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EVALUATION OF DEPTH-FREQUENCY EQUATIONS FOR DETERMINING FLOOD DEPTHS

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INTRODUCTION

Floodplain information was generally not available for most parts of the United States until the late 1960s. In House Document 465 the 89th Congress (1966) recommended preparation of flood-prone area maps to assist in minimizing flood losses by quickly identifying areas of potential flood hazards. This mapping project was undertaken by the U.S. Geological Survey (USGS). In 1969 it was changed to outline the approximate boundaries of the 100-year flood. This was undertaken to assist the Federal Insurance Administration (FIA), whose responsibility it was to identify the nation's floodplains as mandated in the National Flood Insurance Act (1968).

Because of the large scope of the project and the short time frame, the Flood Prone Area Maps were prepared to quickly identify areas subject to flooding using approximate methods. Detailed studies with greater accuracy were to be furnished later through the National Flood Insurance Program (NFIP) or by the U.S. Army Corps of Engineers.

To prepare the maps of flood-prone areas, the methodologies used to estimate the 100-year flood boundaries (Edelen, 1973) were:

1) Regional stage frequency relations
2) Profiles of theoretical floods of specified frequency
3) Profiles of observed floods
4) Aerial photographs of flooding

The elevation of the water surface derived from these methods was used in conjunction with topographic maps to determine and delineate the extent of inundation.

The guidelines provided for delineation of flood-prone areas for all streams with drainage areas larger than those listed below (Edelen, 1973):

1) Urban and suburban areas where the upstream drainage area exceeds 25 square miles and, preferably, much smaller streams.
2) Rural areas in humid regions where the upstream drainage area exceeds 100 square miles.
3) Rural areas in semi-arid regions where the upstream drainage area exceeds 250 square miles.

The profiles from methods 2) through 4) were generally not available for most streams in Illinois; therefore it was necessary to develop regional stage frequency relations in order to derive flood heights for the 100-year flood.

The general procedure used for Illinois, the Depth and Frequency (D & F) Method, is summarized by Prugh (1976). This method can be used to predict flood depths of 2-, 5-, 10-, 25-, 50-, and 100-year frequency for many ungaged sites in Illinois. This method employs data from USGS gaging sites and multiple regression analysis techniques to develop depth-frequency equations. The required parameters (drainage area, slope, etc.) are determined from topographic maps and charts. The equations are recommended for use on Illinois streams under natural conditions, unaffected by backwater, artificial controls, or debris jams.

As noted earlier, the National Flood Insurance Act gave responsibility to FIA to identify the nation's floodplains. This program was only moderately successful and came under criticism in the wake of millions of uninsured flood damages caused by Hurricane Agnes in 1972. Subsequently the Flood Disaster Protection Act of 1973 was passed to move the Flood Insurance Program along. One of the provisions in the Act was an expeditious identification of and dissemination of information concerning flood-prone areas. This information took the form of a "Flood Hazard Boundary Map (FHBM)" for all communities identified as having a flood-prone area. In most cases, these maps showed information similar to the USGS Flood Prone Area Maps, but were not displayed on topographic quadrangle base maps. Instead, base maps were of varying scale and displayed streets and arterial transportation routes along with shaded flood hazard areas. After the flood hazard area was identified, communities were required to join the Emergency Phase of the National Flood Insurance Program as a condition of future federal financial assistance in the floodplain. At this point, anyone buying a home in a flood hazard area was required to buy flood insurance.

FIA recognized the inadequacy of the FHBM and contracted with consultants and governmental agencies to perform detailed Flood Insurance Studies (FIS) on a priority basis for all flood-prone communities. The purpose of the FIS was to identify and rate the flood risk for these communities and to provide detailed floodplain information on flooding sources to assist in enforcing floodplain land use regulations.

The detailed floodplain information in the FIS is a result of extensive hydrologic and hydraulic analysis. The hydrologic analysis consists of developing flood discharges of 10-, 50-, 100-, and 500-year frequencies estimated by regression equations, rainfall runoff relationships, or gage analyses. These discharges are then used in a hydraulic analysis of stream cross section data to determine flood heights for these same four frequencies. The cross sections are surveyed at close intervals and are located at most controlling restrictions such as bridges and culverts. A detailed analysis such as this produces flood elevations that are generally accurate to within 0.5 feet.

Due to the high cost of detailed studies, communities were prioritized with regard to severity of flooding. Detailed studies will ultimately be prepared for approximately half (400) of the flood prone communities in Illinois. The remaining areas will continue to use the FHBM or best information available to regulate flood-prone areas.

In many rural areas and small communities of Illinois, there are no existing floodplain studies that can provide flood elevations. For these areas, it would be too expensive and time consuming to prepare detailed studies. The best available information in these areas is often the FHBM. The FHBM, however, does not show land contours, therefore making it impossible to estimate a 100-year flood elevation. For these areas, the D & F Method can often be used to estimate the 100-year flood depth at a given site. As already noted, the D & F Method is based on a regression analysis of stream rating data at gage sites throughout Illinois. The method provides a depth of flow at any point on a stream for a specified flood frequency. The channel bottom elevation is generally estimated from a USGS topographic map or the flood depth is directly related to the actual elevation of channel bottom at the site. In either case, the resulting flood elevation is a quick estimate and should be used only for provisional floodplain zoning, to be superseded by detailed information, if it becomes available.

The D & F Method has a large standard error of estimate. Equations similar to these have been prepared for other states, such as North Carolina (Coble, 1979) and likewise exhibit a large standard error of estimate. Table 5 in the report by Prugh (1976) lists the ratio of actual depth to predicted depth value (A/P ratio) for all gage sites used in the analysis. The ratios vary considerably from station to station. Examples from 15 stations with their drainage area in square miles and slope in feet per mile are listed below in table 1:

Table 1 - A/P Ratio for Selected Gages (Prugh, 1976)

Station number	Station name	Drainage area	Slope	A/P10	A/P50	A/P100
03336500	Bluegrass Creek at Potomac	35.0	6.92	0.98	0.95	0.95
03345500	Embarras River at Ste. Marie	1516.0	1.58	1.28	1.34	1.36
03378635	Little Wabash River near Effingham	240.0	5.34	0.80	0.76	0.76
05438500	Kishwaukee River at Belvidere	538.0	4.59	1.06	1.03	1.01
05442200	Kyte River near Flagg Center	116.0	5.17	0.85	0.88	0.90
05502080	Hadley Creek at Kinderhook	72.7	15.0	0.62	0.65	0.66
05525500	Sugar Creek at Milford	446.0	4.86	1.30	1.34	1.37
0531000	Salt Creek at Arlington Heights	32.1	13.0	1.19	1.11	1.07
05536215	Thorn Creek at Glenwood	24.7	15.7	0.97	0.94	0.91
0555050	Poplar Creek at Elgin	35.2	9.1	0.55	0.62	0.65
05557000	West Bureau Creek at Wyanet	86.7	9.0	0.83	0.81	0.80
0556100	Ackerman Creek at Farmdale	11.2	39.9	0.64	0.74	0.76
05566000	E. B. Panther Creek near Gridley	6.3	11.1	1.33	1.27	1.24
05569500	Spoon River at London Mills	1062.0	2.3	1.25	1.19	1.15
05576500	Sangamon River at Riverton	2618.0	1.5	1.19	1.17	1.16

The ratios do not fully describe the reliability of the method since the rating tables at the locations tested were used to develop the methodology. In practice, the method would be used at random stream locations away from the restricted cross sections usually associated with stream gage locations.

The detailed methods used to compute flood elevations also have uncertainty involved. The flood discharges used in any detailed flood study have unavoidably wide confidence limits associated with them. The fact is, these discharges are estimated with a limited amount of data which are plotted statistically with a distribution that may or may not represent the true phenomena. Furthermore, in standard hydraulic computations, channels are assumed to be rigid and stationary with time and any hindrance to flow is accounted for by Manning's "n" value. These assumptions do not reflect the dynamic nature of stream channels and floodplains.

Thus, even detailed flood studies such as those prepared for the NFIP are limited in the accuracy they portray. The best available, most economically justified hydrologic and hydraulic methods of flood profile computation are always the most preferred methods. Trade-offs in accuracy result when time and money are not available to explore the flood problem more thoroughly. The use of the D S F Method is a trade-off that can be made in the administration of floodplain regulations where information is lacking. Flood depths computed by this method can be used to define a floodplain when no other information is available to define it. If greater accuracy is necessary, more detailed hydrologic and hydraulic methods can be used, provided the effort is justified.

Should the D & F Method be used to provide provisional 100-year flood depths, the results would vary to ah unknown extent from those determined by detailed analysis.

Objectives

1. To determine the variability of the D & F Method results when compared with detailed flood elevation data generated from flood insurance studies or other regulatory reports.

2. To suggest, if necessary, ways to improve the accuracy of the D & F Method.

Acknowledgments

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Sandra Howard, technical assistant, and Martin Johnson, programmer, helped greatly in processing data and in writing the computer programs used for the study. Pamela Lovett typed the rough drafts and final and John W. Brother, Jr., supervised the preparation of illustations.

METHODOLOGY

Over 1000 locations where detailed methods had been used to compute flood depths were selected for comparison with the D & F Method. Flood depths from table 5 in the report by Prugh (1976) were also used.

The necessary inputs to the D S F Method such as drainage area and slope were either computed or taken from existing data on file at the Water Survey. Also, at each point it was noted whether the location was at an urban or rural site and whether the site was at a road obstruction causing a backwater effect. If an obstruction occurred, another depth upstream was noted where the slope of the channel bottom approached that of the water surface profile.

Points along the various streams are in the 26 basins indicated in figure 1 and were selected on the basis of the following criteria:

1) Parameters for the D & F Method could be readily obtained.
2) A detailed study had been performed in which the 10-, 50-, and 100-year flood elevations were calculated.
3) The streams met the criteria for use of the D & F equations.

Several comparisons were made by screening the data for specific parameters such as drainage area size (square miles), slope (feet/mile), urban or rural location, obstructed or unobstructed site and major river basin, and making the comparisons only from those points which satisfied the constraints.

There were an unlimited number of comparisons that could have been made; however, the number of data points in some cases were too few to prove meaningful. In other cases, there were enough points that a conclusion could be made on the reliability of the D s F equations for estimating flood depths on those streams in the specified data set.

Depth and Frequency Method

This procedure is based heavily on the determination of the two year return period discharge (Q_2) by equation 1. Depth of flow for the 2-, 5-, 10-, 25-, 50-, and 100-year floods are based on the 2 year discharge as shown in equations 2 through 7 (Prugh, 1976).

$$Q_2 = 42.7A^{.776}S^{.466}(I-2.5)^{.834}R$$ (Curtis, 1977) (1)

	std error in percent	
$D_2 = 0.84\ Q_2^{.298}$	31.1	(2)
$D_5 = 1.15\ Q_2^{.282}$	26.1	(3)

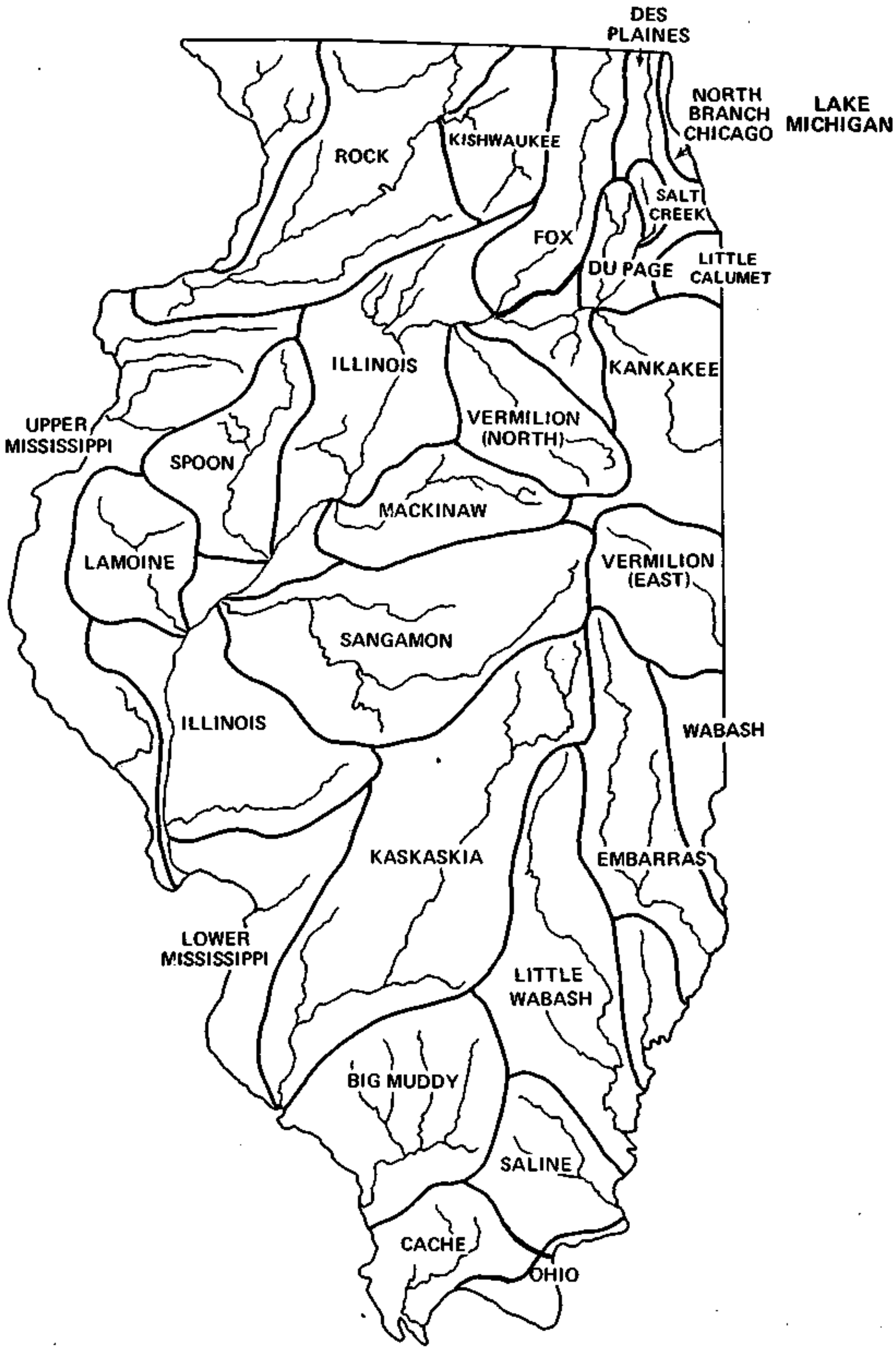

Figure 1. Drainage Basins Used in Study

$$D_{10} = 1.33\ Q_2^{.274} \qquad 27.4 \qquad (4)$$

$$D_{25} = 1.52\ Q_2^{.267} \qquad 23.7 \qquad (5)$$

$$D_{50} = 1.66\ Q_2^{.263} \qquad 23.0 \qquad (6)$$

$$D_{100} = 1.80\ Q_2^{.259} \qquad 22.7 \qquad (7)$$

where:

Q_2 = discharge of the two-year flood in cubic feet per second

A = drainage area in square miles

S = channel slope in feet per mile obtained by determining the difference in elevation at 10 percent and 85 percent of the distance along the channel measured from the site to the basin divide, divided by the distance between these two points

I = the two-year, twenty-four hour rainfall in inches

Rf = a regional factor

D_2 through D_{100} = depths for 2 through 100 year return period floods in feet

Data Management

In order to facilitate the calculation of flood depths and to summarize results by specified parameter, two computer programs were written. The first program, STRANS, took the data from all or any specified number of the 26 basins (see figure 1) and calculated the 10-, 50-, and 100-year depths by the D & F Method. The second program, DAF, then prompted for the parameters that were being investigated. The parameters that could be selected either individually or in any combination were:

1) Basin name - one of the 26 listed in figure 1

2) Slope in feet per mile

3) Drainage area - square miles

4) Rural or urban region - whether site is in a populated metropolitan area or in an agricultural, sparsely populated area.

5) Obstructed or unobstructed location - whether or not a significant obstruction causes a backwater effect. Two depths were computed, one just upstream and the other at such a distance that the slope of the water surface profile approached the channel bottom slope. The difference in depth between these two points determined the amount of backwater effect at obstructed sites.

For any selected combination the DAF program would select the points that satisfied the constraint from a master file, calculate differences and A/P ratios, and compute the average and standard deviation of these. Copies of these programs are included as appendices 1 and 2 of this report.

In order to limit the number of runs, it was necessary to specify ranges of drainage area and slope. The drainage area size intervals were:

Small - 1.0 to 10.0 square miles

Intermediate - 10.0 to 100.0 square miles

Large - >100.0 square miles

Likewise, slope intervals were grouped according to:

Mild - 0.0 to 20.0 feet/mile

Intermediate - 20.0 to 40.0 feet/mile

Steep - >40.0 feet/mile

The abbreviations defined below appear in the following tables, text, and appendices:

1) DIF10, DIF50, DIF100 - The flood depth for the 10-, 50-, and 100-year frequencies taken from profiles computed by detailed

hydraulic methods less the respective 10-, 50-, and 100-year flood depths computed by the D & F Method equations.

2) A/P10, A/P50, A/P100 - The depths of the 10-, 50-, and 100-year floods taken from profiles computed by detailed hydraulic methods divided by the respective 10-, 50-, and 100-year flood depths computed by the D & F Method equations.

3) OB/UN - A parameter indicating if the location is at a channel obstruction (OB) or at an unobstructed site (UN).

4) U/R - Urban (U) or rural (R) location.

Analysis

The first group of computer runs utilized the entire data set and represented a statewide comparison of the results. Listed in table 2 are the parameters specified and the summary results for all runs.

In general, the following conclusions were made from these results:

1) As slope of the stream increases, the actual depth to predicted depth (A/P) ratio decreases. Hereafter, actual depth is defined as the depth measured from profiles computed by detailed hydraulic methods. Predicted depth is that computed by the D & F Method.

2) Values of the A/P ratio in urban locations are greater than those in rural areas.

3) Values of the A/P ratio increase slightly with increasing drainage area size.

4) Points at obstructed sites have higher A/P ratios than those at unobstructed sites.

Table 2. Average Differences and A/P Ratios Using Entire Data Set

Parameters					Avg. of Actual-Predicted Depth (feet)			A/P Ratios		
p.A.	Slope	U/R	OB/UN	No. of points	DIF10	DIF50	DIF100	A/P10	A/P50	A/P100
1-10	0-20	U	UN	108	.74	.72	.85	1.07	1.05	1.07
1-10	20-40	U	UN	79	-.37	-.29	-.28	.87	.90	.90
1-10	40-100	U	UN	27	-1.21	-1.09	-.85	.74	.80	.84
1-10	0-20	R	UN	69	.18	-.07	.02	.96	.92	.95
1-10	20-40	R	UN	35	-.88	-1.10	-1.12	.77	.76	.77
1-10	40-100	R	UN	25	-.90	-.55	-.55	.78	.82	.83
1-10	0-20	U	OB	89	.80	1.13	1.16	1.10	1.13	1.13
1-10	20-40	U	OB	47	.79	.97	1.11	1.09	1.10	1.11
1-10	40-100	U	OB	11	-1.28	-.68	-.47	.75	.86	.89
1-10	0-20	R	OB	40	.39	.24	.35	1.00	.99	1.00
1-10	20-40	R	OB	14	-.69	-.96	-.72	.80	.79	.85
1-10	40-100	R	OB	9	-.78	-.20	.03	.72	.78	.85
10-100	0-20	U	UN	169	.74	.93	.96	1.07	1.08	1.08
10-100	20-40	U	UN	3	1.86	2.20	2.31	1.17	1.19	1.20
10-100	40-100	U	UN	3	-5.80	-5.90	-5.60	.32	.41	.47
10-100	0-20	R	UN	93	1.18	1.09	1.12	1.06	1.01	1.04
10-100	20-40	R	UN	11	-1.21	-1.33	-1.33	.85	.86	.87
10-100	40-100	R	UN	2	-1.55	-1.16	-1.13	.81	.88	.89
10-100	0-20	U	OB	93	1.33	1.74	1.82	1.13	1.17	1.17
10-100	20-40	U	OB	4	2.22	2.26	2.31	1.22	1.20	1.19
10-100	40-100	U	OB	2	-3.08	-3.58	-3.49	.64	.63	.65
10-100	0-20	R	OB	29	.95	1.19	1.43	1.07	1.12	1.12
10-100	20-40	R	OB	0						
10-100	40-100	R	OB	0						
100-10000	0-20	U	OB	29	1.48	1.97	2.16	1.12	1.15	1.15
100-10000	20-40	U	OB	0						
100-10000	40-100	U	OB	0						
100-10000	0-20	R	OB	19	2.51	3.10	3.89	1.12	1.14	1.15
100-10000	20-40	R	OB	0						
100-10000	40-100	R	OB	0						
100-10000	0-20	U	UN	64	.77	1.00	1.11	1.04	1.06	1.07
100-10000	20-40	U	UN	0						
100-10000	40-100	U	UN	0						
100-10000	0-20	R	UN	73	2.21	2.39	2.55	1.13	1.12	1.13
100-10000	20-40	R	UN	0						
100-10000	40-100	R	UN	0						
1-10	0-20	-	-	306	.58	.65	.69	1.04	1.04	1.05
1-10	20-40	-	-	182	-.18	-.12	-.06	.90	.92	.93
1-10	40-100	-	-	72	-1.06	-.75	-.58	.75	.81	.84
10-100	0-20	-	-	371	1.00	1.18	1.23	1.08	1.09	1.09
10-100	20-40	-	-	7	-3.80	-3.90	-3.70	.50	.58	.62
100-10000	0-20	-	-	185	1.63	1.92	2.08	1.10	1.11	1.11

Regional Comparison

In order to discern any regional variability in the depth differences and A/P ratios, the programs were run with basin name as the only constraint. Table 3 and figure 2 show the results of these runs. Figure 2 shows that the majority of basins have average A/P ratios close to 1. Table 3, however, reveals that the variability within a basin can be large.

Since some basins had few points with which to evaluate the A/P ratio, a regional approach was used to provide A/P ratio estimates. Other basins had sufficient points to evaluate the A/P ratio, therefore, constituting an individual region by themselves. The regions or individual basins selected were:

- Southern Illinois - Big Muddy, Saline, Ohio, Lower Mississippi, Little Wabash, Embarras, Sangamon, Vermilion (East), Wabash, Kaskaskia
- North-Central Illinois - LaMoine, Mackinaw, Vermilion (North), Kankakee, Rock, Upper Mississippi, Spoon, Kishwaukee, Illinois
- DuPage River
- Fox River
- Des Plaines River - Salt Creek
- Calumet River
- Lake Michigan - North Branch Chicago River

The parameters selected for use in the regional comparison were drainage area and slope. Urban/rural area designation was specified as a third parameter, but the results were inconclusive due to relatively few points to evaluate. The results of this regional comparison are summarized in table 4. For locations at bridge obstructions, the average change due to backwater effects is shown by region in table 5. The negative effect in basins in the Southern Illinois region is unique. One explanation is that the region characteristically has steeper slopes than other areas of Illinois. At bridge openings, the contracted opening combined with steep slopes can cause increased velocities and a drawdown in the

Table 3. Regional Variability in Depth Difference and A/P Ratio

		10-year				50-year				100-year			
Basin	No. of points	Avg. diff.	Std. dev. diff.	Avg. A/P	Std. dev. A/P	Avg. diff.	Std. dev. diff.	Avg. A/P	Std. dev. A/P	" Avg. diff.	Std. dev. diff.	Avg. A/P	Std. dev. A/P
Big Muddy	36	2.48	4.70	1.15	.4	2.65	5.23	1.14	.38	2.97	5.50	1.17	.38
Saline	3	1.48	2.58	1.02	.39	1.33	2.90	.98	.39	1.32	2.96	.98	.38
Ohio River	3	.26	2.94	.93	.30	-.11	2.94	.92	.30	-.09	2.85	.93	.23
Lower Mississippi	32	3.42	3.57	1.25	.38	3.82	4.09	1.26	.33	4.30	4.28	1.30	.31
Little Wabash	6	4.00	5.09	1.21	.24	3.80	5.30	1.17	.27	3.72	5.43	1.15	.26
Embarras	15	4.13	1.84	1.45	.22	4.41	2.41	1.41	.25	4.67	2.61	1.41	.24
Sangamon	47	1.24	2.53	1.08	.21	1.55	3.04	1.09	.23	1.75	3.23	1.10	.24
Vermilion East	13	2.03	1.99	1.22	.17	2.55	1.98	1.25	.19	2.67	1.97	1.26	.18
Wabash	2	-1.75	4.76	.43	.63	-2.13	4.60	.54	.31	-2.13	4.60	.59	.5
Kaskaskia	67	1.62	2.94	1.09	.33	1.67	3.05	1.09	.30	1.85	3.11	1.11	.28
LaMoine	3	3.47	3.08	1.17	.23	3.02	3.29	1.12	.23	2.85	3.42	1.09	.24
Mackinaw	12	-.16	1.09	.98	.09	-.28	1.50	.97	.11	-.20	1.81	.97	.13
Vermilion North	4	.59	4.21	1.02	.33	1.50	4.38	1.08	.31	1.77	4.46	1.10	.29
Kankakee	20	-1.18	5.26	.84	.38	-.84	5.60	.90	.38	-.50	5.53	.93	.33
Rock	57	-1.41	2.59	.85	.20	-1.64	2.77	.85	.20	-1.57	2.88	.87	.19
Upper Mississippi	26	.04	2.47	.96	.29	.38	2.76	1.01	.27	.60	3.17	1.03	.29
Spoon	5	2.29	3.05	1.12	.22	.22	5.85	.66	.84	2.10	3.57	1.08	.23
Kishwaukee	18	-.32	2.2	.89	.28	-.39	2.63	.89	.28	-.26	2.58	.91	.26
Illinois	68	-0.38	3.21	0.89	.38	.09	3.70	.94	.35	.41	4.01	.98	.35
DuPage	110	.49	1.76	1.04	.33	.43	1.02	1.98	.31	.48	2.07	1.02	.27
Fox	161	-0.09	2.03	.90	.37	-.01	2.12	.93	.35	.06	2.42	.94	.34
Des Plaines	208	.11	1.99	.95	.36	.38	2.36	.97	.38	.26	2.37	.97	.33
Salt Creek	78	.54	2.07	1.03	.37	.63	2.40	1.03	.37	.70	2.41	1.04	.34
Calumet	208	.65	2.22	1.03	.39	.80	2.33	1.04	.34	.88	2.35	1.06	.32
Lake Michigan	16	.15	1.91	.96	.33	.16	2.18	.96	.32	.27	2.17	.99	.30

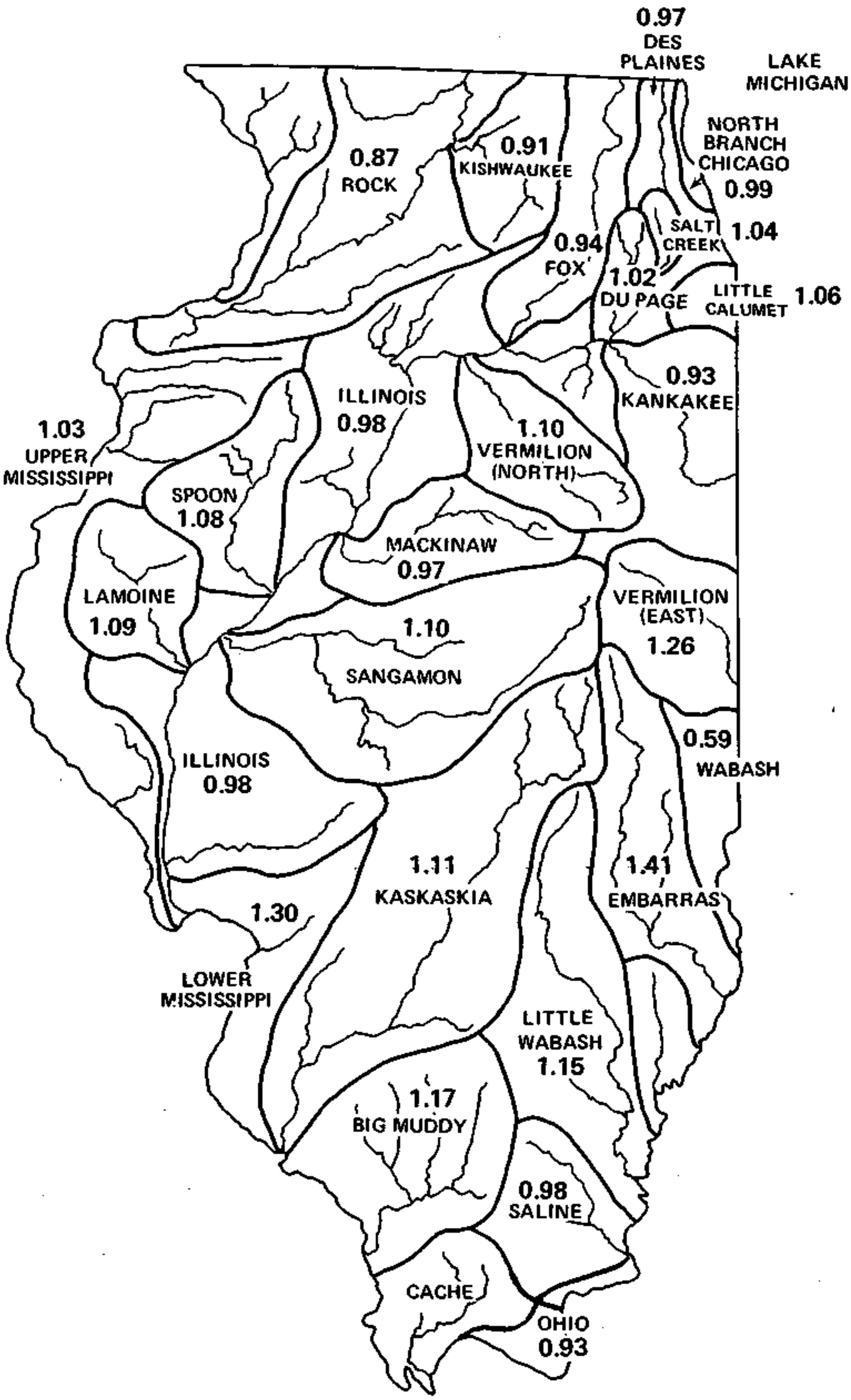

Figure 2. A/P100 Ratios for Individual Drainage Basins

Table 4. Average Differences and A/P Ratios with the Standard Deviation

Parameters				(1)			(2)			(3)			(4)		
Slope (ft/mi)	Drainage area (sq mi)	Region	No. of Points	Average Difference (ft) 10-yr	50-yr	100-yr	Standard Deviation (ft) 10-yr	50-yr	100-yr	Average A/P Ratio 10-yr	50-yr	100-yr	Standard Deviation 10-yr	50-yr	100-yr
0.0-20.0	1.0-10.0	Southern 111.	51	0.63	0.79	0.91	2.22	2.59	2.66	1.03	1.04	1.06	.43	.37	.37
0.0-20.0	10.0-100.0	"	61	3.39	3.43	3.50	3.21	3.51	3.68	1.31	1.27	1.26	.31	.30	.30
0.0-20.0	MOO.O	"	49	4.14	4.50	4.73	4.35	4.96	5.29	1.25	1.24	1.24	.26	.25	.26
20.0-40.0	1.0-10.0	"	25	0.80	0.91	1.29	1.75	2.28	2.42	1.07	1.06	1.10	.26	.30	.29
20.0-40.0	10.0-100.0	"	3	4.36	3.98	3.98	2.26	2.78	3.07	1.42	1.33	1.31	.24	.25	.27
0.0-20.0	1.0-10.0	North-Central III.	15	0.64	0.89	1.06	2.47	2.68	2.93	1.03	1.06	1.07	.39	.36	.37
0.0-20.0	10.0-100.0	"	51	-0.54	-0.50	-1.07	2.20	3.08	3.24	0.92	0.90	0.96	.23	.39	.26
0.0-20.0	MOO.O	"	72	-0.18	-0.12	-0.03	4.56	5.01	5.04	0.96	0.97	0.98	.32	.30	.29
20.0-40.0	1.0-10.0	"	20	0.19	-0.42	-0.32	1.70	1.79	1.75	0.92	0.90	0.92	.29	.26	.24
20.0-40.0	10.0-100.0	"	11	-1.80	-1.75	-1.59	0.99	0.87	1.00	0.80	0.83	0.85	.13	.10	.10
>40.0	1.0-10.0	"	32	-1.35	-0.91	-0.57	0.77	0.84	0.89	0.77	0.84	0.89	.21	.24	.25
0.0-20.0	1.0-10.0	Des Plaines River	96	0.28	0.34	0.34	1.66	1.89	2.09	1.01	1.02	1.01	.33	.32	.32
0.0-20.0	10.0-100.0	"	72	0.59	1.02	0.84	2.18	2.24	2.38	1.05	1.10	1.07	.30	.26	.27
0.0-20.0	>100.0	"	20	2.16	2.44	2.57	2.59	2.36	2.27	1.20	1.21	1.21	.32	.25	.21
20.0-40.0	1.0-10.0	"	57	-0.57	-0.64	-0.59	1.68	2.22	2.13	0.83	0.82	0.85	.31	.32	.29
20.0-40.0	10.0-100.0	"	6	0.38	0.85	0.56	1.31	1.56	1.70	1.04	1.09	1.05	.19	.19	.18
>40.0	1.0-10.0	"	14	-0.97	-0.16'	-0.39	2.02	3.44	2.95	0.75	0.84	0.86	.35	.53	.42
0.0-20.0	1.0-10.0	Calumet River	53	0.79	0.78	0.82	2.33	2.50	2.40	1.09	1.07	1.08	.40	.38	.34
0.0-20.0	10.0-100.0	"	68	0.59	0.86	1.02	2.19	1.70	1.62	1.03	1.08	1.10	.34	.19	.17
0.0-20.0	MOO.O	"	12	3.30	4.90	5.29	1.93	1.33	1.39	1.29	1.38	1.39	.18	.11	.10
20.0-40.0	1.0-10.0	"	31	-0.18	-0.21	-0.07	1.66	1.82	2.18	0.93	0.93	0.95	.30	.29	.31
0.0-20.0	1.0-10.0	DuPage River	33	0.88	0.83	0.84	1.64	1.99	2.11	1.14	1.10	1.09	.38	.38	.36
0.0-20.0	10.0-100.0	"	36	0.79	0.69	0.72	2.06	2.32	2.43	1.08	1.05	1.05	.32	.39	.30
0.0-20.0	MOO.O	"	22	0.13	0.15	0.45	1.41	1.45	1.48	1.00	1.00	1.03	.14	.13	.13
20.0-40.0	1.0-10.0	"	14	-0.17	-0.12	-0.22	1.26	1.25	1.39	0.93	0.95	0.93	.26	.22	.22
0.0-20.0	1.0-10.0	Lake Michigan	16	2.92	3.06	3.10	1.90	2.40	2.15	1.55	1.46	1.46	.41	.45	.38
0.0-20.0	10.0-100.0	"	25	3.47	3.21	3.11	1.75	1.90	1.87	1.53	1.41	1.38	.29	.26	.24
20.0-40.0	1.0-10.0	"	8	-0.20	-0.15	0.01	1.18	1.53	1.52	0.92	0.93	0.96	.24	.26	.25
0.0-20.0	MOO.O	"	2	2.10	1.70	1.92	1.18	1.78	1.53	1.25	1.16	1.18	.15	.19	.16
0.0-20.0	1.0-10.0	Fox River	36	-0.32	-0.32	-0.26	1.42	1.66	1.63	0.85	0.86	0.89	.35	.35	.32
0.0-20.0	10.0-100.0	"	66	0.01	-0.05	0.18	2.12	1.73	2.42	0.96	0.98	0.99	.32	.25	.38
0.0-20.0	MOO.O	"	8	2.55	3.07	3.21	1.71	2.09	2.21	1.28	1.29	1.29	.19	.21	.21
20.0-40.0	1.0-10.0	"	27	-0.32	0.19	0.07	2.48	2.78	3.12	0.82	0.93	0.91	.44	.44	.46
20.0-40.0	10.0-100.0	"	5	-0.17	-0.08	-0.07	0.50	0.79	0.86	0.97	0.98	1.00	.06	.10	.10
>40.0	1.0-10.0	"	17	-1.07	-1.37	-1.40	1.41	1.39	1.50	0.70	0.71	0.72	.36	.27	.27

Table 5. Average Change in Depth as a Result of Bridge Obstruction

Region	No. of points	10-yr avg. (ft)	Std. dev. (ft)	50-yr avg. (ft)	Std. dev. (ft)	100-yr avg. (ft)	Std. dev. (ft)
Southern Illinois	26	0.75	2.6	-0.71	2.5	-0.69	2.5
North-Central Illinois	51	0.86	2.4	0.88	2.1	0.84	2.1
Des Plaines	59	0.72	1.1	1.01	1.4	0.97	1.4
Calumet	50	0.84	1.8	0.70	1.3	0.67	1.3
Fox	36	0.44	1.9	1.24	1.9	0.91	1.9
DuPage	16	0.45	.9	0.67	1.1	0.82	1.2
Lake Michigan	13	0.09	.7	0.14	.8	0.18	.8

surface profile. This drawdown would account for the negative change in depth experienced at several bridge openings when the depths were compared to those upstream from the obstruction.

DISCUSSION OF RESULTS

As mentioned earlier, the D & F Method equations are based on rating curves of depth versus discharge for 177 stream gage sites, located near bridge crossings, throughout Illinois. The reliability of an equation to predict a desired outcome is expressed by the standard error of estimate. The standard error of estimate for the D & F equations was shown with equations 2 through 7. Since the standard error is in percent, this means, for example, that if a 100-year flood depth were 10 feet, with a standard error of 22.7%, we could expect the precicted value to be plus or minus 2.27 feet from this value approximately two-thirds of the time. The purpose of this study was to provide another test of the D & F Method equations. The D S F equations were applied at sites throughout the state and compared to results from calculated flood profiles that closely depict the expected flood depth. By lumping individual points into specified data sets, based on drainage area, slope, etc., the comparison results shown in table 2 indicate that, on the average, the equations will predict depths near those that can be expected to occur. However, in table 3, the results of the average and standard deviation of the A/P ratios show wide variation among the individual basins.

As an example, an examination of the Illinois River basin indicates that the average 100-year A/P ratio is 0.98 with a standard deviation of 0.35. This means that for two-thirds of all sites where depths were compared, the A/P ratios were between 0.63 and 1.33. One-third of the values still fall outside this range.

If the depth computed by the D s F Method was 7 feet, on the average, we can expect that actual depth will range from 4.41 (0.63 x 7 feet) to 9.31 feet (1.33 x 7) approximately two-thirds of the time. Furthermore, the actual depth can be expected to be less than 4.41 feet, or greater than 9.32 feet, one-third of the time. This is a large variation which limits the usefulness of a solution from the D & F Method for a specific location.

Drainage area and slope show the most impact on flood depths at any given location. The results indicate that the D & F Method does not account sufficiently for the influence of these two parameters on flood depths. Most basins used to develop the 2-year discharge equation had relatively mild slopes such that the exponent of the slope term tends to cause overpredictions of depth on steep streams. The drainage area term increases flood depth more than the equations predict, hence A/P ratios are significantly greater than 1 for large basins.

Streams in the southern section of Illinois consistently show A/P ratio greater than 1. This indicates that the D & F equations underpredict flood depths for this portion of the state. In the other regions of the state, the A/P ratio was near or slightly less than 1, except for points with large drainage area. The D & F. equation neither over nor underpredicts the average flood depth in these regions. Note again however, that the standard deviation range is considerable for each region within the designated parameter range. This variation limits the practical use of the D & F Method because of the potential for error in computing flood depths at a particular point. In fact, the error may range as high as 21 feet, if not adjusted, as was encountered along the

Big Muddy River. Because of this potential, the maximum range of error was examined for each region. On table 6, the points within each region that fell below or above one standard deviation of the mean average difference were averaged to get an estimate of the maximum range of error that might be expected to occur in computing flood depths by the D s F Method. It is particularly important to note how much the D & F Method underpredicts (columns 4, 5 and 6). This could be critical for those who rely on the accuracy of the D & F result for a level of flood protection. Whether or not the equations are predicting close to the true level for a given location is strictly a matter of chance, although a knowledge of conditions at the site may indicate if the D & F results are reasonable.

The reason for the unpredictability of the equations is that they do not account for all the necessary inputs to compute flow (or depth) in an open channel. In fact, looking at the well known Manning equation for open channel flow,

$$Q = \frac{1.49}{n} AR^{2/3}S^{1/2} \qquad \text{(Chow, 1959)}$$

where:

Q = discharge in cubic feet per second

n = a roughness coefficient indicative of channel flow resistance

R = hydraulic radius (cross section area divided by the wetted perimeter of the section)

S = slope of the energy gradient (approximately equal to channel bed slope)

A = cross section area,

the only parameters used in the D S F Method are discharge and slope. It can be shown based on the Manning equation that depth is also a function

Table 6. Range of Potential Errors for Points More Than One Standard Deviation From the Mean Encountered in 100-Year Flood Depths by Region

Parameters			(1)	(2)	(3)	(4)	(5)	(6)
Slope (ft/mi)	Drainage area (sq mi)	Region	Average Error (feet)	No. of points	Maximum Error (feet)	Average Error (feet)	No. of points	Maximum Error (feet)
0.0-20.0	1.0-10.0	Southern Ill.	3.5	6	4.17	4.5	11	7.12
0.0-20.0	10.0-100.0	"	1.3	11	3.31	8.9	12	12.0
0.0-20.0	MOO.O	"	1.6	10	3.2	14.6	6	26.0
20.0-40.0	1.0-10.0	"	2.4	4	2.9	5.3	4	7.1
20.0-40.0	10.0-100.0	"	-	1	0.24	-	1	7.8
0.0-20.0	1.0-10.0	North-Central Ill.	2.4	2	3.0	5.6	3	6.6
0.0-20.0	10.0-100.0	"	3.8	9	4.3	5.8	7	10.2
0.0-20.0	>100.0	" "	8.3	12	12.0	7.0	12	15.0
20.0-40.0	1.0-10.0	"	2.3	2	4.4	4.2	3	2.3
20.0-40.0	10.0-100.0	"	2.3	3	4.1	-		
>40.0	1.0-10.0	"	3.2	5	5.5	3.8	5	5.7
0.0-20.0	1.0-10.0	Des Plaines River	2.3	15	3.5	3.8	16	7.7
0.0-20.0	10.0-100.0	"	2.3	10	4.2	4.7	13	6.8
0.0-20.0	MOO.O	"	1.2	4	2.8	5.4	3	6.0
20.0-40.0	1.0-10.0	"	3.1	10	4.5	3.2	9	5.8
20.0-40.0	10.0-100.0	"	1.1	1	1.1	4.0	1	4.0
>40.0	1.0-10.0	"	3.8	2	5.0	5.2	2	8.1
0.0-20.0	1.0-10.0	Calumet River	2.0	11	A.O	5.6	7	9.6
0.0-20.0	10.0-100.0	"	1.0	10	2.2	3.9	9	6.9
0.0-20.0	MOO.O	"	3.0	2	3.0	6.8	2	7.0
20.0-40.0	1.0-10.0	"	2.8	6	4.0	3.8	4	6.5
0.0-20.0	1.0-10.0	Lake Michigan	1.0	3	1.0	5.9	3	6.6
0.0-20.0	10.0-100.0	"	0.25	3	0.1	6.0	3	6.3
20.0-40.0	1.0-10.0	"	1.7	1	1.7	2.7	1	2.7
0.0-20.0	1.0-10.0	Du Page River	2.8	4	2.6	4.0	7	7.4
0.0-20.0	10.0-100.0	"	2.6	5	4.4	4.6	6	7.4
0.0-20.0	HOO.O	"	1.6	6	2.1	2.5	3	2.9
20.0-40.0	1.0-10.0	"	1.7	2	1.7	2.7	2	2.8
0.0-20.0	1.0-10.0	Fox River	2.5	6	3.2	2.3	6	3.4
0.0-20.0	10.0-100.0	"	2.7	9	4.6	3.9	11	9.8
0.0-20.0	MOO.O	"	0.3	1	0.3	6.0	2	6.2
20.0-40.0	1.0-10.0	"	3.2	4	4.3	6.5	4	9.7
20.0-40.0	10.0-100.0	"	1.4	1	1.4	1.1	1	1.1
>40.0	1.0-10.0	"	3.2	4	4.1	1.0	3	1.7

Note: Columns 1 and 3 indicate overprediction of flood depth by the D & F Method
Columns 4 and 6 indicate underprediction of flood depth by the D & F Method

of the roughness coefficient, average channel width and wetted perimeter. It is very difficult to generalize these parameters over the length of a channel. Therefore, conditions at a given site may not be the same as those conditions at gage sites selected for developing the D S F Method. Only a correction factor incorporating channel geometry and "n" value can consistently improve the results. Without knowledge of these additional two parameters at a chosen location, the results will vary as indicated in table 6.

SUMMARY AND RECOMMENDATIONS

1. In this analysis, differences between a) depths predicted by the D & F Method versus those measured from profiles, and b) the corresponding actual depth to predicted depth ratios were used to evaluate the D s F Method. An examination of the mean and standard deviation indicate that, although the mean value produced by the D s F Method is acceptable (less than 1 foot or 10% error) in parts of the state, the variability is high and unacceptable depths may result.
2. An objective of this study was to develop adjustment factors for the D & F Method equations if needed. Drainage area and slope show the most impact on flood depths at any given location. The results indicate that the D & F Method does not account sufficiently for the influence of these two parameters on flood depths. Drainage area increases flood depth more than the equations predict; hence, A/P ratios are greater for larger basins. Streams in the southern part of Illinois with drainage area greater than 10 square miles also exhibited a tendency to produce depths greater than the D S F Method predicts. In circumstances where the A/P ratio was consistently

greater than 1.20 or less than 0.75 and where there is no gage information to adjust results, the following adjustment factors in the form of A/P ratio are recommended:

Parameters				A/P Ratios	
Slope (ft/mi)	Drainage Area (sq. mi.)	Region	10-yr	50-yr	100-yr
0.0-20.0	10.0-100.0	Southern Ill.	1.31	1.27	1.26
0.0-20.0	>100.0	Southern Ill.	1.25	1.24	1.24
20.0-40.0	10.0-100.0	Southern Ill.	1.42	1.33	1.31
0.0-20.0	>100.0	Des Plaines River	1.20	1.21	1.21
0.0-20.0	>100.0	Calument River	1.29	1.38	1.39
0.0-20.0	1.0-10.0	Lake Michigan	1.55	1.46	1.46
0.0-20.0	10.0-100.0	Lake Michigan	1.53	1.41	1.38
0.0-20.0	>100.0	Fox River	1.28	1.29	1.29
>40.0	1.0-10.0	Fox River	0.70	0.71	0.72

In other locations, no adjustment is recommended; however, when a gage is nearby, an adjustment factor from table 5 (Prugh, 1976) should be used.

3. Use of rural and urban location as a variable did not prove to be significant in predicting flood depths by the D & F Method.
4. This study attempts to show the differences that can be expected between the "Depth and Frequency" technique and a more detailed method. If errors such as those shown in table 5 and 6 are of little consequence, then detailed methods may not be justified. If serious consequences could result from a large error, consideration should be given to using more detailed methods.
5. Since the D&F Method equations do not use any channel characteristic information, the results do not reflect local variations in the channel and floodplain that might reduce or increase capacity to convey flood waters. This is a severe limitation when trying to

accurately predict flood depths using the D & F Method. There does not appear to be an efficient way to adjust results of the D & F Method to approach the accuracy of detailed methods. New equations that include cross section area and channel roughness as input might prove to be a better approach.

6. Although this report shows the potential for serious error in flood depth calculation using the USGS D & F Method, the D & F Method still remains the easiest and quickest tool to help planners, inspectors and designers estimate flood depths where none exist. When used with discretion and good engineering judgment, the D & F Method has beneficial uses in providing a starting point towards arriving at a flood depth for a selected frequency at a given site. The most practical use occurs when errors in the depth estimate will have minor consequence to those who use the results.

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      PROGRAM TRANS(INPUT,OUTPUT,TAPE1,DDAF,TAPE2=DDAF)
      INTEGER BAS,POI,LINE(13),DUP(13),NEWLIN(25),STRNAM(3)
60    PRINT *,"WHAT BASIN CODE",
      READ 1,BAS
1     FORMAT(A3)
      IF(EOF(5LINPUT))50,6
6     ENCODE(10,4,FILNAM) BAS
4     FORMAT(A3,"DAF")
      CALL PF("GET",1,FILNAM)
      REWIND 1
10    READ (1,1) POI
      IF(EOF(1).NE.0)GOTO 55
      IF(POI.NE."R " .A. POI.NE."U ")GO TO 30
        BACKSPACE 1
        READ(1,2) LINE
2       FORMAT(A4,3A10,A3,F10.1,F8.1,2F7.1,4F8.1)
        IF(LINE(5).NE."US")GO TO 12
          DO 11 I=1,9
11          LINE(I)=DUP(I)
        LINE(5)="US"
            GO TO 20
12        DO 13 I=1,13
13          DUP(I)=LINE(I)
20      CALL COMPUT(LINE,NEWLIN,BAS,STRNAM)
        WRITE(2) NEWLIN
3       FORMAT(A3,3A10,3A10,2X,A3,A4,F6.1,F7.2,2F6.2/12F7.2)
        GO TO 10
30    IF(POI.GT."ZZZ")GO TO 10
        BACKSPACE 1
        READ(1,5) STRNAM
5       FORMAT(3A10)
      GO TO 10
55    CALL LF("RETURN",FILNAM)
      GO TO 60
50    STOP
      END
      SUBROUTINE COMPUT(LINE,NEWLIN,BAS,STRNAM)
      REAL STRNAM(3),LINE(13),NEWLIN(25),BAS
      NEWLIN(1)=BAS
      DO 50 I=1,3
50      NEWLIN(I+1)=STRNAM(I)
      DO 60 I=2,4
60       NEWLIN(I+3)=LINE(I)
      DO 10 I=10,12
        IF(LINE(I).EQ.0.)GO TO  10
        LINE(I)=LINE(I)-LINE(13)
10      CONTINUE
      NEWLIN(8)=LINE(1)
      DO 20 I=9,16
20      NEWLIN(I)=LINE(I-4)
      DA=NEWLIN(10)
      SL=NEWLIN(11)
      RI=NEWLIN(12)
      RF=NEWLIN(13)
```

```
      Q2=(42.7)*(DA**.776)*(SL**.466)*((RI-2.5)**.834)*(RF)
      NEWLIN(17)=(1.33)*(Q2**.274)
      NEWLIN(18)=(1.66)*(Q2**.263)
      NEWLIN(19)=(1.80)*(Q2**.259)
      DO 30 I=20,22
        IF(NEWLIN(I-6).NE.0.)GO TO 29
          NEWLIN(I)=0.
          GO TO 30
29      NEWLIN(I)=NEWLIN(I-6)-NEWLIN(I-3)
30      CONTINUE
      DO 40 I=23,25
        IF(NEWLIN(I-9).NE.0.)GO TO 39
          NEWLIN(I)=1.
          GO TO 40
39      NEWLIN(I)=NEWLIN(I-9)/NEWLIN(I-6)
40      CONTINUE
      RETURN
      END
/bye
```

```
      PROGRAM DAF(INPUT,OUTPUT,DDAF,ODAF,TAPE1=DDAF,TAPE2=ODAF)
      INTEGER FSEQ(6),N(3),USN(3),LINE(79),LABEL(3)
      REAL SPREAD(2),VARS(36,3),REC(25),XREC(25),USMOB
      LOGICAL CHEQOB,MATCH
      COMMON LINE
      DATA FSEQ/6*0/,LABEL/'D10','D50','D100'/
      PRINT(2,7)
7     FORMAT('BAS  POI',59X,'R  CH  DA   SL    RI   RF'/10X,
     1      'D10    D50    D100   DAF10  DAF50  DAF100 DIF10',
     1      '  DIF50  DIF100 A/P10  A/P50  A/P100'//)
10    REWIND 1
      SPREAD(1)=0.
      SPREAD(2)=0.
      DO 11 J=1,3
        N(J)=0
        USN(J)=0
        DO 11 I=1,36
          VARS(I,J)=0.
11      CONTINUE
13    READ 1,(LINE(I),I=1,78)
1     FORMAT(78R1)
      IF(EOF(5LINPUT).NE.0)STOP
      PRINT (2,8) (LINE(I),I=1,78)
8     FORMAT(78R1/)
      CALL PARSE(FSEQ,CHEQOB)
      IF(FSEQ(1).EQ.65)GOTO 10
20    READ (1) REC
      IF(EOF(1))60,21
21    IF(.NOT.MATCH(FSEQ,REC))GO TO 20
      WRITE(2,2)REC
2     FORMAT(A5,3A10,3A10,2X,A3,A4,F6.1,F7.2,2F6.2/10X,12F7.2/)
      IF(CHEQOB.A.REC(9).EQ.2HUS)GO TO 40
      DO 22 I=1,25
22    XREC(I)=REC(I)
      DO 30 J=1,3
        IF(REC(13+J).EQ.0.)GO TO 30
        N(J)=N(J)+1
        IF(VARS(1,J).GE.ABS(REC(19+J)))GO TO 24
          VARS(1,J)=ABS(REC(19+J))
          DO 23 I=1,7
23          VARS(I+1,J)=REC(I)
24        IF(VARS(9,J).GE.ABS(ALOG10(REC(22+J))))GO TO 26
            VARS(9,J)=ABS(ALOG10(REC(22+J)))
            DO 25 I=1,7
25            VARS(I+9,J)=REC(I)
26        VARS(31,J)=VARS(31,J)+REC(19+J)
          VARS(32,J)=VARS(32,J)+(REC(19+J))**2
          VARS(33,J)=VARS(33,J)+ALOG10(REC(22+J))
          VARS(34,J)=VARS(34,J)+(ALOG10(REC(22+J)))**2
30      CONTINUE
      GO TO 20
```

```
40      DO 50 J=1,3
          IF(REC(13+J).EQ.0.)GO TO 50
          USN(J)=USN(J)+1
          USMOB=REC(13+J)-XREC(13+J)
          IF(VARS(21,J).GE.ABS(USMOB))GO TO 42
            VARS(21,J)=ABS(USMOB)
            DO 41 I=1,7
41            VARS(I+21,J)=REC(I)
42        VARS(35,J)=VARS(35,J)+USMOB
          VARS(36,J)=VARS(36,J)+USMOB**2
50        CONTINUE
        GO TO 20
60      DO 70 J=1,3
          IF(N(J).EQ.0)GO TO 70
          VARS(17,J)=VARS(31,J)/N(J)
          VARS(18,J)=SQRT(VARS(32,J)/N(J)-(VARS(17,J))**2)
          VARS(19,J)=VARS(33,J)/N(J)
          VARS(20,J)=SQRT(VARS(34,J)/N(J)-(VARS(19,J))**2)
          VARS(9,J)=10**(VARS(9,J))
          VARS(19,J)=10**(VARS(19,J))
          VARS(20,J)=10**(VARS(20,J))
70        CONTINUE
        DO 80 J=1,3
          PRINT 4,LABEL(J),N(J)
          WRITE (2,4) LABEL(J),N(J)
          IF(N(J).EQ.0)GO TO 80
          SPREAD(2)=VARS(19,J)*VARS(20,J)
          SPREAD(1)=VARS(19,J)/VARS(20,J)
          PRINT 3,(VARS(I,J),I=1,19),SPREAD
          WRITE(2,3) (VARS(I,J),I=1,19),SPREAD
4         FORMAT(A6,I4,' POI'S FOUND')
3         FORMAT(6X,'MAXDIF=',F5.2,' FEET'/9X,'AT ',A5,6A10/
     1        6X,'MAXA/P=',F5.2/9X,'AT ',A5,6A10/
     1        6X,'AV  DIF=',F5.2,' FEET',
     1        6X,'RMS DIF=',F5.2,' FEET'/
     1        6X,'AV  A/P=',F5.2,
     1        11X,'RMS A/P=',F5.2,' : ',F5.2/)
80      CONTINUE
        IF(.NOT.CHEQOB)GO TO 10
        DO 90 J=1,3
          IF(USN(J).EQ.0)GO TO 90
          VARS(29,J)=VARS(35,J)/USN(J)
          VARS(30,J)=SQRT(VARS(36,J)/USN(J)-(VARS(29,J))**2)
90        CONTINUE
        DO 100 J=1,3
          PRINT 5,LABEL(J),USN(J)
          WRITE (2,5) LABEL(J),USN(J)
          IF(N(J).EQ.0)GO TO 100
          PRINT 6,(VARS(I,J),I=21,30)
          WRITE(2,6) (VARS(I,J),I=21,30)
5         FORMAT(A6,I4,' US POI'S FOUND')
6         FORMAT(6X,'MAX US-OB =',F5.2,' FEET'/9X,'AT ',A5,6A10/
     1         6X,'AV US-OB=',F5.2,' FEET',
     1         6X,'RMS US-OB=',F5.2,' FEET'/)
```

```
100       CONTINUE
      GO TO 10
      END
      SUBROUTINE PARSE(FSEQ,CHEQOB)
      INTEGER FLDNUM,FIRST,LAST,FSEQ(6),NAME(7),CPTR,DLMTR,LINE(79),
     1        DUMMY
      REAL RNAME(7),LONUM,HINUM,SAV
      LOGICAL CHEQOB
      EQUIVALENCE (NAME,RNAME)
      COMMON LINE
      COMMON /NAME/NAME
      CHEQOB=.F.
      K=0
      CPTR=0
10    CALL FIELD(CPTR,FLDNUM)
      IF(FLDNUM.EQ.0)GO TO 70
      GOTO(30,30,40,40,40)FLDNUM
30    DLMTR=1R:
      CALL RNUM(CPTR,DLMTR,LONUM)
      IF(DLMTR.NE.1R:)GOTO 70
      DLMTR=1R,
      CALL RNUM(CPTR,DLMTR,HINUM)
      IF(DLMTR.NE.1R, .A. DLMTR .NE. 66)GOTO 70
      IF(HINUM.GE.LONUM)GOTO 31
        SAV=HINUM
        HINUM=LONUM
        LONUM=SAV
31    RNAME(FLDNUM*2-1)=LONUM
      RNAME(FLDNUM*2)=HINUM
      GOTO 60
40    DLMTR=1R,
      CALL WORD(CPTR,DLMTR,LENGTH)
      IF(LENGTH.NE.0)GOTO 41
        PRINT *,'NO DATA AFTER = '
        GOTO 70
41    FIRST=CPTR-LENGTH
      LAST=CPTR-1
      ENCODE(10,1,DUMMY) (LINE(I),I=FIRST,LAST)
1     FORMAT(10R1)
      NAME(FLDNUM+2)=DUMMY
      IF(FLDNUM.EQ.4. .A. DUMMY.EQ.2HOB)CHEQOB=.T.
60    K=K+1
      FSEQ(K)=FLDNUM
      IF(DLMTR.NE.66)GOTO 10
      FSEQ(K+1)=65
      RETURN
75    PRINT *,'USAGE-  NUMBER:NUMBER'
70    FSEQ(1)=65
      RETURN
      END
      LOGICAL FUNCTION MATCH(FSEQ,REC)
      INTEGER FSEQ(6),NAME(7)
      REAL RNAME(7),REC(25)
      EQUIVALENCE (NAME,RNAME)
      COMMON /NAME/NAME
      K=0
10    K=K+1
```

```
      IF(FSEQ(K).NE.65)GO TO 20
        MATCH=.T.
        RETURN
20    GOTO(21,22,23,24,25)FSEQ(K)
21    IF(RNAME(1).GT.REC(10) .OR. RNAME(2).LT.REC(10))GO TO 30
        GO TO 10
22    IF(RNAME(3).GT.REC(11) .OR. RNAME(4).LT.REC(11))GO TO 30
        GO TO 10
23    IF(RNAME(5).NE.REC(1))GO TO 30
        GO TO 10
24    IF(NAME(6).EQ.2HOB .A. REC(9).EQ.2HUN)GO TO 30
      IF(NAME(6).EQ.2HUS .A. REC(9).NE.2HUS)GO TO 30
      IF(NAME(6).EQ.2HUN .A. REC(9).EQ.2HOB)GO TO 30
      GO TO 10
25    IF(RNAME(7).NE.REC(8))GO TO 30
        GO TO 10
30    MATCH=.F.
      RETURN
      END
      SUBROUTINE FIELD(CPTR,FLDNUM)
      INTEGER CPTR,DLMTR,LENGTH,FLDNAM,FLDNUM,FLIST(6),FIRST,LAST,
     1        LINE(79)
      COMMON /FLIST/ FLIST
      COMMON LINE
      DLMTR=1R=
      CALL WORD(CPTR,DLMTR,LENGTH)
      IF(DLMTR.EQ.1R=)GO TO 10
        FLDNUM=0
        PRINT *,'MISSING = '
        RETURN
10    FIRST=CPTR-LENGTH
      LAST=CPTR-1
      ENCODE(10,1,FLDNAM) (LINE(I),I=FIRST,LAST)
1     FORMAT(10R1)
      CALL LISCHEK(FLDNAM,FLDNUM,FLIST)
      IF(FLIST(FLDNUM).NE.65)RETURN
        PRINT 2,FLDNAM
2       FORMAT(A10,' IS AN ILLEGAL FIELD NAME')
        FLDNUM=0
        RETURN
      END
      BLOCK DATA
      INTEGER FLIST(6)
      COMMON /FLIST/ FLIST
      DATA FLIST/2HDA,2HSL,2HBA,2HCH,2HRE,65/
      END
      SUBROUTINE WORD(CPTR,DLMTR,LENGTH)
      INTEGER LINE(79),CPTR,DLMTR,LENGTH
      LOGICAL SKIP
      COMMON LINE
      LENGTH=0
      IF(CPTR.NE.0)GO TO 30
      DO 10 I=1,79
        II=I
        IF(LINE(79-I).NE.1R )GO TO 20
10      CONTINUE
15    DLMTR=66
      RETURN
```

```
20      LINE(79+1-II)=66
30      SKIP=LINE(CPTR+1).EQ.(1R )
40      CPTR=CPTR+1
        IF(LINE(CPTR).EQ.66)GO TO 15
        IF(SKIP)GO TO 30
        IF(LINE(CPTR).EQ.DLMTR)GO TO 50
        LENGTH=LENGTH+1
        GO TO 40
50      IF(LINE(CPTR+1).EQ.66)DLMTR=66
        RETURN
        END
        SUBROUTINE LISCHEK(NAME,NUMBER,LIST)
        INTEGER NAME,NUMBER,LIST(69)
        NUMBER=0
10      NUMBER=NUMBER+1
        IF(LIST(NUMBER).NE.65 .AND. LIST(NUMBER).NE.NAME)GO TO 10
        RETURN
        END
        SUBROUTINE RNUM(CPTR,DLMTR,NUMBER)
        INTEGER CPTR,DLMTR,LINE(79),LENGTH,DUMMY,FIRST,LAST
        REAL NUMBER
        LOGICAL ERR
        COMMON LINE
        CALL WORD(CPTR,DLMTR,LENGTH)
        IF(LENGTH.NE.0)GO TO 20
          PRINT *,'NO NUMBER'
          DLMTR=68
          RETURN
20      IF(LENGTH.GT.10)GO TO 21
        FIRST=CPTR-LENGTH
        LAST=CPTR-1
        CALL NUMCHK(FIRST,LAST,ERR)
        IF(.NOT.ERR)GO TO 30
21        PRINT*,'ILLEGAL NUMBER'
          DLMTR=68
          RETURN
30      ENCODE(10,1,DUMMY)(LINE(I),I=FIRST,LAST)
1       FORMAT(10R1)
        DECODE(10,2,DUMMY) NUMBER
2       FORMAT(F10.0)
        RETURN
        END
        SUBROUTINE NUMCHK(FIRST,LAST,ERR)
        INTEGER LINE(79),FIRST,LAST
        LOGICAL SIGN,ERR,NUM,POINT,SP
        COMMON LINE
        ERR=.F.
        NUM=.F.
        POINT=.F.
        SP=.F.
        SIGN=.F.
        DO 10 I=FIRST,LAST
          LI=LINE(I)
          IF((LI.GT.1R- .O. LI.LT.1R0) .A. LI.NE.1R. .A. LI.NE.1R )GOTO 20
          IF(LI.EQ.1R. .A. (POINT.O.(NUM.A.SP)))GO TO 20
          IF((LI.EQ.1R+ .O. LI.EQ.1R-) .A. (SIGN .O. POINT .O. NUM))
```

```
    1     GO TO 20
        IF(LI.LE.1R9 .A. LI.GE.1R0 .A. SP)GO TO 20
        IF(LI.EQ.1R  .A. POINT .A. .NOT.NUM)GO TO 20
        IF(LI.EQ.1R.)POINT=.T.
        IF(LI.EQ.1R  .A. NUM)SP=.T.
        IF(LI.LE.1R9 .A. LI.GE.1R0)NUM=.T.
10      CONTINUE
      RETURN
20    ERR=.T.
      RETURN
      END
```