and downstream transects. The representative stream length for the first and last transects was computed as extending half the distance to the adjacent transect and an equal distance in the opposite direction. These segment lengths were adjusted on the basis of the extent of unique conditions such as an island or a constriction. Transverse to the direction of flow, the width of the incremental area represented by depth and velocity measurements was computed as the sum of half of the distance between points or the sum of the distance to the bank and half of the distance to the adjacent point.

Tabular summaries of the field data collected at each reach are provided. The summaries include stationing; transect values of width, depth, and velocity; and descriptive information regarding islands and sandbars. The streamwise variation of transect values of width, depth, velocity, and cross-sectional area are depicted in plots of these values versus distance to the downstream dam for each reach. Statistical weighted averages and standard deviations for all the study reaches are also presented in tabular form.

Serena Reach

The field data collected at the Serena reach are summarized in Table 6. This reach is the most downstream reach, having the largest drainage area. The average bed slope in this segment of the river is somewhat greater than the most upstream reaches (Dundee and Elgin Dam), and significantly less than the Yorkville and Yorkville Dam reaches. This reach was unique in that transects were equally spaced as distinct patterns in bed forms, i.e., riffle and pool areas, could not be identified. Transects 1-5 were positioned at 500 foot intervals downstream of the Route 52 bridge and transects 6-10 were established at 500 foot intervals upstream of the Route 52 bridge. The downstream end of the reach is 9.6 miles upstream from the Dayton Dam. The reach is far removed from the backwater pool, which has an estimated length of 4.1 miles when flow just passes over the dam, i.e., normal pool elevation (Table 1). The channel is dotted with vegetated sandbars and islands. Four of the ten transects cross vegetated islands. However, discharges were sufficiently low so the flow was confined to a single channel at all but one transect. Although field work for both segments was conducted on the same day, the discharges

Table 6. Serena Study Reach Summary of Field Data

		Date:	9/29/90					9/29/90			
		Discharge:	603 cfs					691 cfs			
		Annual Flow Duration:	72.60%					67.60%			
			Transect average						*Transect average*		
Station (ft)	*Tran. no.*	*Description*	*width (ft)*	*depth (ft)*	*velocity (fps)*	*Station (ft)*	*Tran. no.*	*Description*	*width (ft)*	*depth (ft)*	*velocity (fps)*
		50 foot wide silt bar near left bank, no flow measured over the bar									
0	1	P	265(1) 315(2)	2.02	1.05	3000	6	P	280	2.55	0.73
500	2	P	335	2.47	0.78	3500	7	R	278	1.70	1.02
								44 foot wide vegetated sand bar near left bank, no flow measured between island and bank			
1000	3	P	280	2.05	0.98	4000	8	R/D	210(1) 254(2)	1.82	0.63
								171 foot wide island near left bank no flow measured between island and bank			
1500	4	R	355	1.05	1.84	4500	9	R/D	130(1) 301 (2)	1.77	2.80
		side ch	54	0.68	0.43			90 foot wide island near right bank no flow measured between island and bank			
		main ch	260	1.77	1.29						
2000	5	R/D	314	1.23	0.86	5000	10	P	218(1) 308(2)	2.85	0.95
		Transect averages:									
		reach	320	1.70	1.12				284	2.03	1.35
		riffle	335	1.14	1.35				278	1.76	1.48
		pool	233	2.26	0.88				294	2.85	0.95
		pool-riffle difference	-102	1.12	-0.47				16	1.09	-0.53
		Weighted statistics of point values									
		Minimum		0.20	0.02					0.4	0
		Maximum		3.50	3.50					4.2	4.73
		Count		40	40					34	34
		Avg		1.86	1.20					1.98	1.02
		Std		0.80	0.71					1.12	0.95
		CV		0.43	0.59					0.56	0.93

Notes: flow conditions at transects assumed to represent 500 feet of stream length
island and bar widths estimated
Width=bank to bank unless otherwise noted
(1) water width, widths of islands or bars not included
(2) bank to bank width, includes estimated widths of islands and bars

measured above and below the bridge varied from 603 cfs to 691 cfs. This may in part be due to discharge measurement error. The annual flow durations corresponding to these discharges were 72.6 and 67.6 percent, respectively. The flows are sufficiently close in value that parameter values measured above and below the bridge may be compared. Transect values of width, depth, velocity, and cross-section area are plotted versus distance from the Dayton Dam in Figure 9. Width does not vary dramatically along the the upper part of the reach. Transect average depth varies more than one foot, from transect 4 with an average depth of 1.05 feet to transect 10 with an average depth of 2.85 feet. The minimum depth measured was 0.4 feet and the maximum depth measured was 4.2 feet. A wide range of velocities were measured, from 0 to 4.73 fps. Average velocity at a transect varied from 0.73 to 2.8 fps.

Yorkville Dam Backwater Pool Reach

The first downstream transect was located as close to the dam as safety would permit, a little more than 300 feet upstream of the dam. The study reach length is approximately one mile and is within the steepest segment of the river. This reach was characterized by established vegetated islands, two of which exceeded 600 feet in length. Flow is divided into two to three channels at four of the 13 transects located in the reach. Data collected in this study reach are summarized in Table 7. Measurements were conducted at a discharge of 636 cfs, which corresponds to an annual flow duration of 61.6 percent; and at a discharge of 2,016 cfs, which corresponds to an annual flow duration of 18.5 percent. The bank-to-bank stream width at cross sections including the islands was as much as double the width at cross sections where there were no islands. Water width varied from 330 feet at the upstream transect, farthest removed from the dam, to 685 feet at transect 10, which crossed two islands. The streamwise variation of transect average width, depth, velocity, and cross-sectional area at each discharge measured are illustrated in Figure 10. As would be expected, depth generally decreased with increasing distance from the dam. Flow was generally less deep in the side channels when compared to the main channel at a section. Velocity was lowest near the dam, increasing with increasing distance from the dam as would be expected. The width at each transect does not vary significantly from one discharge to another. The average depth at a transect declines sharply at transect 8, approximately 4500 feet upstream of the dam. Transects 9, 10, and 11 cross a well-established island just upstream of transect 8, which appears to be the extent of the backwater pool. Between transects 1 and 8, the depth at each transect, where measurements were made during both discharges, is similar. The greater flow is accommodated by higher velocities. Velocity is nearly 0.5 fps greater during the higher

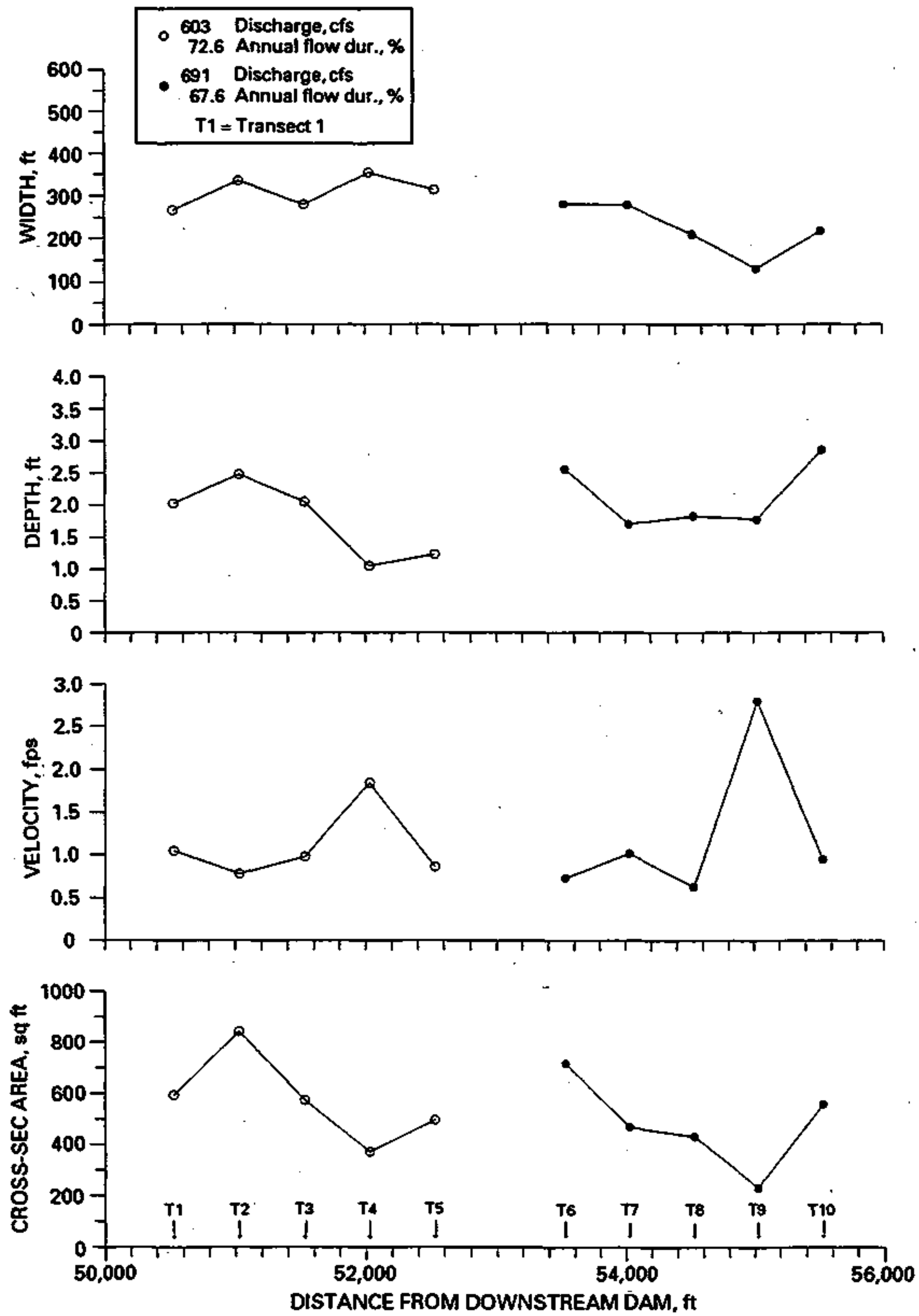

Figure 9. Serena study reach transect average flow parameters versus distance

Table 7. Yorkville Dam Study Reach Summary of Field Data

			Date:	10/15/91			2/27/92		
			Discharge:	636 cfs			2016 cfs		
			Annual Flow Duration:	61.6%			18.5%		
				Transect average			*Transect average*		
Station (ft)	*Tran. no.*	*Segment length (ft)*	*Description*	*width (ft)*	*depth (ft)*	*velocity (fps)*	*width (ft)*	*depth (ft)*	*velocity (fps)*
0	1	533	P	623	4.12	0.24	623	4.40	0.58
			side channel	148	3.53	0.19	131	2.92	0.34
			main channel	420	4.52	0.23	472	4.98	0.65
				567(1)			604(1)		
533	2	493.5	P/D	657(2)	4.02	0.21	694(2)	3.95	0.49
987	3	474.5	P	558	4.02	0.29	574	3.87	0.57
1482	4	541	P		no data		531	5.05	0.73
2069	5	595.5	P	508	4.58	0.36	492	4.47	0.72
2673	6	761	P		no data		574	4.05	0.57
3591	7	704	P	394	4.92	0.54	394	5.33	0.95
4081	8	387	R	607	3.56	0.27	567	3.61	0.73
			main channel	361	3.82	0.29	344	4.35	0.82
			side channel	180	2.93	0.29	184	3.27	0.74
				541(1)			528(1)		
4365	9	318.5	R/D	791(2)	3.38	0.29	778(2)	3.77	0.74
			side channel	92	2.12	0.27			
			main channel	394	2.03	0.34			
			side channel	200	2.7	0.35	no data		
				685(1)					
4718	10	375.5	R/D	910(2)	2.28	0.32			
			side channel	42	1.4	0.12			
			side channel	260	2.23	0.36			
			main channel	350	2.93	0.5	no data		
				612(1)					
5116	11	315	R/D	750(2)	2.58	0.43			
5348	12*	348.5	R		no data		728	2.79	0.87
5813	13	465	R	330	3.39	0.61	394	3.75	0.95
		Transect averages:							
			reach	613	3.69	0.36	577	4.09	0.72
			riffle	678	3.04	0.38	617	3.48	0.82
			pool	548	4.33	0.33	555	4.45	0.66
			pool-riffle difference	-130	1.29	-0.06	-62	0.97	-0.16
			undivided	503	4.10	0.39	542	4.15	0.74
			divided	777	3.07	0.31	736	3.86	0.62
	Weighted statistics of point values								
			Minimum		0.5	0		0.4	0
			Maximum		6.2	0.9		7.5	1.47
			Count		107	107		99	99
			Avg		3.83	0.35		4.22	0.71
			Std		1.58	0.18		1.62	0.31
			CV		0.41	0.51		0.38	0.44

Notes:
(1) water width
(2) bank to bank width
Width =bank to bank

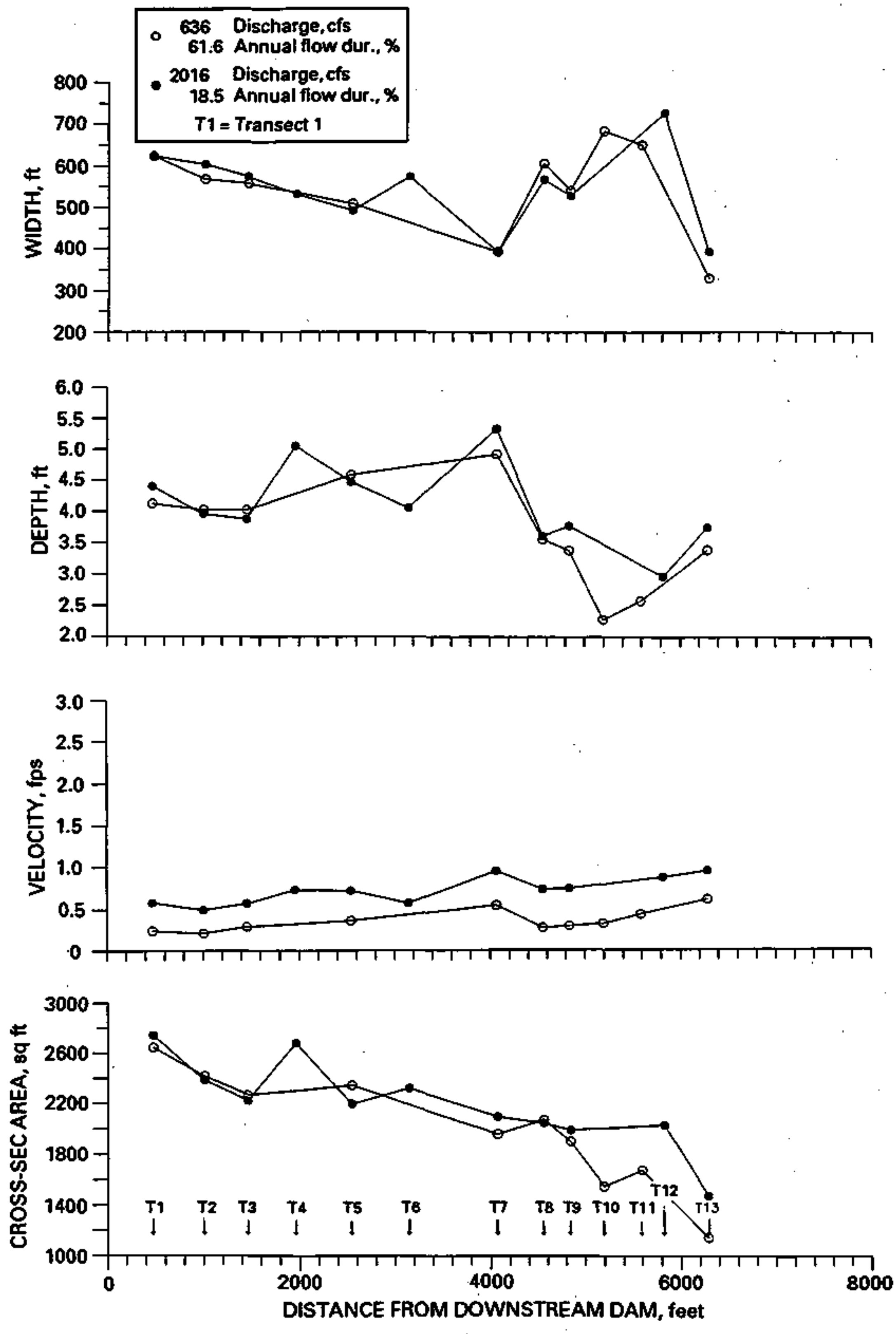

Figure 10. Yorkville Dam study reach transect average flow parameters versus distance

discharge than at the lower discharge. Upstream of transect 8, depths are less at the lower discharge compared to those at the higher discharge. Cross-sectional area of flow declines steadily with increasing distance from the dam.

Yorkville Reach

The first downstream transect of the Yorkville reach is located approximately 3000 feet upstream of the end of the Yorkville Dam reach. Riffle and pool areas were identified along this reach and well-established, vegetated islands dominate the upstream portion of the reach. Like the Yorkville Dam reach, this reach is within the steepest segment of the river. The flow is divided at transects 9-12. Measurements were made at discharges of 507 cfs and 574 cfs. Field data are summarized in Table 8. Velocities measured were nearly the same at both discharges with the slightly greater flow accommodated with depths, typically 0.3 feet higher at the greater discharge. The average transect values of width, depth, velocity, and cross-sectional area plotted in Figure 11. It may be observed that parameter values follow the same pattern of variation from transect to transect at both discharges, with depth and cross-sectional area slightly higher at the larger discharge.

The greater discharge measured in this reach, 574 cfs, is close to the discharge of 635 cfs measured at the Yorkville Dam reach. The water width below the island in the Yorkville reach is considerably less, approximately 250 to 400 feet across, than observed in the backwater pool where widths were approximately 500 to 600 feet, exclusive of islands.

Comparing other parameter values in the two reaches at these discharges, it may be observed that depths in the Yorkville reach are on the order of 1 foot less, velocities on the order of 1 fps higher, and cross-sectional area of flow is considerably less than observed in the Yorkville Dam reach. The first downstream transect, transect 1, of the Yorkville reach was located nearly 9000 feet (1.7 miles) upstream of the Yorkville Dam. The backwater pool created by the dam was estimated to extend 2.2 miles at normal pool elevation (Table 1). However, for this range of discharges, the backwater pool does not appear to extend to this section of river.

Elgin Dam Reach

Elgin Dam is located within the city of Elgin beginning about 500 feet above the Kimball Street Dam. Approximately 4500 feet upstream of the dam, a natural constriction confines the flow. This study reach was divided into two sections, one downstream (transects 1-6) and one upstream (transects 7-11) of the natural constriction. The backwater pool is confined just upstream of the dam with measured water width on the

Table 8. Yorkville Study Reach Summary of Field Data

				Date:	8/16/90		9/15/90	
				Discharge :	507 cfs		574 cfs	
				Annual flow duration:	70.4%		65.8%	
					Transect average		*Transect average*	
Station (ft)	*Tran. no.*	*Segment length (ft)*	*Width (ft)*	*Description*	*depth (ft)*	*velocity (fps)*	*depth (ft)*	*velocity (fps)*
0	1	104	325	R	0.87	1.45	1.22	1.41
104	2	324	320	P	0.97	1.48	1.27	1.50
645	3	541	340	P	1.48	0.89	1.72	0.92
1186	4	540.5	265	P	1.97	0.82	2.22	0.95
1726	5	540.5	255	P	2.23	0.71	2.52	0.67
2267	6	370.5	295	gravel bar R/D	1.04	0.86	1.13	0.86
2467	7	241.3	340	R	0.85	1.38	1.05	i.46
2749.5	8	282.5	390	R	0.94	1.13	1.33	1.42
			235	main channel	1.35	1.15	1.58	1.23
			138	side channel	0.65	1.37	0.87	1.16
3032	9	282.5	373(1) 440(2)	R/D	1.00	1.26	1.23	1.19
			265	main channel	0.92	1.17	1.07	1.44
			115	side channel	0.87	1.24	1.00	1.13
3314.5	10	282.5	380(1) 500(2)	R/D	0.89	1.21	1.04	1.30
			233	main channel	0.64	1.19	flow not divided	
			214	side channel	0.82	1.00		
3597	11	199	447(1) 545(2)	R/D	0.73	1.10	0.87	1.37
			358	main channel	0.73	1.26	0.84	0.71
			152	side channel	1.30	1.15	1.12	1.82
3712	12	115	510(1) 550(2)	vegetated sandbar R/D	0.92	1.23	0.97	1.24
	Transect averages:							
		reach	380		1.16	1.12	1.38	1.19
		riffle	423		0.90	1.20	1.10	1.28
		pool	295		1.66	0.98	1.93	1.01
		pool-riffle difference	-128		0.76	-0.22	0.83	-0.27
		undivided	316		1.29	1.09	1.56	1.15
		divided	509		0.89	1.20	1.03	1.27
	Weighted statistics of point values							
			Minimum		0	0	0	0
			Maximum		3.2	2.99	3.3	2.7
			Count		99	99	103	103
			Avg		1.33	1.10	1.52	1.15
			Std		0.76	0.58	0.82	0.53
			CV		0.57	0.52	0.54	0.46

Notes:
(1) water width
(2) bank to bank width
Width =bank to bank

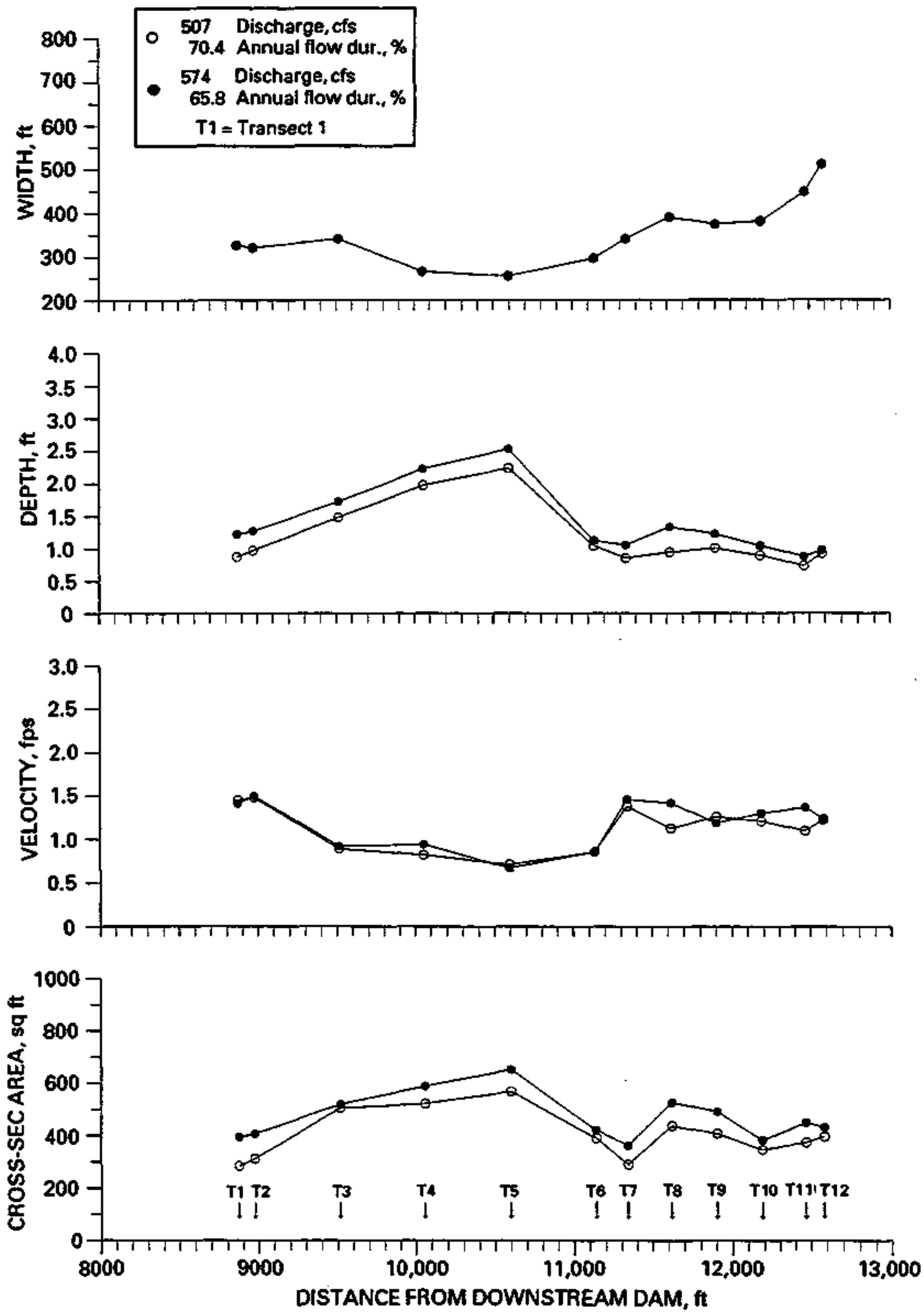

Figure 11. Yorkville study reach transect average flow parameters versus distance

order of 500 feet. Width increases progressively to over 800 feet until the constriction where it narrows to approximately 300 feet. Measurements were conducted at discharges of 259 cfs (annual flow duration 84.3 percent) and 1808 cfs (annual flow duration 15.2 percent). Field data from both measurements are summarized in Table 9 and transect average values are plotted versus distance in Figure 12. Depths measured along transects 1-6 decrease with increasing distance from the dam for both discharges measured. Above the constriction, transect 7, depths are similar to those measured just above the dam, decreasing systematically in the upstream direction. There was little variation in velocity from transect to transect, velocities were slightly lower at transects 1 and 2 nearest the dam.

Dundee Reach

The Dundee reach is located along that portion of the Fox River bordered by the communities of East Dundee and West Dundee. This reach has the smallest drainage area of the five reaches studied and the smallest slope. The first downstream transect is located just above a large established island. It begins approximately 3.8 miles above Elgin's Kimball Street Dam, separated by about 9000 feet from the last upstream transect of the Elgin reach. This reach exhibits a distinct riffle pool sequence and is the only study reach in which there are no established islands. Discharge measurements were made at discharges of 354 cfs (annual flow duration 72.4 percent) and 472 cfs (annual flow duration 61.1 percent). Field data are summarized in Table 10. The average values of flow parameters at a transect are plotted versus distance from the downstream dam in the graphs shown in Figure 13. Width varied from 140 feet to 285 feet. The river channel passes through several constrictions in this area, widening below the study reach and widening again some distance upstream of the end of the study reach. It may be observed from the plots in Figure 13 that variations in parameter values from transect to transect follow the same pattern at both measured discharges. Depths followed the characteristic pattern of alluvial streams: alternating shallow to deep (riffle to pool). Generally higher velocities were observed at transects with relatively lesser depth, and conversely lower velocities were associated with greater average depth. Cross-sectional area declined in the upstream direction.

Bed Material

At each site qualitative examination of sediments was undertaken. Sediment samples were obtained using an Eckman dredge at 100 foot intervals along each cross

Table 9. Elgin Dam Study Reach Summary of Field Data

			Date:	7/9/91			3/18/92		
			Discharge:	259 Cfs			1808 cfs		
			Annual Flow Duration:	84.3%			15.2%		
		Segment		*Transect average*			*Transect average*		
Station (ft)	*Tran no.*	*length (ft)*	*Description*	*width (ft)*	*depth (ft)*	*velocity (fps)*	*width (ft)*	*depth (ft)*	*velocity (fps)*
0	1	745	P	475	5.24	0.09	500	6.4	0.67
745	2	832	P	690	3.74	0.09			
1663	3	853	P	660	3.42	0.06	750	4.62	0.62
2450	4	626	R	870	2.91	0.14			
2916	5	676	R	835	2.23	0.1	750	2.92	0.78
3802	6	886	P	610	3.42	0.09	600	3.98	0.74
			constriction						
0	7	410	P	338	5.4	0.12	420	6.4	0.7
410	8	558	P	505.1	4.69	0.15			
1115	9	618	P	415	5.17	0.16	400	4.6	0.62
1647	10	749	R	577	3.53	0.13	600	6.6	0.77
2614	11	1083	R	349	4.38	0.13	400	5.87	0.8
			main channel	300	4.52	0.21	340	5.72	0.78
			side channel	258	3.02	0.11	240	4.72	0.62
3814	12	1000	R/D	558.0(1) 578.0(2)	3.96	0.17	580.0(1) 600.0(2)	5.22	0.7
		Transect averages:							
			transects 1-6	690	3.50	0.10	650	4.48	0.70
			transects 7-13	437	4.42	0.15	455	5.98	0.72
			reach	575	3.98	0.12	553	5.38	0.71
			riffle	658	3.26	0.13	583	5.13	0.78
			pool	528	4.44	0.11	534	5.20	0.67
			pool-riffle difference	-130	1.18	-0.02	-49	0.07	-0.11
Weighted statistics of point values:									
			transect 1-6 downstream of constriction						
			minimum		1.00	0.00		2.20	0.26
			maximum		5.80	0.55		7.00	1.14
			Avg		3.39	0.10		5.05	0.73
			std		1.55	0.08		1.49	0.23
			CV		0.46	0.85		0.29	0.32
			transect 7-12 upstream of constriction						
			minimum		1.00	0.02		2.00	0.00
			maximum		7.10	0.90		13.00	1.10
			Avg		4.06	0.14		6.79	0.80
			std		1.76	0.11		2.30	0.24
			CV		0.43	0.75		0.34	0.30
			transects 1-12						
			minimum		1.00	0.00		2.00	0.00
			maximum		7.10	0.90		13.00	1.14
			count		100	100		60	60
			Avg		3.66	0.11		6.22	0.78
			std		1.63	0.09		2.07	0.24
			CV		0.45	0.81		0.33	0.31

Notes:
(1) water width
(2) bank to bank width
Width = bank to bank unless otherwise noted

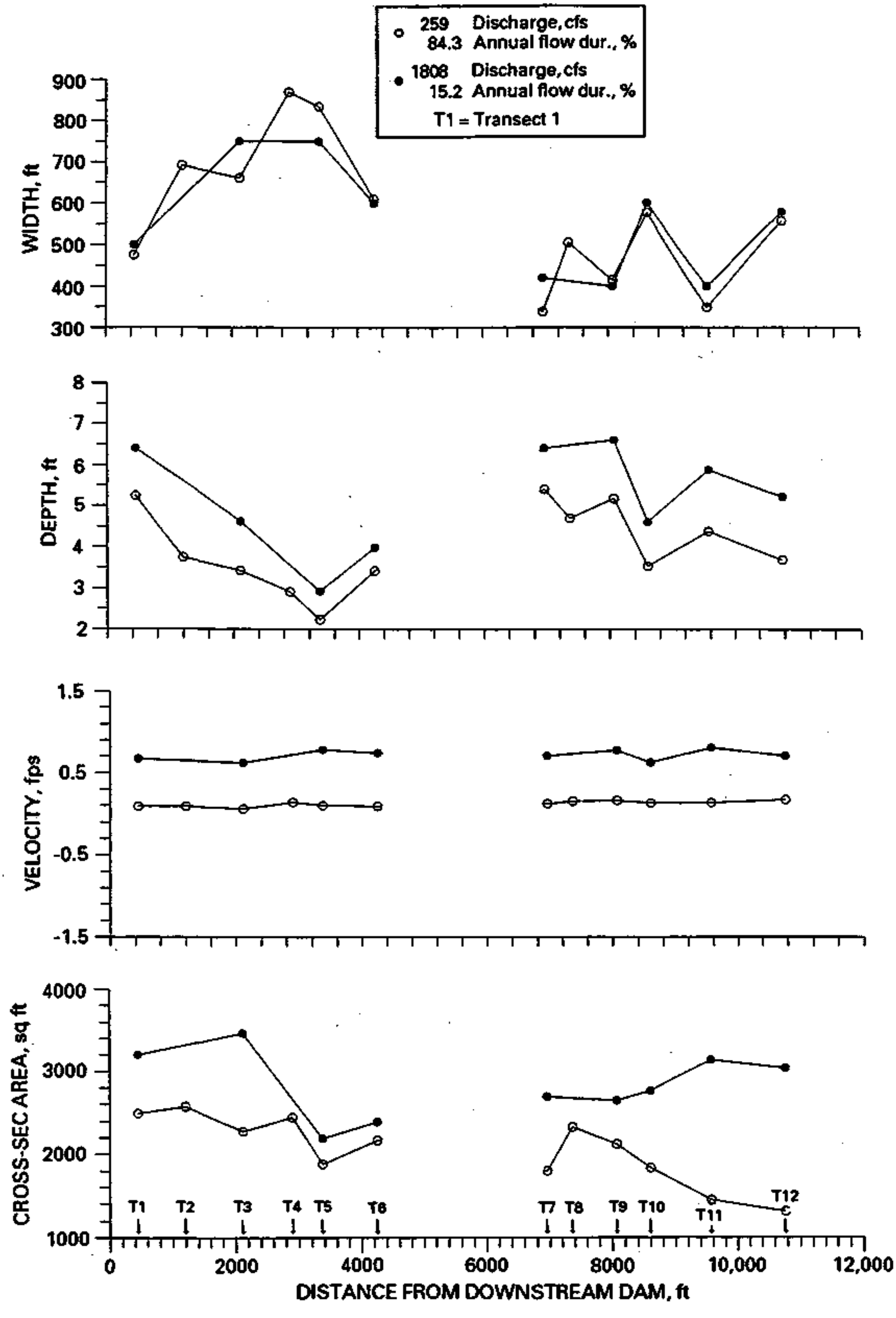

Figure 12. Elgin Dam study reach transect average flow parameters versus distance

Table 10. Dundee Study Reach Summary of Field Data

				8/15/90			9/9/90		
			Date:	8/15/90			9/9/90		
			Discharge:	354 cfs			472 cfs		
			Annual flow duration:	72.4%			61.1%		
		Segment		*Transect average*			*Transect average*		
Station (ft)	*Tran. no.*	*length (ft)*	*Description*	*width (ft)*	*depth (ft)*	*velocity (fps)*	*width (ft)*	*depth (ft)*	*velocity (fps)*
0	1	233	R	285	1.25	0.80	285	1.38	1.09
233	2	233	P	272	1.60	0.59	270	1.72	0.80
466	3	233	P	208	1.98	0.61	210	2.10	0.85
699	4	233	P	183	2.15	0.75	185	2.23	0.94
932	5	233	P	154	1.93	0.93	154	2.18	1.38
1165	6	233	P	167	2.32	0.61	170	2.53	0.82
1398	7	231	R	248	1.37	0.90	250	1.50	1.11
1626	8	228	R	255	1.32	0.96	260	1.47	1.13
1854	9	228	P	195	1.67	0.83	195	1.87	1.31
2082	10	228	P	150	2.17	0.82	150	2.23	1.08
2310	11	228	P	140	1.74	1.01	140	2.00	1.17
2538	12	228	P	180	1.42	1.21	180	1.62	1.62
2766	13	228	R	185	1.17	1.66	190	1.27	1.91
		Transect averages:							
			reach	201.69	1.70	0.90	203.00	1.85	1.17
			riffle	239.33	1.26	1.12	241.67	1.38	1.37
			pool	190.40	1.83	0.83	191.40	2.00	1.11
			pool-riffle difference	-48.93	0.57	-0.28	-50.27	0.61	-0.26
Weighted statistics of point values:									
			Minimum		0.40	0.06		0.20	0.06
			Maximum		3.40	2.04		3.60	2.54
			Count		86	86		86	86
			Avg		1.65	0.88		1.80	1.15
			Std		0.73	0.43		0.77	0.50
			CV		0.44	0.49		0.43	0.44

Note:
Width= water width

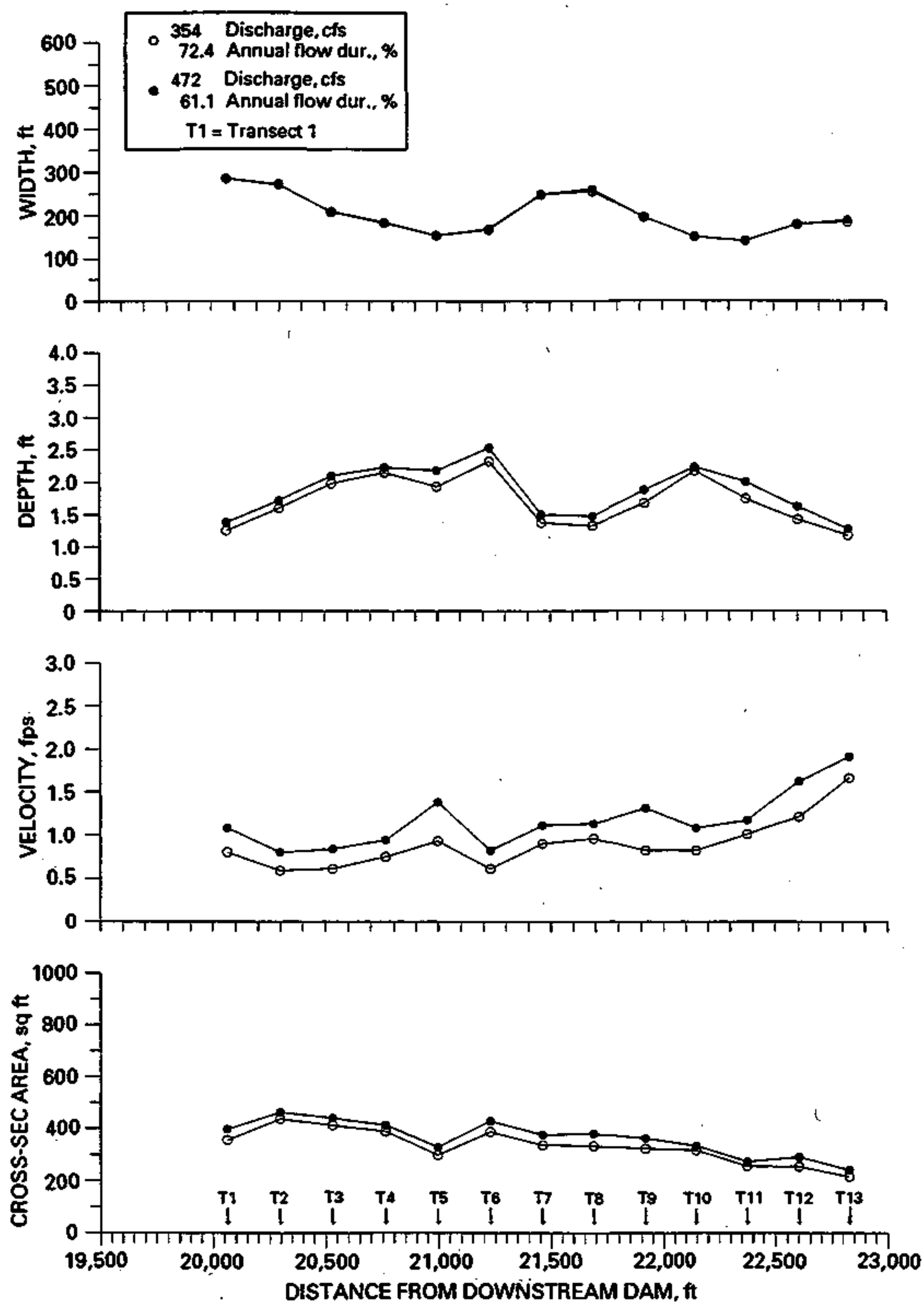

Figure 13. Dundee study reach transect average flow parameters versus distance

section. Each sample was placed in a white bucket and visually examined with regard to particle size and distribution.

The three reaches located beyond the influence of the backwater pools have sediment deposits similar in composition. There is no noticeable decrease in grain size with increasing drainage area, which may be observed in some large rivers. However, given the length of the section of the reach studied, a variation in grain size may not be detectable with a visual inspection. Riffles were characterized by bed materials coarser than those found in the pool.

Both backwater pool sites were different from the other sites. As would be expected, the backwater pools have a greater extent of silt deposits, particularly in the areas adjacent to the dam where lower velocities allow finer particles to settle out.

Brief summaries of the sediment characteristics of each site follow:

Serena: Riffle areas were dominated by coarse sand, fine gravel, and medium gravel with varying amounts of cobble present. Pools had a silt and sand substrate, with a few areas scoured to expose a hard claypan.

Yorhrille Dam: The lower sections of riffles were typically sand and gravel while the upper sections consisted of coarse sand and gravel. Claypan and some deep silt deposits were found in some of the secondary channels. The pools had silt and silt/sand deposits with a few small areas of exposed claypan. Small amounts of cobble were found in isolated patches. Large amounts of allonchthonous detritus, particularly leaf litter, were found throughout the pools.

Yorkville: The riffle areas consisted of coarse sand and gravel deposits with a small amount of cobble. Pooled areas were dominated by silt/sand substrates, with few deep silt deposits found.

Elgin Dam: Little gravel was found in the riffles except near mid-channel. Substrates composed of sand, silt, and gravel were predominant. In pools, deep silt deposits dominated near the dam, while further upstream thinner silt deposits and silt and sand substrates were most common. Large amounts of detritus were found throughout the pools.

Dundee: In riffle areas the predominant substrate type was sand and fine gravel with small amounts of cobble. Silt and sand were the primary constituents in pools.

Comparison of Field-Measured Parameters and Gaging Station Relationships

The transect average and weighted point average values of width, cross-sectional area, depth, and velocity measured at the field sites are summarized in Tables 11, 12, and 13. Some transects were positioned to cross islands and exposed sandbars; these transects

Table 11. Summary of Average Widths and Cross-sectional Area of Flow Measured at Field Sites

Reach	*Drainage area (sq mi)*	*River mile*	*Overall average bed slope (ft per mi)*	*Discharge (cfs)*	*Annual flow dur. (%)*	*Average cross-sectional area*	*Avg. bank to bank width (ft)*	*Average riffle width (ft)*	*Average pool width (ft)*	*Average undivided flow width (ft)*	*Average divided flow width (ft)*
Serena (1)	2273.5	14.97	2.7	603	72.6	561	320	335	233	NA	NA
Serena (2)	2273.5	14.97	2.7	691"	67.6	486	284	278	294	NA	NA
York. dam	1788.7	36.17	4.5	636	61.6	1974	613	678	548	503	777
York. dam	1788.7	36.17	4.5	2016	18.5	2242	577	617	555	542	736
Yorkville	1783	37.76	4.5	507	70.4	402	380	423	295	316	509
Yorkville	1783	37.76	4.5	574	65.8	471	380	423	295	316	509
Elgin dam	1507.2	71.06	2.1	259	84.3	1988	575	658	528	NA	NA
tran. 1-6	1507.2	71.06	2.1	259	84.3		690			NA	NA
tran. 7-12	1507.2	71.06	2.1	259	84.3		437			NA	NA
Elgin dam	1507.2	71.06	2.1	1808	15.2	2795	553	583	534	NA	NA
tran. 1-6	1507.2	71.06	2.1	1808	15.2		650			NA	NA
tran. 7-12	1507.2	71.06	2.1	1808	15.2		455			NA	NA
Dundee	1451.1	74.8	2.1	354	72.4	332	202	239	190	NA	NA
Dundee	1451.1	74.8	2.1	472	61.1	365	203	242	191	NA	NA

Notes:

(1) river reach downstream of bridge

(2) river reach upstream of bridge

NA= not applicable

Table 12. Summary of Average Depths Measured at Field Sites

Reach	Drainage area (sq mi)	Overall average bed slope (ft per mi)	Annual flow dur. (%)	Weighted statistics of point values for depth: Avg (ft)	Std (ft)	CV	Transect averages: riffle depth (ft)	pool depth (ft)	pool-riffle difference (ft)	undivided flow depth (ft)	divided flow depth (ft)
Serena(1)	2273.5	2.7	72.6	1.86	0.80	0.43	1.14	2.26	1.12	1.70	NA
Serena(2)	2273.5	2.7	67.6	1.98	1.12	0.56	1.76	2.85	1.09	2.03	2.00
York. dam	1788.7	4.5	61.6	3.83	1.58	0.41	3.04	4.33	1.29	4.10	3.07
York. dam	1788.7	4.5	18.5	4.22	1.62	0.38	3.48	4.45	0.97	4.15	3.86
Yorkville	1783	4.5	70.4	1.33	0.76	0.57	0.90	1.66	0.76	1.29	0.89
Yorkville	1783	4.5	65.8	1.52	0.82	0.54	1.10	1.93	0.83	1.56	1.03
Elgin dam	1507.2	2.1	84.3	3.66	1.63	0.45	3.26	4.44	1.18	3.98	NA
tran. 1-6	1507.2	2.1	84.3	3.39	1.55	0.46					
tran. 7-12	1507.2	2.1	84.3	4.06	1.76	0.43					
Elgin dam	1507.2	2.1	15.2	6.22	2.07	0.33	5.13	5.20	0.07	5.38	NA
tran. 1-6	1507.2	2.1	15.2	5.05	1.49	0.29					
tran. 7-12	1507.2	2.1	15.2	6.79	2.30	0.34					
Dundee	1451.1	2.1	72.4	1.65	0.73	0.44	1.28	1.83	0.57	1.70	NA
Dundee	1451.1	2.1	61.1	1.80	0.77	0.43	1.38	2.00	0.61	1.85	NA

Notes:
(1) river reach downstream of bridge
(2) river reach upstream of bridge
NA = not applicable
Avg = average
Std = standard deviation
CV = coefficient of variation

Table 13. Summary of Average Velocities Measured at Field Sites

				Weighted statistics of point values for velocity			*Transect averages*				
Reach	*Drainage area (sq mi)*	*Overall average bed slope (ft per mi)*	*Annual flow dur. (%)*	*Avg (ft)*	*Std (ft)*	*CV*	*riffle velocity (fps)*	*pool velocity (fps)*	*pool-riffle difference (fps)*	*undivided flow vel (fps)*	*divided flow vel (fps)*
Serena(1)	2273.5	2.7	72.6	1.02	0.95	0.93	1.35	0.88	-0.47	1.12	NA
Serena(2)	2273.5	2.7	67.6	1.20	0.71	0.59	1.48	0.95	-0.53	NA	1.46
York. dam	1788.7	4.5	61.6	0.35	0.18	0.51	0.38	0.33	-0.06	0.39	0.31
York. dam	1788.7	4.5	18.5	0.71	0.31	0.44	0.82	0.66	-0.16	0.74	0.62
Yorkville	1783	4.5	70.4	1.10	0.58	0.52	1.20	0.98	-0.22	1.09	1.20
Yorkville	1783	4.5	65.8	1.15	0.53	0.46	1.28	1.01	-0.27	1.15	1.27
Elgin dam	1507.2	2.1	84.3	0.11	0.09	0.81	0.13	0.11	-0.02	0.11	NA
tran. 1-6	1507.2	2.1	84.3	0.10	0.08	0.85					
tran: 7-12	1507.2	2.1	84.3	0.14	0.11	0.75					
Elgin dam	1507.2	2.1	15.2	0.78	0.24	0.31	0.78	0.67	-0.11	0.71	NA
tran. 1-6	1507.2	2.1	15.2	0.73	0.23	0.32					
tran. 7-12	1507.2	2.1	15.2	0.80	0.24	0.30					
Dundee	1451.1	2.1	72.4	0.88	0.43	0.49	1.12	0.83	-0.28	0.90	NA
Dundee	1451.1	2.1	61.1	1.15	0.50	0.44	1.37	1.11	-0.26	1.17	NA

Notes:
(1) river reach downstream of bridge
(2) river reach upstream of bridge
NA = not applicable
Avg = average
Std = standard deviation
CV = coefficient of variation

are identified as "divided flow" in the column headings in Tables 11- 13. The spacing between transects is fairly uniform, thus the weights computed from the water surface area represented by a point value do not have a broad range of values. Therefore the average of transect parameter values and the weighted reach average values do not differ drastically as can be seen in the summary tabulations (Tables 11-13). Discharge measurements made at the three reaches unaffected by backwater pools fall within a very narrow range of flow durations. One set of comparable measurements includes flows having annual flow durations of 72.6, 70.4 and 72.4 percent at the Serena, Yorkville, and Dundee reaches, respectively. The second set of measurements includes discharges having annual flow durations of 67.6, 65.8, and 61.1 percent at Serena, Yorkville, and Dundee, respectively. In the two backwater pools, one set of measurements was made during flows having annual flow durations of 61.6 and 84.3 percent at Yorkville Dam and Elgin Dam reaches, respectively. These are comparable flow durations to those at the other three sites. The second set of measurements at the backwater pool sites was made at higher discharges. The flow durations of the higher discharges are sufficiently close in value that flow characteristics measured at the two sites may be compared. A comparison of the tabulated transect average values of flow parameter at the field sites with those plotted for the gaging stations (Figure 8) provides information on the variation of flow characteristics along the river course as well as some insight into the representativeness of the gaging station data. The gaging station data represent average transect values, hence it is appropriate to compare the gaging station data and the transect average values computed from the field data.

Widths

When compared at flows having the same frequency of occurrence, width typically increases with increasing drainage area in alluvial streams (Dunne and Leopold, 1978). The width of a river in such cases may serve as an indicator of the flood magnitude in ungaged areas (Riggs, 1976). Along the Fox River there is no pattern of increasing width with drainage area. The in-channel dams create pools with widths greater than the immediate downstream section or above the section of backwater pool. In reaches not affected by the backwater pools, the geology and topography of the area tend to control the river width. The plot showing width versus drainage area developed from the gaging station data (Figure 8a) illustrates the erratic variation in width along the river. The widths representative of the field reaches also appear to vary in an inconsistent pattern.

The Serena reach (drainage area 2274 sq mi) has water width on the order of 300 feet for flows corresponding to annual flow durations between 65 and 75 percent. At the

Dayton gage (drainage area 2642 sq mi), located approximately 10 miles downstream, the flow width is less, about 230 feet, at comparable flow durations. Evidence of rock outcrops were observed below the Serena reach, near Wedron. Upstream, between the Serena and the Yorkville Dam reaches, the river is braided and has numerous vegetated islands.

The Yorkville reach (drainage area 1783 sq mi) is just downstream of the Montgomery gage (drainage area 1732 sq mi). Average bank to bank width computed from measurements at Yorkville were approximately 380 feet for flows corresponding to flow duration between 65 and 70 percent; average undivided flow width was 316 feet. At Mongomery flow width was on the order of 170 feet at the constricted section and about 230 feet at the unconstricted section for this range of flow durations.

The Dundee reach lies between the South Elgin and Algonquin gages. At flows having flow durations between 60 and 75 percent, the average width at South Elgin was on the order of 270 feet, about 200 feet at the Dundee reach, while at Algonquin, away from the dam, widths were about 120 feet for comparable flows. These three locations do show a pattern of increasing width values with increasing drainage area. However, the constricted section described as part of the Elgin Dam reach would interrupt this pattern.

Along the study area, from Algonquin to Dayton, width is significantly influenced by natural and artificial channel controls, not carved by discharge as in evolving alluvial rivers (Ikeda, Parker, and Kimura, 1988). Water width does not change significantly with increasing (or decreasing) discharge at a cross section, banks tend to be steep. Depth and velocity tend to adjust to accommodate changes in discharge. Sections with islands have bank to bank widths on the order of 50 percent greater than the water width at undivided sections. The average width at cross sections identified as riffles was consistently greater than the width at pool sections at all of the field sites.

The in-channel dams create reaches with somewhat greater widths than the reaches immediately upstream, as would be expected. The Yorkville and Elgin Dams are two of the higher dams in the study area. The average bank to bank width in the Yorkville Dam reach is about 50 percent greater than the average bank to bank width in the Yorkville reach. The Elgin Dam is located at a somewhat constricted section of the river; about 400 feet upstream of the Elgin Dam the water width is about 500 feet. A quarter to a half mile upstream of the dam, the backwater pool is significantly wider (750 feet). The average bank to bank width in the Elgin Dam reach is more than two times the average bank to bank width in the Dundee reach just upstream.

Depths

It may be observed from inspection of Figure 8b, which shows the gaging station depth values at selected annual flow durations versus drainage area, that with the exception of measurements made in the Algonquin Dam backwater pool, average depths do not vary over a wide range of values. Average depths at the stations for flows corresponding to annual flow duration between 60 and 75 percent vary from about 0.9 to just over 2 feet. The transect-average flow depths (for undivided flow sections) in the three non-backwater reaches likewise stay within this range of values. Transect average depths and reach-wise average depths are summarized in Table 12 for the field sites. The average transect depth for cross sections with a single channel ranged from 1.29 to 2.03 feet in the non-backwater reaches. The backwater pools had average transect depths between 3.98 and 5.38. The depth of flow is less at sections were there are multiple channels as illustrated by the data form the Yorkville and Yorkville Dam reaches.

The Yorkville Dam has a reported height of 7 feet and the Elgin Dam has a reported height of 13 feet. However, less than 500 feet upstream of the Yorkville Dam, at the first study cross section, average transect depth measured was only 4.4 feet at a discharge with an annual flow duration of 18.5 percent. Less than 400 feet upstream of the Elgin Dam, the transect average depth measured at a discharge with annual flow duration of 15.2 percent was 6.4 feet. Maximum point depth measured during high flows (annual flow durations less than 20 percent) at the first cross sections upstream from the dams, were just over 7 feet.

Inspection of the plots of depth versus distance for the Yorkville Dam and Yorkville reaches (Figures 10 and 11) shows that at the last (upstream) transect in the Yorkville Dam reach, depths are about 2 feet greater than found at the first (downstream) transect in the Yorkville reach, at comparable flow durations. The last transect of the Yorkville Dam reach (1.2 miles upstream of the dam) is approximately 0.5 miles downstream of the first transect in the Yorkville reach, which is 1.7 miles upstream of the dam. The backwater pool formed by the Yorkville Dam does not appear to extend as far as 1.7 miles upstream. Reach average depths computed from the weighted point values have a fairly narrow range from 1.33 to 1.93 in the three non-backwater reaches. The Serena and Elgin reaches have higher average depths than those in the Yorkville reach, which has greater width and is characterized by numerous islands and sandbars. Differences between the maximum and minimum depths measured were about 3 feet at these reaches (see Tables 6, 8, and 10). The difference between average pool depth and average riffle depth *does* consistently increase with increasing drainage area (in the downstream direction) for this range of flows. The difference between average pool depth and average riffle depth is about 0.6 feet at Dundee, 0.8 feet at Yorkville, and 1.1 feet at Serena. This progressive increase in pool-riffle depth differences was observed in the Sangamon and Vermilion Basin river systems (Broeren and Singh, 1990; Singh et al., 1987).

The standard deviation of the point values of depth is a measure of the variability of depths throughout a reach. The standard deviations of depth calculated from the field data at each discharge are summarized in Table 12. Field measurements of depth and velocity similar to that measured in the Fox River had been previously made at sites along the Sangamon River (Broeren and Singh, 1990). These data show a positive correlation between the standard deviation of depth and the pool-riffle depth difference. This relationship indicates that the standard deviation is primarily influenced by riffle-pool bedforms (streamwise variations in average depths) rather than variations in depth across a section (transverse to the direction of flow). The standard deviation of depth was a little greater at the higher discharge than at the lesser discharge in each of the three non-backwater reaches. However, the difference between the two computed values of the standard deviation at any of the reaches is within rounding error and not significant.

For each reach the coefficient of variation for depths was less at the higher discharge than at the lower discharge. In other words, the relative variability in depths in the reach is less at the higher discharge. The coefficient of variation of depth ranges from 0.29 to 0.57.

In the backwater pools, measurements in each reach were made at two significantly different discharges. The difference between pool and riffle depths decreased notably with increasing discharge. At the Elgin Dam reach the difference between pool and riffle depths is significantly lower at the higher discharge when the average values are compared. However, inspection of the individual transect values shows that this is due to depth increases at "riffle " transects located upstream of the constriction. The constricted channel which divides the two sections of the reach where measurements were made, appears to influence flow conditions as much or more than the in-channel dam. The standard deviation of depths is greater at the higher discharge than at the lower discharge in both reaches, however the coefficient of variation is less at the higher discharge. Thus, the numerical range of depth values is greater at the higher discharge, but the relative variability is less than observed at lower discharges. At higher discharges the influence of local bed features on flow conditions decreases and flow parameters become more uniform along the reach.

Velocities

Summary statistics for velocity are provided in Table 13. The average velocity for undivided flow sections in each reach ranges from about 0.90 to 1.17 fps (feet per second) in the reaches unaffected by the backwater pools. The average velocities at transects across riffle areas are notably greater than observed in the pool sections of the reach. Inspection of Figure 8c shows that these values are similar to those characteristic of measurements at the gaging stations in the range of flows having annual flow durations between 60 and 75 percent. It may also be observed from the plot in Figure 8c that velocities measured near the gaging stations increase to fairly high values with increasing discharge. At discharges having annual flow durations of 50 percent or less, average velocities are typically greater than 2 fps and at high discharges (annual flow duration of 10 percent) are over 3 fps at some stations. In the backwater pools, transect average velocities are typically less than 0.5 fps at flows comparable to those measured in the other three reaches. Even at the considerably higher discharges, transect average velocities in the backwater pool reaches are on the average less than 0.8 fps.

The weighted point average velocities range from 0.88 to 1.2 fps in the Serena, Yorkville, and Dundee reaches. The Yorkville Dam and Elgin Dam reaches have weighted reach average velocities less than 0.5 fps at the low flows measured and just over 0.7 fps at the higher discharge. Point values of velocity are highly variable as indicated by the standard deviation. The standard deviation in the three non-backwater reaches has a low of 0.43 at the Dundee reach and a high of 0.95 at the Serena reach. As the numerical values of velocity are close to one, the coefficient of variation is close in value to the standard deviation. In the backwater pools, the standard deviation is less than found at the other three reaches. However, the values of the coefficients of variation are close to those found in the other reaches. Point values of velocity vary considerably throughout each reach.

Cross-sectional Area of Flow

Cross-sectional area of flow at selected annual flow durations (estimated from the gaging station relationships) is plotted versus drainage area in Figure 8d. In contrast to the width, depth, and velocity of the flow, this parameter does show a pattern of increasing values with increasing drainage area (downstream direction along the river). In the plot shown in Figure 8d, cross-sectional area estimated for sites not affected by backwater from the dam range from about 150 to 500 square feet (sq ft) for flows corresponding to annual flow durations between 60 and 75 percent. Typical cross-sectional areas measured at the study reaches are listed in Table 11. The average cross-sectional areas at the study reaches are close to the values at nearby gages. Along the reaches, the areas measured at the individual transect did show some variability. Along the Serena reach the cross-sectional areas varied from about 250 to over 800 sq ft, but at most of the transects the area was close to the average reported in Table 11. The Yorkville reach showed somewhat less variability, with cross-sectional area varying from close to 300 sq ft to just over 600 sq ft, the averages of 402 and 471 sq ft are representative of the reach. At the nearby Montgomery gage, there is some overlap of data for annual flow durations between 60 and 75 percent from measurements made at both the unconstricted and constricted portions of the river. For this range of flows, the cross-sectional area at both the constricted and unconstricted sections is very nearly the same and similar to the Yorkville reach, lying between 400 and 500 sq ft over this range of flow durations. The cross-sectional area of flow measured in the Dundee reach ranged from a little over 200 sq ft to about 450 sq feet. The area of flow was greatest at the downstream portion of the reach. This is somewhat greater than found approximately 6 miles upstream, near the Algonquin Dam where the cross-sectional area of flow was in the range of 200 to 300 sq ft for flow duration.

Cross-sectional area of flow is dramatically greater in the backwater pools. As can been seen from the values shown in Table 11, areas around 2000 sq ft are typical. The area of flow section estimated from flow measurements in the Algonquin Dam pool is in this range (Figure 8d).

Channel Forms

Well-established vegetated islands and sandbars occur along the Fox River from Elgin to Dayton. The divided flow pattern is referred to as braided. This channel pattern does not imply a lack of equilibrium in the channel, or suggest aggradation. A braided river may be as close to equilibrium as a meandering or straight pattern. Leopold et al. (1964) maintain that when two rivers of a given size are compared, braided channels occur on steeper slopes than meanders. Braided channels offer greater resistance to flow. Braided sections occur in both the backwater pools and those reaches of the river unaffected by the backwater. Although not within the study area, one of the larger islands observed during the reconnaissance study of the river is located downstream of the Elgin Dam. Footbridges have been constructed from the bank to the treed parklike island. The Yorkville reach, which has the steepest slope, is dominated with islands. It does not appear that the presence of the islands is a function of the in-channel dams.

The effect of the in-channel dams does not appear to propagate more than a few thousand feet upstream. The variation in flow depth and the observation of coarse bed material and bed material sorting in the backwater pool study reaches demonstrates the presence of riffle and pool features. Reservoir studies indicate that a rising base level (such as created by an in-channel dam) controls deposition in the river system only up to the level at which the backwater transition curve intersects the original streambed profile (Leopold et al., 1964). At the Yorkville and Elgin Dam reaches, deep silt deposits were observed only in the river section immediately upstream of the dams. Silt deposits thinned and coarse materials were observed in the most upstream portions of the backwater pools. The pool lengths reported in Table 2 appear to be greater than the most upstream extent of observed effects of the dams on bed forms.

In those reaches where a riffle-pool-riffle sequence could be identified, riffle to riffle spacing was closer to seven times the channel width. Average riffle to riffle spacing tends to fall between five to seven times the channel width. On the basis of streamwise distance, riffles tend to account for 30 to 40 percent of the reach in the downstream reaches, Serena, Yorkville Dam, and Yorkville; and 15 to 20 percent of the reach length in the Elgin Dam and Dundee reaches.

AQUATIC HABITAT STUDY

Aquatic Habitat Assessment Methodology

The Instream Flow Incremental Methodology (IFIM) was developed by the Cooperative Instream Flow Service Group (IFG) of the U. S. Fish and Wildlife Service as a method to relate flow parameters (e.g., depth, velocity, and substrate) and usable fisheries habitat. Habitat variables are assumed to act independently and are equally weighted. By providing a link between flow and stream characteristics and aquatic habitat suitability, the IFIM can be used to assess if these characteristics are limiting factors to fisheries support or may become limiting with flow or channel modifications. Fisheries supported by a given water body are indicative of overall stream habitat conditions as fish are the top consumers in the aquatic food chain.

Usable habitat availability is quantified by the calculation of a habitat index value, the weighted usable area (WUA). The WUA of a stream can be calculated for a variety of fish species at different life stages under various flow conditions.

In the IFIM, habitat availability is determined by conceptually segmenting the stream into cells, each of which represents a different hydraulic environment characterized by depth, velocity, and substrate. The utility as habitat in each cell is evaluated by species- and life-stage-specific fish preference indices for each habitat variable considered (Bovee and Milhous, 1978; Bovee, 1982). The Instream Flow Group (IFG) has developed preference data (preference curves) for more than 500 fish species (Milhous et al., 1984).

The WUA was calculated for adult and juvenile life-stages of 4 fish species using the field data (velocities and depths) described in the field study section. The Illinois Natural History Survey (INHS) has developed preference curves of several fish species for the low-gradient, prairie stream environment common in Illinois (Wiley et al., 1987). The INHS preference curves were used in this study for species with available data, otherwise the IFG curves were used. The species selected for this study are the largemouth bass, smallmouth bass, channel catfish, and bluntnose minnow. INHS preference data are available for all the species but the largemouth bass.

The WUA of each reach was calculated by summing the product of the cell suitability indices and the lateral flow surface area of the cell:

$$WUA = \sum_{i=1}^{n} S_d(d_i) \times S_v(v_i) \times a_i$$

n = number of depth and velocity pairs (i.e., number of cells)

where S(d) and S(v) are preference index values for depth (d) and velocity (v), of cell i and a_i is the surface area of the cell.

Habitat-Discharge Relationships

Data for the free-flowing reaches (Dundee, Serena, and Yorkville) were collected over a narrow range of medium flows, from 61.1 to 72.6 percent annual flow durations. By contrast, data collected from the backwater sites were over a much wider range of flow conditions, from 15.2 to 84.3 percent annual flow durations. Development of a relationship between WUA and flow duration for the entire basin is not discernible in the data collected for this study because of the limited range of flows measured. It is possible, however, to note the response of individual study sites over the flows observed and to make some inter-site analyses.

In the following description of the results of the WUA computations, values are of WUA per 1000 feet of stream. For the sake of brevity, the two measurements at each site will be referred to as "higher" and "lower" flows, although at some sites they could more accurately be described as medium and low-medium flows.

Largemouth Bass

Table 14 presents the WUA for largemouth bass WUA for the five sites. At the free-flowing sites, WUA for adult largemouth bass was relatively low (<12,000 at Serena, <6500 at Dundee and Yorkville) at all three sites. WUA showed little response to changing flows over the range of flows observed. At the backwater sites, except during the higher flow at the Elgin Dam site, WUA was an order of magnitude higher than at the free-flowing sites. At both the Elgin Dam and Yorkville Dam sites, WUA was higher at the lower flows. The higher flow at the Elgin Dam produced much lower WUA than at the lower flow, while the two measurements at the Yorkville Dam produced a much smaller range of WUA The decrease in WUA at the Elgin Dam site is a result of the preference largemouth bass have for lower velocities.

Juvenile largemouth bass WUA of free-flowing sites were much higher than adult largemouth bass WUA for the same reaches. The highest value was at the Serena reach (WUA = 78,805) and lowest at the Dundee site (WUA = 31,444). At all three sites WUA was higher at the lower flow, with the greatest response to changing flow at the Dundee site. At the dam sites WUA response was similar in a relative sense to that for largemouth bass, i.e., WUA at the higher flow at the Elgin Dam was much lower than at the lower flow. Also like the largemouth bass, the decrease in WUA at higher flows is due to a preference for lower velocities.

Smallmouth Bass

Table 14 presents the WUA for smallmouth bass. Of the free-flowing sites, WUA showed the greatest response at the Dundee site, ranging from 75,587 (annual flow duration of 72.4 percent) to 12,992 (annual flow duration of 61.1 percent) The WUA increase at the lower flow primarily occurred in the riffle transects. The pool transects showed little difference in WUA at the two flows. At Serena, the WUA at a flow of 603 cfs was 12,992 and increased to 19,970 at 691 cfs. At Yorkville the WUA was high at both flows, ranging from 49,992 to 54,455. At the Elgin Dam site, WUA was virtually nonexistent, ranging from 11 to 23. The WUA at the Yorkville Dam site was only slightly better, ranging from 213 to 385. The deeper depths at both sites cause the low WUA values. According to the INHS preference curve used, optimal depths for adult smallmouth bass range between 3.8 and 4.1 ft. At greater depths, the INHS preference curve indicates a suitability or preference of 0.

The juvenile smallmouth bass WUA for the free-flowing sites ranged from 12,530 to 25,780. Values were highest at the Yorkville site. At all sites the WUA was higher at the measurement with the higher flow. At the Elgin Dam site, the WUA was low, ranging

Table 14. Weighted Usable Area per 1000 Feet of Stream Length

Site	Discharge (cfs)	Annual flow dur. (%)	Largemouth bass		Smallmouth bass		Channel catfish		Bluntnose minnow	
			adult	juvenile	adult	juvenile	adult	juvenile	adult	juvenile
Serena	603	72.6	10455	73865	19970	18390	15290	12993	15256	12559
	691	67.6	11562	78805	14580	4771	17129	1380	27343	7175
Yorkville Dam	636	61.6	16674	352007	213	25780	28244	114940	655	436
	2016	18.5	129543	228814	385	34858	36051	222706	152	234
Yorkville	507	70.4	5211	54455	26506	12530	6916	10863	40386	16995
	574	65.8	6434	49992	21988	14646	7891	7439	17207	25175
Elgin Dam	259	84.3	218436	509089	23	6056	19298	36936	157	13
	1808	15.2	14004	15740	11	1002	2259	8142	0	5
Dundee	354	72.4	5331	59906	75587	16345	6705	4160	82825	46955
	471	61.1	3781	31404	12992	6842	6108	2206	17377	13748

from 1,002 to 6,056. It was higher at the Yorkville Dam site, where WUA ranged from 25,780 to 34,858. The difference in WUA between the two dam sites is due to the prevalence of deeper depths at the Elgin Dam site.

Channel Catfish

The WUA for channel catfish are given in Table 14. The adult WUA at free-flowing sites ranged from 6,108 to 17,129. Over the range of observed flows, little response to changes in flow is evident at any of the free-flowing sites. The backwater sites exhibited opposite response in WUA to changes in flow. The Yorkville Dam site ranged from 28,244 (annual flow duration of 61.6 percent) to 34,858 (annual flow duration of 18.5 percent), while at the Elgin Dam site WUA ranged from 2,259 (annual flow duration of 15.2 percent) to 28,244 (annual flow duration of 84.3 percent).

Higher WUA of juvenile channel catfish at all three free-flowing reaches was found at the lower flows. At the Serena reach the difference was more significant than at the Dundee and Yorkville reaches. The WUA ranged from 1,380 to 12,993 at the Serena reach, while values at Dundee and Yorkville were intermediate. At the Yorkville Dam site, the WUA values were high, exceeding 220,000 at 18.5 percent annual flow duration and nearly 115,000 at 61 percent annual flow duration Lower values (36,936 and 8,142) were observed at the Elgin Dam site.

Bluntnose Minnow

The greatest value of adult bluntnose minnow WUA (Table 14) was found at the Dundee reach (WUA = 82,825) at the flow corresponding to a 72.4 percent annual flow duration, followed by the Yorkville reach (WUA = 40,386) at the 70.4 percent annual flow duration. The WUA at both sites dropped to less than 17,500 at the higher observed flow. At the Serena reach, it was greater for the higher flow (WUA = 27,343) than the lower flow (WUA = 15,256). At both backwater sites, it was very low (WUA < 700).

The WUA for juvenile bluntnose minnow (Table 14) was also greatest at the Dundee reach (46,995) at the 324 cfs flow (annual flow duration of 72.4 percent). With the exception of the Yorkville reach at the 574 cfs flow, at all free-flow sites and observed flows the WUA was lower for juvenile bluntnose minnows than for adults. At the backwater sites, low values of juvenile WUA were predicted, with a high value at the Yorkville Dam site (WUA < 500). The lower values of WUA for juveniles at both backwater and free-flowing sites are attributed to the very narrow range of suitable depths according to the INHS suitability curves.

SUMMARY

The Fox River system does not follow a predictable progression of increasing width, depth, and velocity with increasing drainage area when compared at flows having similar annual flow durations as found in many other Illinois rivers. Historical data collected near gaging stations and data from the study reaches demonstrate that, when compared at flows having the same frequency of occurrence, average width, depth, and velocity do not follow a systematic progression along the river. Parameter values of width, depth, velocity and cross-sectional area measured at the field sites are consistent with values determined from historical data collected at nearby gaging stations. Discernible segments of the river have distinct channel characteristics, backwater pools, braided channels, and sinuosity. Within these segments of the river, there is a certain degree of consistency, and segments with similar channel forms have comparable flow characteristics. However, flow characteristics differ between these segments.

Width varies erratically along the river, and is primarily controlled by the local topography and geology or by artificial controls. The in-channel dams create short sections of wider, deeper, and slower flow; however, some semblance of riffle-pool bed flows and the variability of flow characteristics associated with them may be observed less than a mile upstream of the dams. The constriction in the Elgin Dam reach (between transects 5 or 6) exerts as significant an influence on flow conditions as does the dam, producing depths and velocities similar to those just above the dam. Riffle and pool patterns may be observed to a greater or lesser extent in all of the reaches. During low flows (annual flow duration 60 to 70 percent) the in-channel dams produce depths 2 to 3 feet higher than in reaches upstream of the backwater pools and velocity on the order of 0.3 fps less. The Dundee reach located in the portion of the river with the mildest slope was the only one that did not include any significant islands or sandbars. Islands and sandbars were most predominant in the Yorkville and Yorkville Dam reaches, which are located in that part of the river having the greatest overall slope. Several well-established islands were observed near the Elgin reach. Some sorting of bed materials is evident in the somewhat coarser materials found in riffle areas of each reach. While fine grain deposits are characteristic of the backwater pools where lower velocities allow some settling, there are few deep silt deposits in the natural pooled areas in segments of the river outside of the backwater pools. There is some evidence of scour from high velocities in the exposed claypan found in some of the reaches. The gaging station data show that velocities occurring at flows having an annual flow duration of 50 percent are typically close to 2 fps and at higher flows, annual flow duration of 10 percent or lower, velocities exceeding 3 fps are not uncommon.

The variety of hydraulic conditions available in the Fox River provides a diverse aquatic habitat supporting several different fish species, including some highly desirable sport fishes. The presence of dams on the Fox River has clearly altered the nature of the fish habitat in the backwater pool reaches. However, the overall effect is to provide greater diversity than the natural conditions. Of the four species considered in this study, the habitat availability of bluntnose minnow (adults and juveniles) and the adult smallmouth bass is much lower in the backwater areas than in the riffle-pool areas. Habitat availability of both adult and juvenile channel catfish, on the other hand, is much higher in the backwater pools. Habitat availability for largemouth bass is also greater in the backwater pools than in the unaffected portions of the river. While not specifically studied in this project, the tailwater areas below the dams are popular sport fishing areas. Walleye, white bass, crappie, and channel catfish are abundant below several of the dams: Dayton, Yorkville, Montgomery, North Aurora, St. Charles, and Stratton (McHenry) Dams being the most popular areas (Brown, 1989).

Assessment of whether the modifications to the aquatic habitat created by the dams represents an improved or degraded fish habitat would depend on the relative value/desirability of a particular fish species. It is not within the scope of this study to assess if these alterations to habitat have improved or degraded fish habitat conditions in general. However, species-specific habitat models, as applied in this study, would be useful in such a task once particular species are targeted for protection or habitat enhancement.

Generalized basin relationships for predicting average flow parameters of width, depth, and velocity are not applicable to the main stem of the Fox River. The identified flow and channel conditions along the Fox may be categorized as backwater pool, braided, sinuous, and a fourth category for sections immediately downstream of the dams may be appropriate. While regional or basinwide relationships may not be applicable, the study reaches do form a representative sample of the variety of flow conditions present along the Fox, with the exception of reaches immediately downstream of the dams. Appraisal of the habitat availability and variation with discharge in the study reaches would provide a quantitative assessment of the habitat response to changes in discharge in other similar areas.

The present study indicates several avenues for future research. More detailed substrate analysis would allow an analysis of its influence on habitat utility in terms of WUA. The appropriateness of the preference data used warrants further scrutiny. The use of the IFG preference data in Illinois is often criticized (Wiley et al., 1987) as much of it was developed with data from high-gradient western streams. Though the INHS preference data were developed using data from Illinois streams, the Salt and Middle Forks of the Vermilion River, the streams are much smaller (drainage area < 500 sq mi) than the Fox River in Illinois. Using preference data from smaller streams may lead to misleading results when applied to a larger river such as the Fox. Deep pools, for example, are much more numerous in the Fox River. The development of habitat preference and availability data specific to the Fox River should thus be explored.

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