EFFECTS OF URBANIZATION ON
VARIOUS FREQUENCY PEAK DISCHARGES

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for Fall Meeting
Texas, New Mexico and Mexico Sections

Albuquerque, New Mexico

6-8 October 1977

Abstract: The results of hydrologic studies in various urban areas of Texas are presented and discussed. These studies, in such areas as San Antonio, Dallas-Fort Worth, and Austin have been made for flood plain information reports and flood insurance reports.

TABLE OF CONTENTS

INTRODUCTION

The urban centers of Texas include some of the most rapidly growing population centers in the United States. The Fort Worth District of the Corps of Engineers over the last several years has produced numerous flood plain information and flood insurance studies for various Texas cities. Numerous discharge points have been required in each of these studies, making desirable a relatively uniform and quick procedure for estimating unit hydrograph coefficients to use with a particular watershed for various degrees of urbanization. Based on U. S. Geological Survey gage data, urbanization curves relating various unit hydrograph parameters have been developed for Fort Worth-Dallas, Austin and San Antonio.

Literature exists from several studies dealing with the effects of urbanization on unit hydrographs and frequency peak discharges for specific areas scattered across the United States. Results are quite varied from one location to another and are generally not absolutely conclusive. Results of studies presented in this paper are no exception. The urbanization curves indicate shorter lag time and higher-peaked unit hydrographs with urbanization. Percent impervious cover, location of impervious cover, percent of watershed storm sewered, size of storm sewers, length and size of channelization, and other factors complicate the effects of urbanization on the runoff and the unit hydrograph.

Measurement or quantification of these factors would be very time consuming for a flood insurance study where several hundred discharge locations were to be evaluated. In addition, sufficient data are not available to calibrate the effects of each individual complicating factor. The urbanization curves in this paper require measurement or estimation of stream length, length along the stream from the discharge point to the center of gravity of the drainage area, streamslope, and per cent urbanization. Though the curves do not consider all the camplicating factors, they do lend themselves to production of discharge-frequency information at numerous locations and do produce reasonable results. The curves have been verified with reproductions of observed hydrographs for watersheds with various percentages of urbanization.

The assumption that future urbanization practices will approximate those of the past is inherent in the use of urbanization curves based on historical records. Modifications of urbanization practices such as no future mainstem channelization or a policy of no increased runoff with development would somewhat limit the application of the urbanization curves.

Under natural conditions, generally a greater percentage of the rainfall causing a frequent flood is absorbed as loss than with a rare flood. For example, if four inches of rain fall uniformly in two hours and two inches are absorbed, 50 percent of the rain runs off, while, if three inches of rain fall uniformly in two hours and two inches are losses, 33 percent of the rain runs off. Thus imperviousness, reducing the loss to near zero for both floods, has a greater effect on the volume and peak discharge of a frequent flood. Hydrology studies being conducted as part of the Fort Worth District's Expanded Flood Plain Information Study on Rowlett Creek indicate a greater increase in the peak and volume of the 10 percent exceedence frequency (10-year) flood than the 1 percent (100-year) flood when future increased urbanization alternatives are considered. The Rowlett basin is being modeled hydrologically on the HEC-1 Flood Hydrograph Program using a puls or storage discharge type routing and considering the effects of imperviousness on loss rates. The Rowlett model has 101 subareas; 23 land uses are being considered. The effects of urbanization in improving watershed hydraulic efficiency and reducing t_p is estimated for each small subwatershed. The subarea hydrographs are then routed and combined. When the mainstem routing is not changed, ie. no channelization is assumed, the model indicates that increases in the 1 percent flood are small or negligible for areas greater than 12 to 15 square miles. Thus routing effects tend to dominate in the model for larger floods for areas greater than 15 square miles. The results of the Rowlett study are preliminary and more computations are being made.

DEFINITION OF VARIABLES

C_t and C_p640: Snyders unit hydrograph coefficients which are dependent on drainage basin characteristics.

L: river mileage from the discharge station to the upstream limits of the drainage area.

L_{ca}: river mileage from the discharge station to the center of gravity of the drainage area.

t_p: lag time from mid-point of unit rainfall duration, t_r, to peak of unit hydrograph in hours.

t_r: unit rainfall duration equal to $t_p/5.5$, in hours.

t_R: unit rainfall duration other than the standard duration, t_r, adopted in a specific study, in hours.

S or S_{st}: streamslope over the full distance L, in feet/feet or feet/mile.

$\overline{S}$ or $\overline{S}_{st}$: weighted slope over the distance from 0.1 L to 0.85 L above the discharge station.

FORT WORTH - DALLAS (D-FW) CLAY URBANIZATION CURVES

In 1970, T. L. Nelson of the Fort Worth District developed urbanization curves (plate 1) for watersheds with generally clay soils in a paper entitled "Synthetic Unit Hydrograph Relationships, Trinity River Tributaries, Fort Worth-Dallas Urban Area." Nelson studied 8 watersheds at various stages of development. Review of available literature indicated that t_p generally correlated well with the parameter $LL_{ca}/\overline{S}^{0.5}$. Studies in California (Linsley), Louisville (Eagleson), and Houston (Van Sickle) were used in establishing the slope which the relationship between t_p and $LL_{ca}/\overline{S}^{0.5}$ should have. Since 1970, additional watersheds have been studied. Table 1 presents pertinent unit hydrograph data for 22 D-FW predominantly clay watersheds. Plate 1 presents the D-FW Clay Urbanization Curves with plotting points for various watersheds identified by table 1 reference number and average percent urbanization.

The determination of urban areas for the D-FW and other curves presented in this paper was made by measuring or estimating the indicated urban area from recent U.S. Geological Survey 7.5 - minute quadrangle maps (pink shaded areas and other areas where urbanization is obviously indicated), from field trips, from city maps, and from recent aerial photos. No estimate was made of the degree of storm sewer coverage or miles of channel improvement. The percent impervious area included in each urban area was not estimated. The U.S. Geological Survey has determined the percent imperviousness for some of the watersheds for specific dates (see references).

The curves indicate that in the D-FW area a complete change from a rural to a fully developed urban condition would reduce the lag (t_p) for a watershed by about fifty percent. If the general D-FW C_p640 of 460 is adopted as a constant value, the peak discharge of the unit hydrograph will be approximately doubled.

The clay watersheds were generally prairie under natural conditions. The land resource areas involved are often referred to as Blackland Prairie and Grand Prairie. On the periphery of the D-FW Metroplex these watersheds are generally used for farming and ranching today.

TABLE 1

PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN DEVELOPING THE FORT WORTH-DALLAS CLAY URBANIZATION CURVES

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Observed peak (c.f.s.)	C_p640	t_p	Date	$LL_{ca}/\overline{S}^{0.5}$	% urban
White Rock Creek at Keller Springs Road	29.4	3.39	1.49	8,300	590	2.77	6 May 69	27.6	4
		1.97	0.84	4,420	612	3.5	29-30 Jun 62	27.6	0
		5.84	2.50	9,410	686	3.5	27 Jul 62	27.6	0
		1.77	0.77	3,460	423	2.5	27 Sep 64	27.6	0
		2.35	0.90	3,170	605	3.5	18 Nov 64	27.6	0
		1.75	0.65	4,560	868	3.5	27-28 May 64	27.6	0
		2.52	1.43	9,020	763	3.5	28 Apr 66	27.6	0
				Average	650	3.25			1
White Rock Creek at Greenville Avenue	66.4	3.93	1.65	24,500	620	2.5	8 Oct 62	78.4	10
		1.56	0.70	6,940	759	4.5	27 Sep 64	78.4	10
		1.96	1.00	7,500	626	4.5	18 Nov 64	78.4	10
		3.37	2.44	11,000	616	5.5	8-9 Feb 65	78.4	10
		2.64	1.77	13,800	469	3.5	10-11 May 65	78.4	10
				Average	618	4.1			10
Turtle Creek at Dallas, Texas	7.98	1.73	0.64	3,050	439	0.75	30 Apr 62	2.9	100
		4.36	2.18	4,640	338	0.75	27 Jul 62	2.9	100
		3.80	1.68	3,450	291	0.75	8 Oct 62	2.9	100
		2.82	1.81	4,290	479	0.75	28 Apr 63	2.9	100
		2.12	1.66	4,520	489	0.75	19 May 65	2.9	100
		3.55	3.04	12,200	658	0.75	28 Apr 66	2.9	100
				Average	449	0.75		2.9	100
Bachman Branch at Midway Road	10.0	5.35	3.21	9,200	255	0.75	8 Oct 62	2.6	
		4.10	1.28	3,620	468	1.25	20-21 Sep 64	2.6	
		1.10	0.69	2,910	337	0.75	21 Sep 64	2.6	
		1.36	0.58	3,050	195	0.25	22 Sep 64	2.6	
		2.36	1.52	5,170	595	1.25	10 May 65	2.6	
				Average	370	0.85			70

TABLE 1 (Cont'd)

PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN DEVELOPING THE FORT WORTH-DALLAS CLAY URBANIZATION CURVES

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Observed peak (c.f.s.)	C_p640	t_p	Date	$LL_{ca}/\overline{S}^{0.5}$	% urban
Joes Creek at State Highway 114	7.51	4.77	3.71	6,350	316	1.25	28 Apr 66	2.9	55
		4.64	3.28	7,300	380	0.58	8 Oct 62	2.9	50
				Average	348	0.92		2.9	53
Duck Creek at Garland, Texas (Beltline Road)	31.6	4.38	3.52	10,500	550	3.83	6 May 69	23.5	37
		3.56	1.99	7,400	388	2.5	26 Apr 58	23.5	37
		0.77	0.64	2,140	364	3.5	28-29 Apr 58	23.5	
		3.05	1.09	4,160	358	2.5	1 Oct 59	23.5	
		7.00	4.54	16,000	395	2.5	27 Jul 62	23.5	
		3.02	1.63	7,400	530	2.5	28 Apr 63	23.5	
		3.53	1.78	5,620	497	3.5	9 Feb 65	23.5	
		3.91	2.72	9,500	325	2.5	28 Apr 66	23.5	
		2.46	1.81	8,600	395	2.5	29 Apr 66	23.5	
				Average	422	2.87		23.5	35
Big Fossil Creek at Haltom City	53.8	6.15	3.73	27,200	590	3.63	7 Sep 62	47.6	5
		4.43	2.69	7,770	420	4.5	25-26 Apr 57	47.6	5
		5.86	4.62	13,000E	420	4.5	25-26 May 57	47.6	5
		6.54	2.06	18,300	603	3.5	24-25 Jun 61	47.6	5
		5.29	1.69	12,600	462	3.5	30 Sep-1 Oct 59	47.6	5
				Average	499	3.93		47.6	5
Village Creek at Handley	130.00	1.54	0.50	4,180	460	5.2	19 May 26	95.6	
		3.41	0.85	9,400	460	5.2	1 Oct 27	95.6	
		3.46	1.38	14,800	460	5.2	17 Dec 28	95.6	
				Average	460	5.2		95.6	0
Duck Creek at Buckingham Road	7.90	2.50	0.90	2,500	250	0.64	30 May 70	5.32	40
		3.17	1.79	3,960	280	0.89	16 Sep 74	5.32	60
				Average	265	0.77		5.32	50

TABLE 1 (Cont'd)

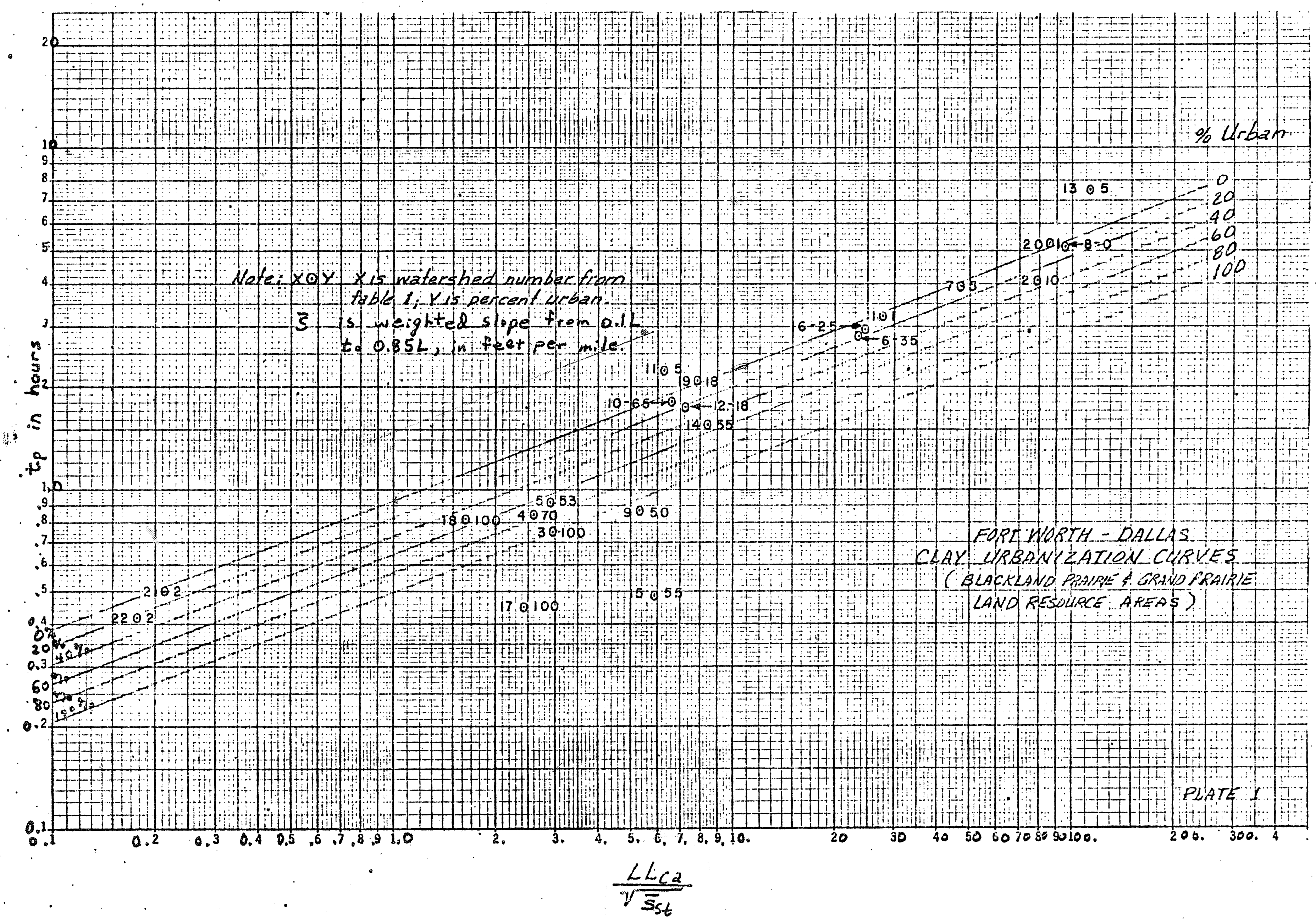
PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN
DEVELOPING THE FORT WORTH-DALLAS CLAY URBANIZATION CURVES

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Observed peak (c.f.s.)	C_p640	t_p	Date	$LL_{ca}/\overline{S}^{0.5}$	% urban
South Mesquite Creek at Highway 352	13.4	2.89	1.86	3,420	400	1.89	23 Apr 73	6.61	65
		2.30	1.58	3,090	420	1.75	20 Sep 73	6.61	65
				Average	410	1.82			65
Marine Creek at NW 33d Street	17.3	1.45	0.56	1,680	405	2.25	26 Apr 57	6.3	5
Sycamore Creek at I.H. 35W	17.7	1.38	0.28	1,140	450	1.77	30 May. 70	7.19	18
Rowlett Creek near Sachse (Hwy 78)	120.3	3.40	2.01	24,400	600	8.36	6 May 69	112.7	4
		3.41	2.48	24,700	600	6.62	9 Dec 71	112.7	6
				Average	600	7.49			5
Five Mile Creek at Lancaster	37.9	1.85	0.70	7,040	460	1.55	30 May 70	8.44	55
		2.36	0.85	8,540	440	1.55	7 Jul 73	8.44	55
				Average	450	1.55			55
Five Mile Creek at Highway 77	13.2	3.02	1.45	6,180	300	0.49	30 May 70	5.91	55
Ten Mile Creek at Highway 342	52.8	3.74	1.86	8,820	320	2.91	3 Jun 73	24.77	25
Cedar Creek at Bonnie View Road	9.42	2.15	0.75	4,840	350	0.45	29 May 73	2.42	100
Coombs Creek at Sylvan Avenue	4.75	4.40	2.73	2,960	320	0.82	6 May 69	1.64	100

TABLE 1 (Cont'd)

PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN
DEVELOPING THE FORT WORTH-DALLAS CLAY URBANIZATION CURVES

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Observed peak (c.f.s.)	C_{p640}	t_p	Date	$LLca/\sqrt{S}$ ($^{0.5}$)	% urban
Little Fossil Creek at Mesquite Street	12.3	2.12	1.28	1,530	260	2.27	6 May 69	7.9	18
		1.61	0.83	1,370	280	1.91	30 Apr-1 May 70	7.9	18
				Average	270	2.09		7.9	18
Mountain Creek near Cedar Hill	103.5	3.38	2.35	18,500	433	5.60	25-26 Apr 70	86	1
		5.92	4.81	28,300	324	4.95	6-8 May 69	86	1
				Average	379	5.28		86	1
Honey Creek SCS Site No. 12 near McKinney	1.26	1.46	1.46	1,170	360	0.40	29 Apr 58	.216	2
		1.62	1.62	1,480	380	0.26	1 May 58	.216	2
		1.03	0.95	850	550	0.73	28 Apr 66	.216	2
		1.72	1.72	1,400	550	0.62	30 Apr 66	.216	2
				Average	460	0.50		.216	2
Honey Creek SCS Site No. 11 near McKinney	2.14	1.22	0.93	1,250	340	.50	28 Apr 66	.177	2
		2.36	2.30	3,230	320	.33	30 Apr 66	.177	2
				Average	330	.42		.177	2


% Urban
0
20
40
60
80
100
13 ⊙ 5
2001⊙←8-0
7⊙5
2⊙10
6-25→⊙
1⊙1
⊙←6-35
11⊙5
19⊙18
10-65→⊙
⊙←12-18
14⊙55
5⊙53
18⊙100
4⊙70
30⊙100
9⊙50
21⊙2
22⊙2
17⊙100
5⊙55
0%
20%
40%
60%
80%
100%
Note: X⊙Y X is watershed number from table 1; Y is percent urban.
S̄ is weighted slope from 0.1L to 0.85L, in feet per mile.
FORT WORTH - DALLAS
CLAY URBANIZATION CURVES
(BLACKLAND PRAIRIE & GRAND PRAIRIE LAND RESOURCE AREAS)
PLATE I
tp in hours
$\frac{LL_{ca}}{\sqrt{\bar{S}_{st}}}$

FORT WORTH - DALLAS SANDY LOAM ("CROSS TIMBERS")

URBANIZATION CURVES

Examination of data from flood hydrograph reproductions for sandy loam basins in the D-FW area indicate a significantly different relationship between $LL_{ca}/\overline{S}^{\,0.5}$ versus t_p than exists for clay watersheds in the Metroplex. Channels of sandy loam watersheds are generally smaller in c.f.s. capacity per square mile of drainage area, with more trees and brush retarding flow, than with clay watersheds. The data indicate that the t_p value for a sandy watershed is approximately twice that of a clay watershed with a similar $LL_{ca}/\overline{S}^{\,0.5}$.

Table 2 displays pertinent data for four D-FW area sandy loam and mixed clay and sandy loam watersheds. Plate 2 presents the D-FW Sandy Loam Urbanization Curves with plotting points for various watersheds and notes on percent sand and clay in each watershed. Considering the percent soil - mixes, the mixed watersheds produce plot points which are reasonable.

For mixed - soil areas where the sand and clay are uniformly mixed in patches, a weighted t_p may be developed by determing t_p from the sand and clay curves and weighting each t_p according to the percent of each soil type in the watershed. A similar weighting procedure may be used for mixed - soil watersheds where the soils are separated basically parallel along the length of the stream. However, if the upper part of a mixed - soil watershed is one soil type and the lower portion is the other, a routing and combining model should be used with separate unit hydrographs for the sand and clay areas.

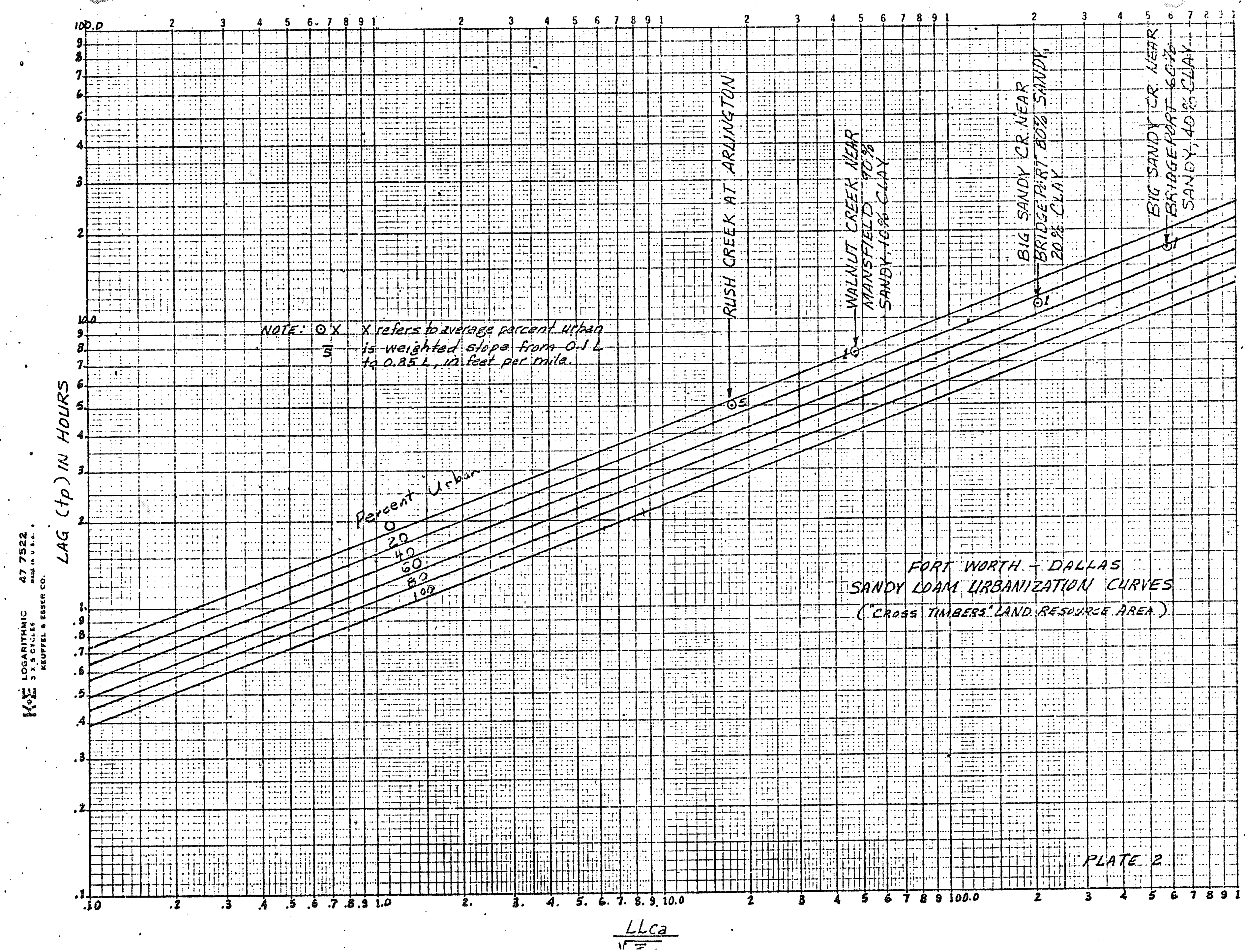
There are significant weaknesses associated with the D-FW Sandy Loam Urbanization Curves. Only one of the four watersheds serving as plot points on the curves is a pure sandy loam watershed. The maximum percent urbanization for any of the four watersheds is five percent. Stream gages are needed on rapidly urbanizing and significantly developed sandy watersheds to help substantiate the D-FW Sandy Loam Urbanization Curves.

A C_p640 value of 460 to 520 is recommended for use with the sandy loam curves.

TABLE 2

PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN DEVELOPING THE FORT WORTH-DALLAS SANDY LOAM URBANIZATION CURVES

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Initial loss (inches)	Infiltration rate (in/hr)	C_p640	t_p	C_t	Observed peak (c.f.s.)	Computed peak (c.f.s.)	% urban	L (miles)	L_{ca} (miles)	$\bar{S}$ (ft/mi)	$LL_{ca}/\bar{S}^{0.5}$	Date	Remarks
Walnut Creek near Mansfield	62.8	3.22	1.45	.7	.13	450	7.87	1.7	4,730	4,800	1	19.72	8.38	12.6	46.5	8-10 Feb 65	90% sandy, 10% clay
		2.08	1.22	0.5	.07	550	7.87	1.7	5,390	5,200	1	19.72	8.38	12.6	46.5	30 Apr-1 May 66	
		4.70	1.67	1.4	0.2	550	7.87	1.7	6,840	6,840	1	19.72	8.38	12.6	46.5	6-7 May 69	
Rush Creek at Arkansas Lane	27.11	2.89	1.20	.6	.18	460	5.0	1.43	2,500	2,510	5	11.54	5.62	14.3	17.2	12-13 Oct 73	Personal stage observations
Big Sandy Creek near Bridgeport	333	5.00	3.15	1.75	.01	640	13.4		53,000		1				564	10-12 Jun 41	60% sandy 40% clay
	333	4.40	1.98	1.20	.08	610	21.0		17,350		1				564	7-10 Apr 42	
				Average		625	17.2										
Big Sandy Creek near Bridgeport (Area Modified by Lake Amon Carter)	233.2	8.72	2.86	4.60	.06	400	11.3		19,110		1				202	3-6 Oct 59	80% sandy, 20% clay



LAG (t_p) IN HOURS
$\frac{LLca}{\sqrt{S}}$
NOTE: ⊙X X refers to average percent urban
S is weighted slope from 0.1 L to 0.85 L, in feet per mile.
Percent Urban
0
20
40
60
80
100
RUSH CREEK AT ARLINGTON
WALNUT CREEK NEAR MANSFIELD 90% SANDY, 10% CLAY
BIG SANDY CR. NEAR BRIDGEPORT 80% SANDY, 20% CLAY
BIG SANDY CR. NEAR BRIDGEPORT 60% SANDY, 40% CLAY
FORT WORTH - DALLAS
SANDY LOAM URBANIZATION CURVES
("CROSS TIMBERS" LAND RESOURCE AREA)
PLATE 2
K&E LOGARITHMIC 3 X 5 CYCLES KEUFFEL & ESSER CO. 47 7522 MADE IN U.S.A.

AUSTIN URBANIZATION CURVES

In 1970, following development of the D-FW Clay Urbanization Curves, the Fort Worth District developed similar curves for the Austin area. Hydrographs were reproduced for rural Wilbarger Creek near Pflugerville and for urban Waller Creek at 23rd and 38th Streets in Austin. Results of those studies and of subsequent reproductions are presented in table 3. Average t_p and average percent urbanization are plotted versus $LL_{ca}/S_{st}^{0.5}$ on Plate 3, the Austin Urbanization Curves, for the three watersheds considered.

The Fort Worth District is in the early stages of an expanded flood plain information study on Walnut Creek at Austin. In connection with that study, hydrographs will be reproduced for gages on Walnut Creek, Bull Creek and other Austin - area watersheds as information is available.

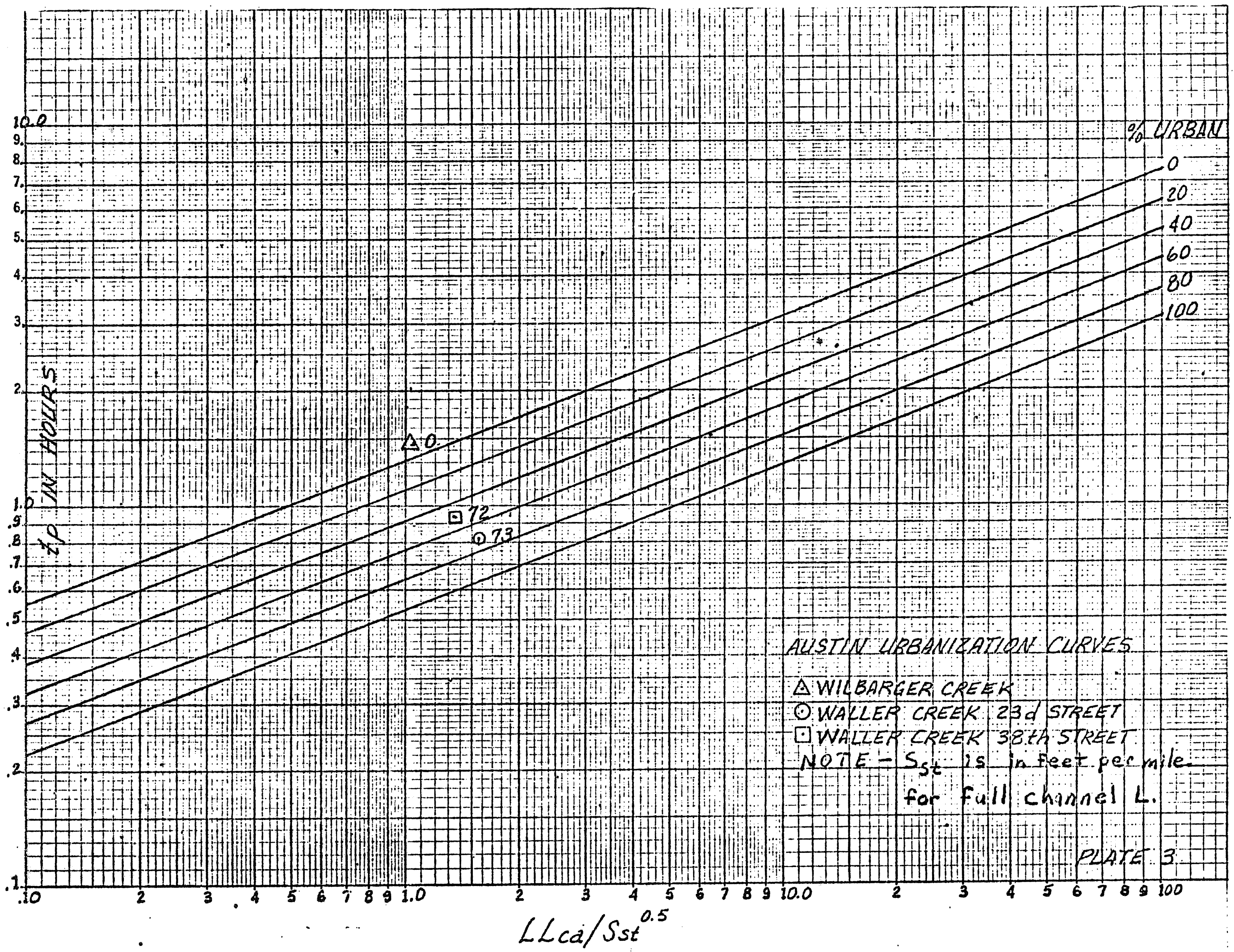
While hydrograph reproductions in the Austin area indicate a C_p640 value of approximately 400, comparison with D-FW and San Antonio watersheds indicate that 460 to 500 is a more appropriate value.

TABLE 3

PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN DEVELOPING THE AUSTIN URBANIZATION CURVES

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Initial loss (inches)	Infiltration rate (in/hr)	C_{p640}	t_p	C_t	Observed peak (c.f.s.)	Computed peak (c.f.s.)	% urban	L (miles)	Lca (miles)	S_{st} (ft/mi)	$LL_{ca}/S^{0.5}$	Date	Remarks
Waller Creek at 38th St.	2.31					357	0.9	0.46			70	4.1	2.3	50	1.33	1960's-60's	Record beings '54*
	2.31	2.95	.97	0.9	0.52	550	1.66	0.85	530	570	85	4.1	2.3	50	1.33	15 Oct 67	**
	2.31	2.53	.98	0.3	1.00	500	0.74	0.38	1,400	1,370	85	4.1	2.3	50	1.33	1 May 72	**
				Average		378	0.94	0.48			72				1.33		
Waller Creek at 23d Street	4.13					385	0.76	0.37			70	5.1	2.1	47	1.56		
	4.13	2.97	1.29	.70	.40	500	1.71	0.84	1,220	1,090	90	5.1	2.1	47	1.56	1950's-60's	Record begins '54*
	4.13	2.44	0.74	.6	1.00	500	0.64	0.31	2,160	2,030	90	5.1	2.1	47	1.56	15 Oct 67	**
				Average		400	.82	0.40			73	5.1	2.1	47	1.56	1 May 72	**
Wilbarger Creek near Pflugerville	4.61					358	1.38	0.78			0	3.48	1.89	39.2	1.05	1960's	Record begins '63*
	4.61	3.38	0.67	.80	.60	450	1.73	0.98	630	713	0	3.48	1.89	39.2	1.05	15 May 70	**
	4.61	2.17	0.39	0.7	1.42	450	1.56	0.89	560	520	0	3.48	1.89	39.2	1.05	17 Nov 71	**
				Average		384	1.45	0.82			0				1.05		

*From original 1970 study of 14 floods at 38th Street; 13 floods at 23d Street; and 5 floods on Wilbarger Creek
**Reproductions by Groves, Fernandez, Frazier, Telford, and Associates Incorporated, San Antonio


% URBAN
0
20
40
60
80
100
tp IN HOURS
LLca/Sst 0.5
Δ0
⊡72
⊙73
AUSTIN URBANIZATION CURVES
Δ WILBARGER CREEK
⊙ WALLER CREEK 23d STREET
⊡ WALLER CREEK 38th STREET
NOTE – Sst is in feet per mile for full channel L.
PLATE 3

SAN ANTONIO STEEP - AREA (UPPER SALADO)

URBANIZATION CURVES

The San Antonio Steep - Area Urbanization Curves, plate 4, were originally developed in conjunction with a flood plain information study of Salado Creek. The curves were drawn from one plotting point based on several flood hydrograph reproductions for Salado Creek at northern Loop 410, the upper Salado gage. Slope and spacing of the curves was based on Nelson's D-FW Clay Urbanization Curves. In the interim following completion of the Salado Creek Flood Plain Information Study, peaks from crest stage gages have been reproduced on Martinez, Alazan, San Pedro and Apache Creeks; and full hydrographs have been reconstituted for Olmos Creek at Dresden Drive. Results of these studies are tabulated in table 4 and plotted on plate 4.

The results plot very well, though less weight should be given to the peak - only reproductions than to the hydrograph reproductions. It should also be noted that Corps channelization somewhat decreased the t_p for Martinez, Alazan and San Pedro Creeks.

A general C_p640 value of 500 is recommended for use with the San Antonio Steep - Area Urbanization Curves.

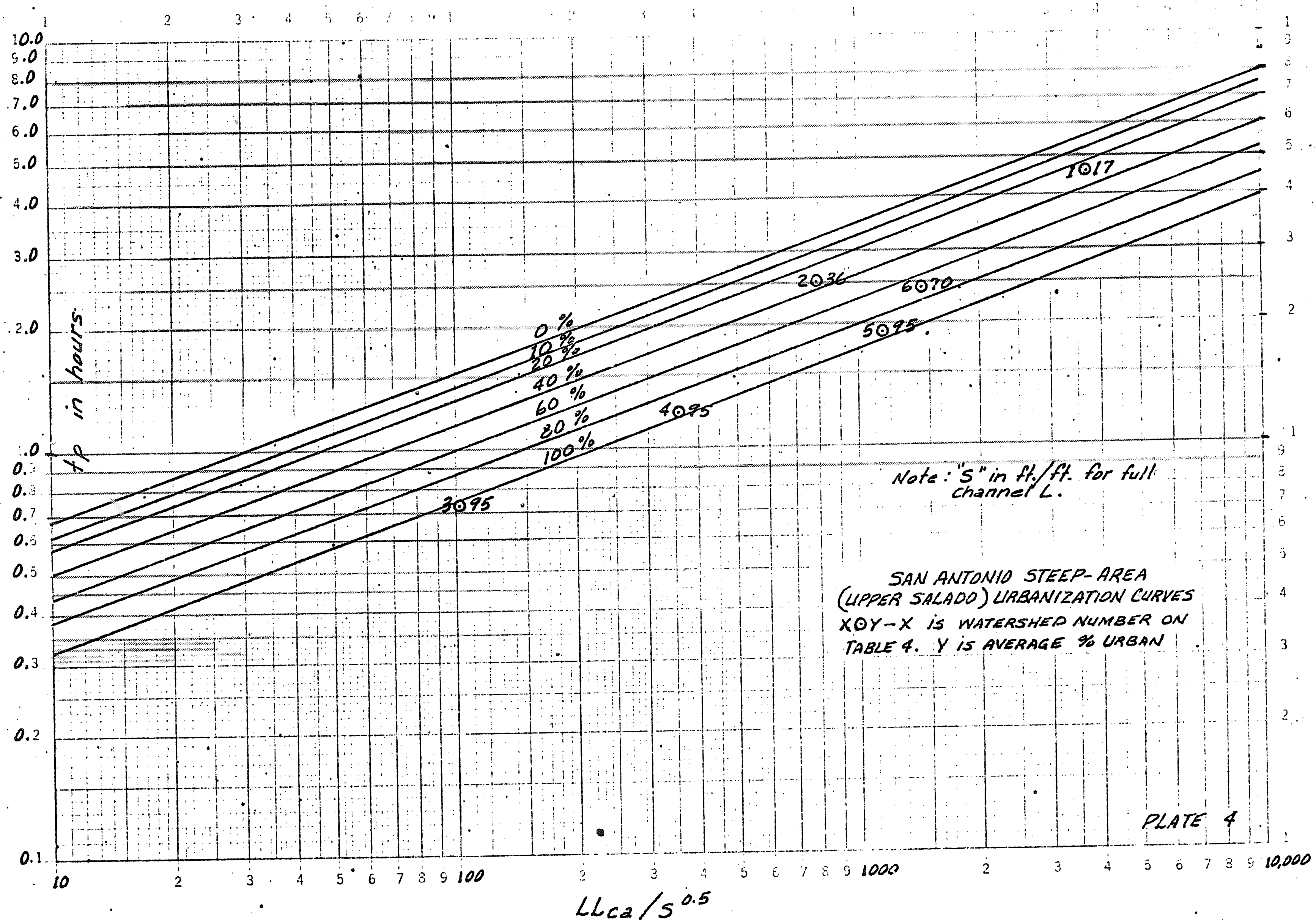
Reproductions of flood hydrographs for very steep San Antonio area (hill country) watersheds are presented, for information only, in table 5.

TABLE 4

PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN DEVELOPING
THE
SAN ANTONIO STEEP-AREA (UPPER SALADO) URBANIZATION CURVES

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Initial loss (inches)	Infiltration rate (in/hr)	C_{p640}	t_p	C_t	Observed peak (c.f.s.)	Computed peak (c.f.s.)	% urban	L (miles)	Lca (miles)	S (ft/ft)	$LL_{ca}/S^{0.5}$	Date	Remarks
1 Salado Creek at northern Loop 410 (upper gage)	137.0	4.08	0.61	1.7	0.3	600	4.87	0.9	13,000	10,200	15	25.3	10.6	.0052	3,684	2-3 Dec 65	
	137.0	4.00	0.47	2.5	0.3	600	4.87	0.9	8,100	7,690	15	25.3	10.6	.0052	3,684	16-17 Jun 64	
	137.0	2.90	0.67	1.5	0.13	600	4.87	0.9	10,000	10,150	15	25.3	10.6	.0052	5,684	16-17 May 65	
	137.0	5.00	1.04	1.8	0.37	500	4.00	0.74	16,200	15,850	20	25.3	10.6	.0052	3,684	26-27 Sep 73	
	137.0	4.84	1.23	1.2	0.26	500	4.00	0.74	17,100	17,250	20	25.3	10.6	.0052	3,684	14-17 Jul 73	
	137.0	2.90	0.47	2.0	0.2	600	4.87	0.9	6,600	7,860	17	25.3	10.6	.0052	3,684	18-19 Jan 68	
				Average		567	4.58	0.79			17						
2 Olmos Creek at Dresden Drive	21.2	4.12	0.87	-	variable	500	2.50	0.72	2,500	2,505	35	11.59	5.53	.0066	791	12 Jun 73	
	21.2	5.47	1.98	-	variable	500	2.50	0.72	4,600	4,650	35	11.59	5.53	.0066	791	26-27 Sep 73	
	21.2	4.05	0.53	-	variable	500	2.50	0.72	1,670	1,990	38	11.59	5.53	.0066	791	8 Aug 74	
				Average		500	2.50	0.72			36						
3 Martinez Creek at Fredericksburg Rd	6.15	7.27	3.83	1.2	0.3	500	0.52	0.25	9,000	9,030	95	5.11	1.99	.01	102	26-27 Sep 73	Peak only, Corps Channel In*
	6.15	4.31	4.02	0.2	0.02	500	0.78	0.43	7,500	7,530	95	5.11	1.99	.01	102	8 Aug 74	
				Average		500	0.65	0.34			95						
4 Alazan Creek at West Martin Street	16.19	7.27	3.83	1.2	0.3	500	1.22	0.43	16,400	16,480	95	7.61	4.2	.008	358	26-27 Sep 73	Peak only, Corps Channel In*
	16.19	4.53	4.43	0.1	0.0	500	1.22	0.43	16,600	16,580	95	7.61	4.2	.008	358	8 Aug 74	
				Average		500	1.22	0.43			95						
5 San Pedro Creek at Furnish Street	43.12	7.27	3.62	1.25	0.34	450	1.9	0.5	30,200	30,310	95	15.8	5.4	.005	1,176	26-27 Sep 73	Peak only, channel Part complete*
	43.12	4.12	3.74	0.2	0.04	450	1.9	0.5	29,200	29,120	95	15.8	5.4	.005	1,176	8 Aug 74	
				Average		450	1.9	0.5			95						
6 Apache Creek at South Zarzamora Street	21.47	7.27	4.58	0.7	0.24	500	2.42	0.6	16,300	16,240	70	13.9	7.42	.005	1,444	26-27-Sep 73	Peak only, channel under constr.*

*Crest stage gage



tp in hours
LLca/S^0.5
0 %
10 %
20 %
40 %
60 %
80 %
100 %
1⊙17
2⊙36
6⊙70
5⊙95
4⊙95
3⊙95
Note: "S" in ft./ft. for full channel L.
SAN ANTONIO STEEP-AREA
(UPPER SALADO) URBANIZATION CURVES
X⊙Y–X is WATERSHED NUMBER ON
TABLE 4. Y is AVERAGE % URBAN

PLATE 4

TABLE 5

PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN DEVELOPING
FOR
VERY STEEP (HILL COUNTRY) SAN ANTONIO AREA WATERSHEDS

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Initial loss (inches)	Infiltration rate (in/hr)	C_{p640}	t_p	C_t	Observed peak (c.f.s.)	Computed peak (c.f.s.)	% urban	L (miles)	L_{ca} (miles)	$LL_{ca}^{.03}$	$(LL_{ca}/S)^{0.5}$	Date	Remarks
Cibolo Creek above Boerne	68.4	5.0	0.92	0.6	0.7	600	1.58	0.4	18,200	18,800	0	14.2	6.9	3.96	1,210	16-17 May 65	
	68.4	3.51	0.55	0.75	0.46	600	1.58	0.4	5,300	5,340	0	14.2	6.9	3.96	1,210	13 Aug 71	Good peak fit Missed hydrograph shape
Cibolo Creek, Boerne to Selma	205.6	3.3	1.05	0.8	0.28	600	7.96	0.9	25,300	26,830	1	51.7	27.6	8.84	28,540	16-17 May 65	
	(≤274)	4.62	0.42	2.35	0.29	600	7.96	0.9	6,400	6,090	1	51.7	27.6	8.84	28,540	3-4 Dec 65	
Medina River, Pipe Creek gage	474	3.97	1.68	1.15	0.35	400	3.0	0.3	72,900	73,300	1	68.0	32.0	10.03		14-17 Jul 73	
Red Bluff Creek Pipe Creek gage	56.3	4.50	0.91	2.85	0.30	650	3.0	0.77	10,920	10,750	1	14.11	6.69	3.91		14-17 Jul 73	

SAN ANTONIO ROLLING - AND FLATTER-AREA

(LOWER SALADO) URBANIZATION CURVES

The San Antonio Flatter-Area Urbanization Curves, plate 5, were developed as a part of the flood plain information study of Salado Creek. The flows from the upper Salado gage were Muskingum routed to the lower Salado gage at Loop 13. The local contribution from the flatter area between the gages was computed and added to the routed hydrograph to give a total computed hydrograph which reproduced the observed discharges at the gage. As part of a system flood routing, the 26-27 September 1973 flood hydrograph for the area between the upper Salado gage and the Salado Creek confluence with the San Antonio River was calculated. The hydrograph for the total area above the San Antonio River near Elmendorf gage was reproduced by the system routing. Results of these studies are tabulated in table 6 and plotted on plate 5.

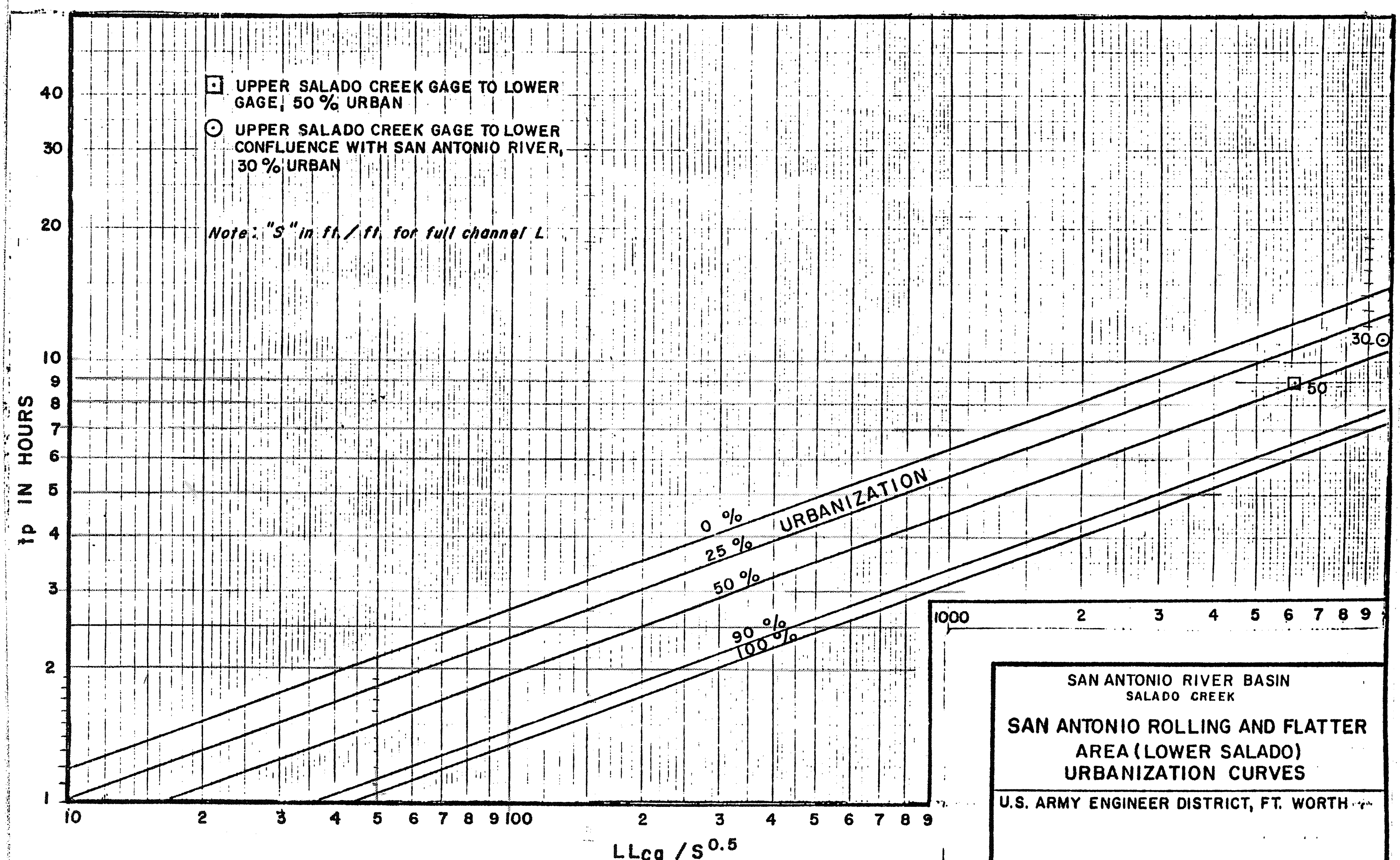
Hydrograph reproductions for Salado Creek will be attempted soon to better validate the San Antonio Flatter - Area Urbanization Curves.

TABLE 6

PERTINENT DATA FROM REPRODUCED HYDROGRAPHS USED IN DEVELOPING
THE
SAN ANTONIO ROLLING AND FLATTER AREA (LOWER SALADO) URBANIZATION CURVES

Gage location	DA (sq mi)	Average rain (inches)	Direct runoff (inches)	Initial loss (inches)	Infiltration rate (in/hr)	C_{p640}	t_p	C_t	Observed peak (c.f.s.)	Computed peak (c.f.s.)	% urban	L (miles)	Lca (miles)	S_{st} (ft/ft)	$LL_{ca}/S^{0.5}$	Date	Remarks
Salado Creek, upper gage to lower gage (Loop 13)	52 (≤189)	3.35	1.96	0.95	0.1	600	9.0	1.61	6,630	6,850	50	22.5	13.4	.0024	6,150	18-19 Jan '68	Muskingum routing used
Salado Creek, upper gage to mouth	86 (≤223)	6.5	2.90	1.4	0.35	450	11.1	1.98	-	10,000**	30	29.5	14.8	.0020	9,700	26-27 Sep'73	*

*Data is based on system routings with incremental areas computed, routed and combined. Total hydrographs were reproduced at stream gages.
**Peak flow calculated from incremental area of 86 square miles.



SAN ANTONIO RIVER BASIN
SALADO CREEK

SAN ANTONIO ROLLING AND FLATTER AREA (LOWER SALADO) URBANIZATION CURVES

U.S. ARMY ENGINEER DISTRICT, FT. WORTH

PLATE 5

CONCLUSIONS

Urban development is a complex process with an infinite number of possibilities as to mix of land use and drainage modifications. The exact quantification of the effects of the various factors involved in urbanization on peak discharge and runoff volume is not yet possible. The urbanization curves presented in this paper offer a quick, relatively consistent and reasonable procedure for estimating the effect of urbanization on the unit hydrograph for a specific watershed in a specific urban area. Data are continually being collected in the U.S. Geological Survey Urban Study Program in Texas (partially funded by the Corps). The Fort Worth District will analyze these data as time and funds permit in an attempt to more accurately quantify the effects of urban development on surface hydrology.

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