EFFECT OF URBANIZATION AND OTHER FACTORS ON SYNTHETIC UNIT HYDROGRAPHS

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The public and private sectors of the United States are demanding more and better flood studies from the engineering profession. Flood studies are requested for streams with and without flood discharge records. The studies on gauged streams use frequency analysis of the gauge records and hydrographic analysis. A synthetic flood analysis based on the unit hydrograph method is the engineering method currently used for flood studies on streams without gauge records. The Snyder method, a typical synthetic hydrograph technique, is used in this study to evaluate the urbanization factors that are needed for calculating the 100-year flood level on Dallas area streams.

The synthetic unit hydrograph procedure as presented by F. F. Snyder is based on his study of streams in the Appalachian Mountains region (Snyder, 1938). Snyder's technique develops the shape of the unit hydrograph, which is the building block for all flood hydrographs. His method is widely used by engineers in private practice and by those working for government agencies and has therefore been carefully evaluated.

Many regional studies have been published that relate t_p to various physical properties of a watershed. T_p is defined as the time to peak of the synthetic unit hydrograph from the centroid of the unit rainfall. For example, Eagleson (1962), VanSickle (1962), Carter (1961), Espey (1966), and Nelson (1970) have published papers on this subject. On September 1-3, 1970, the Hydrologic Engineering Center of the Corps of Engineers held a seminar on Urban Hydrology. Several of the papers addressed the problem of the change in runoff with increasing urbanization. The dominant theme of the presentations was that channelization, not just urbanization, determines the ultimate effect on t_p.

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An additional paper by T. L. Nelson specifically related t_p to a shape factor for varying percentages of urbanization in Dallas-Fort Worth watersheds. $LL_{ca}/S^{0.5}$ is defined as the shape factor, where L is the stream length, L_{ca} is the stream length to the centroid of the basin, and S is the weighted slope of the stream. Nelson's paper also states that further study is required "to improve the relationships developed, and to isolate the effect that channel improvement produces." With Nelson's statement in mind, our study investigated the relationship between t_p and $LL_{ca}/S^{0.5}$, urbanization, and channelization for Dallas area streams.

The percentage of urbanization was determined from U.S. Geological Survey 7.5 minute quadrangle maps. The study uses storms covering a 49-year time span, thereby covering a significant change of urbanization within four of the individual stations. The amount of urbanization was evaluated for each storm in each basin. The amount of urbanization was measured by planimeter for both the original and the photo-revised U.S.G.S. quadrangle maps.

The next variable introduced into the analysis is the percentage of the main channel length, L, that is channelized. The amount and date of completion of channelization is based on information obtained from the City of Dallas Public Works files, the City of Richardson, and U.S.G.S. 7.5 minute quadrangle maps.

Data were collected on 84 storms in the following eleven basins:

1) White Rock Creek at Keller Springs Road
2) White Rock Creek at Greenville Avenue
3) Turtle Creek at Hall Street
4) Bachman Branch at Midway Road
5) Big Fossil Creek at Haltom City
6) Village Creek at Handley
7) Joe's Creek at Spur 348
8) Duck Creek at Belt Line Road
9) Joe's Creek at Royal Lane
10) Elam Creek at Seco Road
11) Rush Creek at Arapaho Road.

The 84 storms were reproduced using the Hydrologic Engineering Center HEC-1 Flood Hydrograph Package (1973). The HEC-1 computer program contains a subroutine, OPTIM, that derives unit hydrograph parameters, including t_p, using the actual rainfall and several other parameters. The results of the optimization are shown in table 1 (pp. 19-21). Snyder's t_p is tabulated for each storm along with the percentage error between the observed peak discharge and the HEC-1 calculated peak discharge, based upon the HEC-1 reproductions.

TABLE 1

DATA POINTS USED IN ANALYSIS

Creek		Date	Observed Q	Reproduced Q	Percentage of Error	t_p	$\frac{LL_{ca}}{S^{0.5}}$	Percentage of Urbanization	Percentage of Channelization
White Rock at Keller Springs	1	06/19/73	4,550	4,148	−8.8	1.99	27.6	1	0
	2	10/03/71	4,310	4,228	−1.9	2.12		1	0
	3	10/19/71	4,920	4,835	−1.7	2.40		1	0
	4	08/14/71	488	478	−2.0	2.54		1	0
	5	08/14/71	3,100	3,027	−2.4	2.69		1	0
	6	04/25/70	342	337	−1.5	5.04		1	0
	7	06/01/70	3,620	3,568	−1.4	1.75		1	0
	8	05/30/70	267	251	−6.0	2.69		1	0
	9	05/30/70	2,620	2,707	+3.3	1.54		1	0
	10	06/29/62	4,420	4,048	−8.4	3.36		1	0
	11	07/27/62	9,410	9,112	−3.2	2.65		1	0
	12	09/27/64	3,460	3,525	+1.9	2.74		1	0
	13	05/10/65	5,720	5,396	−5.7	2.66		1	0
White Rock at Greenville	14	05/11/73	5,740	5,626	−2.0	3.21	78.4	24	6
	15	06/19/73	10,000	9,365	−7.3	2.75		25	6
	16	10/03/71	14,400	13,363	−7.6	2.86		23	0
	17	10/19/71	9,860	10,123	+2.7	1.74		23	0
	18	08/14/71	1,370	1,343	−2.0	2.54		23	0
	19	04/25/70	1,270	1,379	+8.6	2.56		21	0
	20	04/25/70	7,700	7,819	+1.5	4.69		21	0
	21	10/08/62	24,500	20,800	−15.1	2.68		13	0
	22	09/21/64	38,100	33,715	−11.5	5.88		16	0
	23	09/22/64	6,220	5,603	−9.9	2.45		16	0
	24	02/08/65	11,000	10,090	−8.3	5.28		16	0
	25	05/09/65	4,480	4,359	−2.7	2.79		16	0
	26	05/10/65	13,480	13,410	−0.5	3.13		16	0

Turtle Creek at Hall Street	27	05/12/73	3,300	3,210	−2.7	0.63	2.9	100	100
	28	06/03/73	3,230	3,197	−1.0	0.57		100	100
	29	10/03/71	3,000	3,036	+1.2	0.89		100	100
	30	10/19/71	3,590	3,592	+0.1	0.85		100	100
	31	08/14/71	1,020	996	−2.4	1.18		100	100
	32	10/12/69	3,130	2,935	−6.2	0.76		100	100
	33	10/12/69	1,400	1,381	−1.4	0.87		100	100
	34	08/31/70	82	82	0.0	1.37		100	100
	35	09/01/70	826	857	+3.8	0.72		100	100
	36	09/02/70	2,900	2,922	+0.8	0.75		100	100
	37	04/30/62	3,050	2,793	−8.4	0.89		100	100
	38	07/27/62	4,640	4,546	−2.0	0.69		100	100
	39	10/08/62	3,450	3,410	−1.1	0.86		100	100
	40	04/28/63	4,290	4,038	−5.9	0.93		100	100
Bachman Branch at Midway Road	41	10/03/73	3,580	3,673	+2.6	1.04	2.6	90	15
	42	10/19/73	5,650	5,567	−1.5	0.92		90	15
	43	08/14/71	1,110	1,151	+3.7	0.60		90	15
	44	08/14/71	3,480	3,592	+3.2	0.88		90	15
	45	04/25/70	2,840	2,829	−0.4	1.27		88	15
	46	09/01/70	335	334	−0.3	1.51		89	15
	47	09/02/70	3,130	3,840	−9.3	1.65		89	15
	48	10/08/62	8,775	8,675	−1.1	1.08		73	0
	49	09/21/64	3,620	3,543	−2.1	1.20		77	5
	50	09/21/64	2,910	2,851	−2.0	0.90		77	5
	51	09/22/64	3,050	2,901	−4.9	0.99		77	5
	52	05/10/65	5,170	4,924	−4.8	1.34		78	5
Joe's Creek at Spur 348	53	07/12/72	1,850	1,890	+2.2	0.70	2.9	88	63
	54	08/14/71	664	640	−3.6	1.37		86	60
	55	08/17/71	1,940	1,590	−17.6	1.40		86	60
	56	05/30/70	1,780	1,753	−1.5	1.02		82	40
	57	04/28/66	6,350	6,461	+1.7	1.14		70	7

	58	09/20/74	1,440	1,449	+0.6	1.51		94	63
	59	09/20/74	1,730	1,782	+3.0	1.34		94	63
	60	10/09/68	1,520	1,506	−0.9	1.63		77	15
Duck Creek at	61	03/10/73	5,980	5,472	−8.9	2.79	23.5	45	2
Belt Line Road	62	09/26/73	7,670	7,090	−7.6	3.70		46	4
	63	10/03/71	7,550	6,982	−7.5	3.72		42	0
	64	08/24/71	497	424	−14.7	3.87		42	0
	65	08/25/71	2,510	2,174	−13.4	3.90		42	0
	66	09/24/71	1,760	1,469	−16.5	3.94		42	0
	67	07/27/62	16,000	16,151	+0.9	2.64		23	0
	68	04/28/63	7,400	6,858	−14.3	2.98		25	0
	69	02/09/65	5,620	5,100	−6.5	3.07		28	0
	70	04/28/66	9,800	9,764	−8.8	3.89		31	0
	71	04/29/66	8,600	8,231	−4.7	3.10		31	0
Big Fossil Creek at	72	09/30/59	12,600			3.5	47.6	2	2
Haltom City	73	04/24/60	5,170					2	2
t_p from F.W.D.-C.O.E.	74	06/24/61	18,300					2	2
Village Creek at	75	05/19/26	4,180			5.2	95.6	0	0
Handley	76	04/19/27	1,210					0	0
t_p from F.W.D.-C.O.E.	77	10/01/27	9,400					0	0
	78	12/17/28	14,500 estimated					0	0
Rush Creek at	79	06/19/73	504	474	−6.0	0.78	0.50	2	0
Arapaho Road	80	04/08/75	472	450	−4.7	0.91		2	0
Elam Creek at	81	09/17/74	599	569	−5.0	0.43	0.14	100	100
Seco Road	82	03/10/73	1,240	1,222	−1.5	0.25		100	100
Joe's Creek at	83	03/26/75	1,230	1,333	+8.4	0.20	0.38	98	24
Royal Lane	84	10/30/75	1,600	1,647	+2.9	0.40		98	24

TABLE 2

MULTIPLE REGRESSION RESULTS

Regression Analysis	
Dependent Variable	TP
Residual Standard Deviation	0.3189
Standard Error of the Mean	0.0348
Multiple R	0.9089
Multiple RSQR	0.8261
Variable Entered	URB

Variable	B-Coef	Std Error of B	Partial-R	Beta-Coef	Std Error of Beta
CHAN	−0.0030	0.0013	−0.2401	−0.1605	0.0725
URB	−0.0009	0.0017	−0.0620	−0.0528	0.0951
LL /S	0.3383	0.0339	0.7445	0.7589	0.0760
Constant	−0.1051				

ANALYSIS OF VARIANCE TABLE

Source	D.F.	Sum of Square	Mean Square	F
Mean	1	0.24418E 02	0.24418E 02	
Regression	3	0.38684E 02	0.12894E 02	0.12672E 03
Error	80	0.81405E 01	0.10175E 00	

The data on 84 storms in 11 different drainage basins included the percentage of urbanization and the percentage of channelization associated with each storm. The data were analyzed using a multiple regression method on the variables $\ln t_p$ (ln is the natural logarithm) versus $\ln LL_{ca}/S^{0.5}$, percentage of urbanization, and percentage of channelization. The regression analysis summarized on table 2 provides the following equation:

$$t_p = \frac{0.90(LL_{ca}/S^{0.5})^{0.338}}{e^{0.0009\text{URB}}\, e^{0.0030\text{CHAN}}} \quad ,$$

where URB = percentage of urbanization, CHAN = percentage of channelization, and $e = 2.7182$.

A plot of the resulting equation is shown in figure 1. The curves show only the extremes, i.e., Curve No. 1: 0% URB, 0% CHAN; Curve No. 2: 100% URB, 0% CHAN; Curve No. 3: 0% URB, 100% CHAN; and Curve No. 4: 100% URB, 100% CHAN.

The analysis shows that a total of 82.6% of the variance in t_p is explained by the three variables in conjunction, using the procedure defined in Nie (1975). But of the 82.6%, 80.3% is explained by $LL_{ca}/S^{0.5}$ alone. The addition of channelization and urbanization picked up only 2.3% and 0.1%, respectively, of the remaining 17.4% unexplained variance in t_p. Urbanization and channelization do not significantly affect t_p for this set of data. This may be explained either because the data do not reflect urbanization and channelization correctly or because urbanization and channelization do not affect t_p for these streams. A further possible explanation may be that the interrelationship between channelization and the shape factor $LL_{ca}/S^{0.5}$ is causing an incorrect relationship to be used. Future studies should also account for the fact that the data for the 84 storms show percentage of urbanization and percentage of channelization to have a fairly high correlation coefficient of 0.766.

The same data were then analyzed by using a regression method on the variables $\ln t_p$ versus $\ln LL_{ca}/S^{0.5}$. The 84 storms provided the following relationship between t_p and $LL_{ca}/S^{0.5}$:

$$\ln t_p = 0.40 \ln \frac{LL_{ca}}{S^{0.5}} - 0.37$$

with a correlation coefficient of 0.90.

The statistical analysis shows that $LL_{ca}/S^{0.5}$ is by far the dominant independent variable in the relation. The shape factor, based on this work, can account for enough of the variance in t_p to justify a single variable analysis.

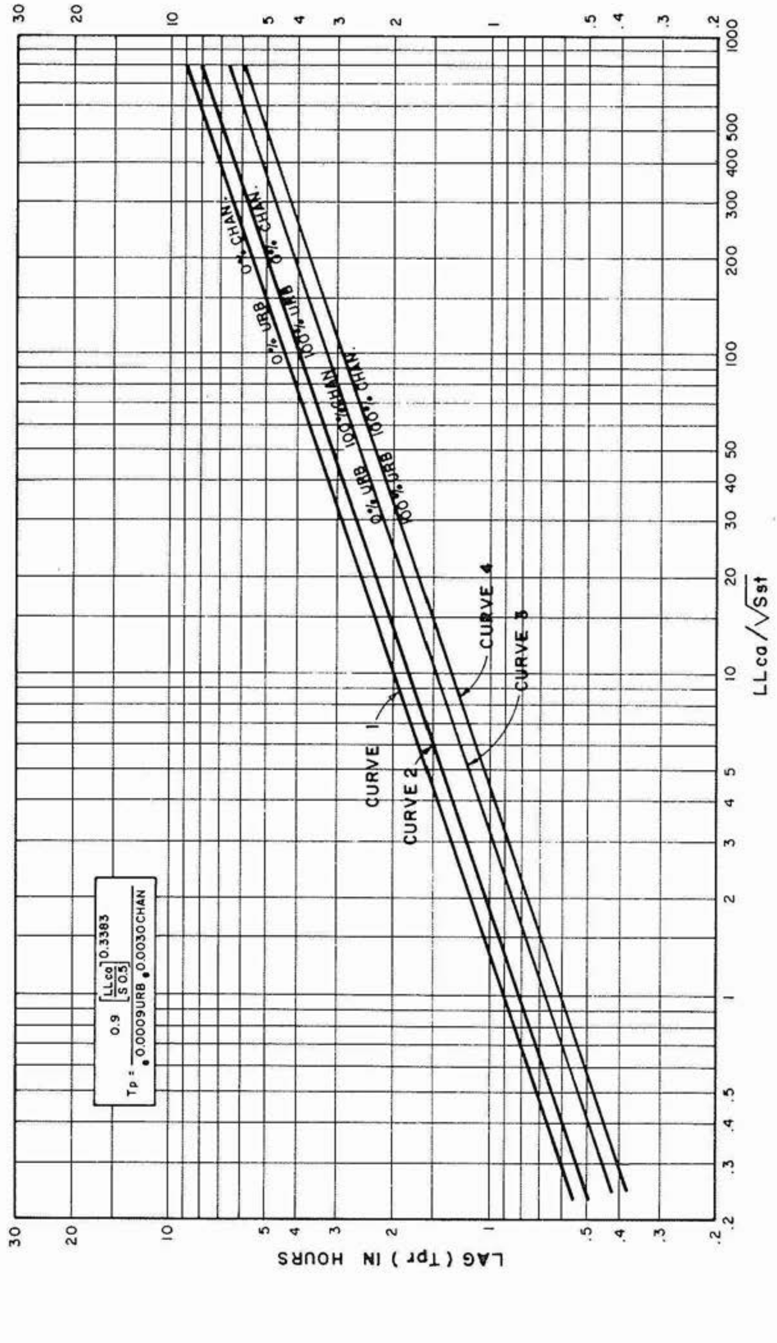

FIG 1. TIME TO PEAK VS. SHAPE, URBANIZATION AND CHANNELIZATION

Examination of the data showed that White Rock at Greenville, Bachman at Midway, Duck Creek at Belt Line Road, and Joe's Creek at Spur 328 had significant changes in urbanization. Joe's Creek was the only one of the eleven streams that had a range of variance in channelization. A linear regression was run on t_p vs. percentage of urbanization for the four streams, with results as shown in table 3.

TABLE 3

EFFECT OF URBANIZATION ON t_p

Stream	Number Of Floods	Equation $\ln t_p = A + (m)(\mathrm{URB})$		Correlation Coefficient
		Slope (M)	Intercept (A)	
White Rock at Greenville	13	−0.03	+1.6	−0.31
Bachman at Midway	12	−0.003	+0.345	−0.08
Duck Creek at Belt Line Road	11	+0.01	0.85	+0.57
Joe's Creek at Spur 348	8	0.001	0.1	+0.04

The slopes of the linear equations are flat, up to the right and down to the left. The correlation coefficients are low. Either the sample is too small, or urbanization does not significantly relate to t_p for these creeks and these storms.

A multiple regression was run of $\ln t_p$ vs. urbanization and channelization on Joe's Creek.

The resulting equation is:

$$\ln t_p = 0.04 \text{ URB} - 0.15 \text{ CHAN} - 2.5.$$

The correlation coefficient of t_p vs. urbanization alone is 0.04. The correlation coefficient of t_p vs. channelization is −0.14. The multiple R for both URB and CHAN is 0.46. The correlation coefficients are low. Either the sample is too small or channelization does not significantly relate to t_p.

Since the shape factor alone left 20% of the variance in t_p unexplained, a new variable, storm movement, was studied to try to improve the relationship. Storm movement data are available from the United States National Weather Service. The information is in the form of observation log sheets prepared by the radar operators and also of microfilm photographs of the radar screens. The radar operator log sheets for the Dallas area from 1961 to 1976 are located at the Stephenville, Texas, Radar Station. The radar operators note the velocity and the azimuth of the storms. Our investigations related the storm movement azimuth and velocity term, SMOV, to the t_p

values of 68 of the 84 storm reproductions for which storm movement data were available.

The equation developed was:

$$t_p = 0.853 \frac{(\text{SMOV})^{.0033}\, e^{.0003\text{URB}}\, (LL_{ca}/S)^{.346}}{e^{.0036\text{CHAN}}}.$$

The final results of the regression analysis relating t_p to storm movement indicate that a storm moving upstream would decrease the t_p.

The addition of storm movement to the relationship accounted for little, if any, of the variance in t_p. Therefore, the value of the relationship was discounted for the available data.

The validity of the relationship of t_p vs. urbanization, channelization, and the shape factor shown in figure 1 was further analyzed by testing its ability to reproduce recorded storms. The test was performed using the same techniques used in developing synthetic storm discharges. The curves were tested by trying to reproduce the 84 storms of table 1.

The Corps of Engineers of the Fort Worth District developed a computer program, "Dallas," to facilitate the development of discharges for the Flood Insurance Agency study of the Dallas area. The program incorporates the Corps loss rates for Dallas County, the T. L. Nelson urbanization curves, the rainfall depths from Technical Paper 40, and the Snyder's storage coefficient (640 C_p) values for Dallas County. The program was modified to accept the time to peak vs. shape, urbanization and channelization curves, actual rainfall, and various loss rates. The modifications did not alter the original methods of determining rainfall from T.P. 40, Snyder's coefficients, unit hydrograph ordinates, or flood hydrograph discharges.

The 84 recorded storms of table 1 were incorporated in the program. The rainfall excess, as optimized by HEC-1 in the t_p optimization, was the input rainfall. The flood peaks were predicted to within 29.6% of the recorded values by using the time to peak vs. shape and urbanization and channelization curves.

Several reasons may be offered to explain the 30% mean error. First, the testing technique uses the entire drainage area above the gauge without any flood routing procedure. A flood routing procedure would account for the effect of tributary flow on the timing of the flood peak. Second, the test procedure assumes a uniform rainfall over the basin. Any variation in rainfall over the drainage area may affect the flood peak. Third, a constant C_p value was used in the test procedure. The C_p value may be a function of many variables, such as rainfall. A constant C_p may not be applicable to the basin over the time span of the various storms. Fourth, as Leo R. Beard (1977) pointed out in a critique of the study, the t_p value may be influenced by the magnitude of the flood. Fifth, Beard also pointed out that the relative Manning's "n" factors, the roughness coefficient of creeks, may also affect the timing of the peak of the unit hydrograph.

The T. L. Nelson curves were also tested against the same 84 storms with all other variables remaining the same. The Nelson curves use only the urbanization factor, not the channelization factor. They predicted the flood peaks to within 36.4% of the recorded values. Even given its slightly better prediction record, the channelization factor needs more study before it can be accepted as a worthwhile addition to the equation relating time to peak and shape.

Conclusions

The data from 84 storms on 11 streams in the Dallas area showed that a strong relationship existed between the lag time (t_p) and the shape factor ($LL_{ca}/S^{0.5}$). The slope of 0.4 in the equation $\ln t_p = 0.04 \ln LL_{ca}/S^{0.5} - 0.37$ checks Nelson's work for the Dallas area.

Analysis of the same data for the relationship between lag time and urbanization, channelization, and direction of storms was inconclusive. A narrow interpretation of the best equation using shape factor, urbanization, and channelization shows that t_p is reduced by increasing urbanization and channelization. Further, the equation shows that for the data analyzed, channelization has a greater effect on t_p than does urbanization. A more intensive analysis of the data, however, shows that the addition of channelization and urbanization to the relation explains only 2% of the variance in t_p. Therefore, the overall conclusion is that percentage of urbanization and percentage of channelization do not significantly affect t_p for this set of data. More information is needed to establish the final relationship among the variables.

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