TEXAS WATER DEVELOPMENT BOARD

REPORT 115

TIME OF TRAVEL OF TRANSLATORY WAVES ON THE BRAZOS, LEON, AND LITTLE RIVERS, TEXAS

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TIME OF TRAVEL OF TRANSLATORY WAVES ON THE BRAZOS, LEON, AND LITTLE RIVERS, TEXAS

ABSTRACT

Travel times of peaks for the 346.4-mile reach of the Brazos River between Whitney and Richmond varied from 213 hours at 1,000 cfs (cubic feet per second), to 92 hours at 40,000 cfs, to 168 hours at 100,000 cfs.

Minimum travel time of peaks for the 82-mile reach between Leon River near Belton and Little River at Cameron varied from 57 hours for initial flow less than 15 cfs at Belton to 42 hours for initial flow above 200 cfs at Belton.

Minimum travel time of peaks for the 65-mile reach between Little River at Cameron to Brazos River near Bryan varied from 30 hours for 1,000 cfs, to 22 hours for 3,500 cfs, to 25 hours for 65,000 cfs, to 34 hours for 134,000 cfs.

Travel time was not consistent for any discharge, and was even more inconsistent in the low discharge range. Minimum peak travel time for each channel condition was fairly well defined.

TIME OF TRAVEL OF TRANSLATORY WAVES ON THE BRAZOS, LEON, AND LITTLE RIVERS, TEXAS

INTRODUCTION

The purpose of this study was to determine the time required for translatory waves to travel through the reach of the Brazos River from Whitney Reservoir to the Richmond stream-gaging station, and through the reach of the Leon, Little, and Brazos Rivers from Belton Reservoir to the Bryan stream-gaging station (Figure 1).

Three previous reports have been written on time of travel on the Brazos River (Havelka, 1960; Breeding and Holland, 1960; and Holland, 1960) and one report has been written on time of travel on the Leon and Little Rivers (Havelka and Parten, 1960). Even though data for this report were obtained by different methods than those used in the previous investigations, no contradictions were found.

Data were obtained from streamflow records of the Brazos River at Whitney, Waco, Bryan, Hempstead, and Richmond for the period from December 10, 1951, to September 30, 1967. Data were obtained from streamflow records of the Leon River near Belton, Little River near Little River, and Little River at Cameron for the period from March 8, 1954, to September 30, 1967.

Travel times were obtained by examining the original gage-height charts for each stream-gaging station. Times were noted for: (1) beginnings of rises; (2) when channel reached equilibrium (when the pen trace leveled off); (3) beginnings of recessions; and (4) peaks from flood runoff. Definition sketches for these items are shown on Figure 2. Each of these items is a translatory wave traveling downstream. Peaks from flood runoff (item 4) are one type of translatory wave; however, this report will refer to them as *peaks* or *peak discharges*. All other waves will be called *translatory waves*.

Whitney Reservoir was built for flood control and power development, and water is usually released for a period each day for power generation. This causes the record of stage at downstream stream-gaging stations to appear as a variable sine curve. In addition, releases from Waco Reservoir on the Bosque River at Waco cause changes in the streamflow pattern. Many of the releases from Whitney Reservoir could not be timed because of the downstream interaction with other releases; therefore, peaks are the only items shown for the Brazos River in this report.

Belton Reservoir was built for flood control and conservation storage. Changes in release rates are usually made quickly, and the new release rate continues for a sufficient period of time to eliminate any interaction with the next rate of change. Therefore, translatory waves were used to determine travel times on the Leon and Little Rivers.

The reader is cautioned not to use travel times as shown in this report for the travel times of contaminants or water particles. Buchanan (1968) states:

> By applying the Manning and Chezy formulas, the ratio of the velocity of a flood wave to the mean velocity of water particles is shown to be between 1.3 and 1.7. The results of an actual study with a fluorescent dye in an open channel to determine the ratio show good agreement with the expected ratios in channel reaches without dams, but reaches with dams give ratios greater than 2.0."

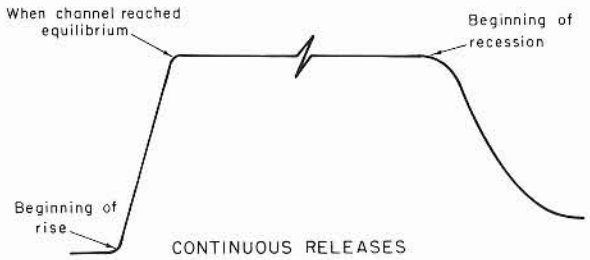
A dye-tracer time-of-travel study would have provided much more accurate data concerning water-particle travel time; but because of the additional costs involved, this type of study was not warranted.

This study was made by the U.S. Geological Survey under the provisions of the 1968 cooperative agreement with the Texas Water Development Board. The Brazos River Authority provided cooperative funds through the Texas Water Development Board.

BRAZOS RIVER REACH

Description

The study was made in a 346.4-mile reach of the Brazos River between the stream-gaging station Brazos River near Whitney (3.4 miles downstream from Whitney Dam) in Bosque County and the streamflow



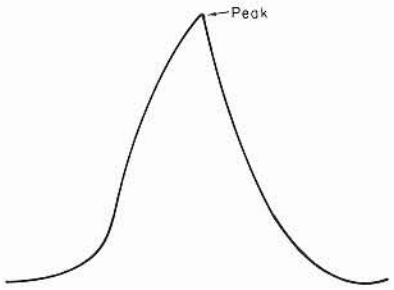


Figure 2.—Definition Sketches of Points for Which Travel Times Were Obtained From Gage-Height Charts

station Brazos River at Richmond in Fort Bend County (Figure 1). Richmond is upstream from the Gulf of Mexico at river mile 92.7, and the Whitney station is at river mile 439.1. The air-line distance between these points is about 200 miles.

The Brazos River flows southeast to the Gulf of Mexico. The main stream has cut a 30 to 50-foot-deep channel in the alluvium-filled flood plain. At low flow, the channel is made up of long pools and riffles. At medium and high flow, the bed and bank act to control the flow. There are no major man-made obstructions within the reach. Cronin and Wilson (1967) describe the Brazos River reach in more detail.

Five stream-gaging stations were used between Whitney and Richmond (Figure 1). Two stations established in 1965 (Highbank and Washington) did not have sufficient periods of record to be used. River-mile locations and streambed elevations for each station and the gradients between stations are given in Table 1.

Travel Time

The travel times of peaks from the stream-gaging station near Whitney to the stream-gaging station at Richmond varied from 213 hours at 1,000 cfs (cubic feet per second) to 92 hours at 40,000 cfs, to 168 hours at 100,000 cfs (Table 2). The generalized relationship between travel time and peak discharge is shown on Figure 3.

Travel times of peaks are affected by many factors, such as the initial discharge in the channel, the amount of inflow, the time required for the flood to peak, the gradient, and the size of the peak. The individual effect of each of these factors could not be determined.

Travel time is longest for low flows (Figure 3). As peak discharge becomes greater, travel time decreases until the minimum time occurs at a discharge of about 40,000 cfs. Then peak travel time increases as the floods become larger.

Table 1.—Stream-Gaging Stations in Operation on the Brazos River Reach During Period of Report

STATION NUMBER	SITE	LOCATION (RIVER MILES)[1/]	STREAMBED ELEVATION (FEET)	GRADIENT BETWEEN STATIONS (FEET PER MILE)
8-930	Brazos River near Whitney	439.1	417	
				1.73
8-965	Brazos River at Waco	404.5	357	
				1.43
8-982.9	Brazos River near Highbank	350.1	279	
				1.33
8-1090	Brazos River near Bryan	284.6	192	
				1.00
8-1102	Brazos River at Washington	232.6	140	
				.61
8-1115	Brazos River near Hempstead	196.5	118	
				.74
8-1140	Brazos River at Richmond	92.7	41	
--	Study reach	--	--	1.09

[1/] Data furnished by U.S. Army Corps of Engineers; river miles measured upstream from the mouth.

Table 2.—Travel Time of Peaks on the Brazos River

PEAK DISCHARGE AT DOWNSTREAM STATION (CFS)	TRAVEL TIME (HOURS)				
	WHITNEY TO WACO	WACO TO BRYAN	BRYAN TO HEMPSTEAD	HEMPSTEAD TO RICHMOND	WHITNEY TO RICHMOND
100	40	–	–	–	–
500	26	89	–	–	–
1,000	21	74	55	63	213
2,000	17	61	48	55	181
3,000	14	53	43	51	161
4,000	13	49	39	47	148
6,000	11	44	36	42	133
8,000	10	41	33	38	122
10,000	10	39	31	36	116
20,000	10	38	25	27	100
30,000	10	39	22	24	95
40,000	10	40	20.5	21.5	92
50,000	10	42	20	21	93
60,000	10	43	21	24	98
80,000	12	49	31	35	127
100,000	15	58	50	45	168

One of the reasons why travel time increases as the flood increases above 40,000 cfs is because wave velocity varies directly with the square root of mean depth (d_m). At about 40,000 cfs, d_m is at a maximum; as overflow from the main channel begins, d_m becomes smaller. In addition, floodflow is retarded by the heavy growth of vegetation along the channel.

The average travel-time curves the spread in travel-time points for the subreaches of the Brazos River reach are shown on Figures 4-7. In these illustrations, peak discharge for the downstream site is plotted by discharge and travel time. A connecting line is drawn from the left margin to the corresponding peak discharge at the downstream site, and a generalized curve is drawn for each subreach.

LEON, LITTLE, AND BRAZOS RIVERS REACH

Description

The study was made in a 147.0-mile reach between the stream-gaging station Leon River near Belton (3.2 miles downstream from Belton Dam) in Bell County and the stream-gaging station Brazos River near Bryan in Brazos County (Figure 1). The Belton gage is on the Leon River 115.9 river miles upstream from the mouth of Little River, and the Bryan gage is on the Brazos River 31.1 river miles downstream from the mouth of Little River. The air-line distance between these points is about 70 miles.

The Leon River flows southeast to the point of confluence with the Lampasas River, where Little River is formed at river mile 102. Little River flows southeast to near Cameron, then east to the Brazos River.

Two stream-gaging stations have been established between the Belton and Bryan stream-gaging stations. The streambed elevation and river-mile location for each station and the gradients between stations are given in Table 3.

Travel Time

The travel times of translatory waves from Leon River near Belton to Little River at Cameron and from Little River at Cameron to Brazos River near Bryan are shown on Figure 8 and Table 4.

Travel times for peaks were obtained by computing the additional time required for the flow at Little River and Cameron to become constant when compared to the time of rise at Belton. This additional time was then added to the time of travel for the translatory wave. The time required for the pen trace to level off became longer as the initial flow in the channel

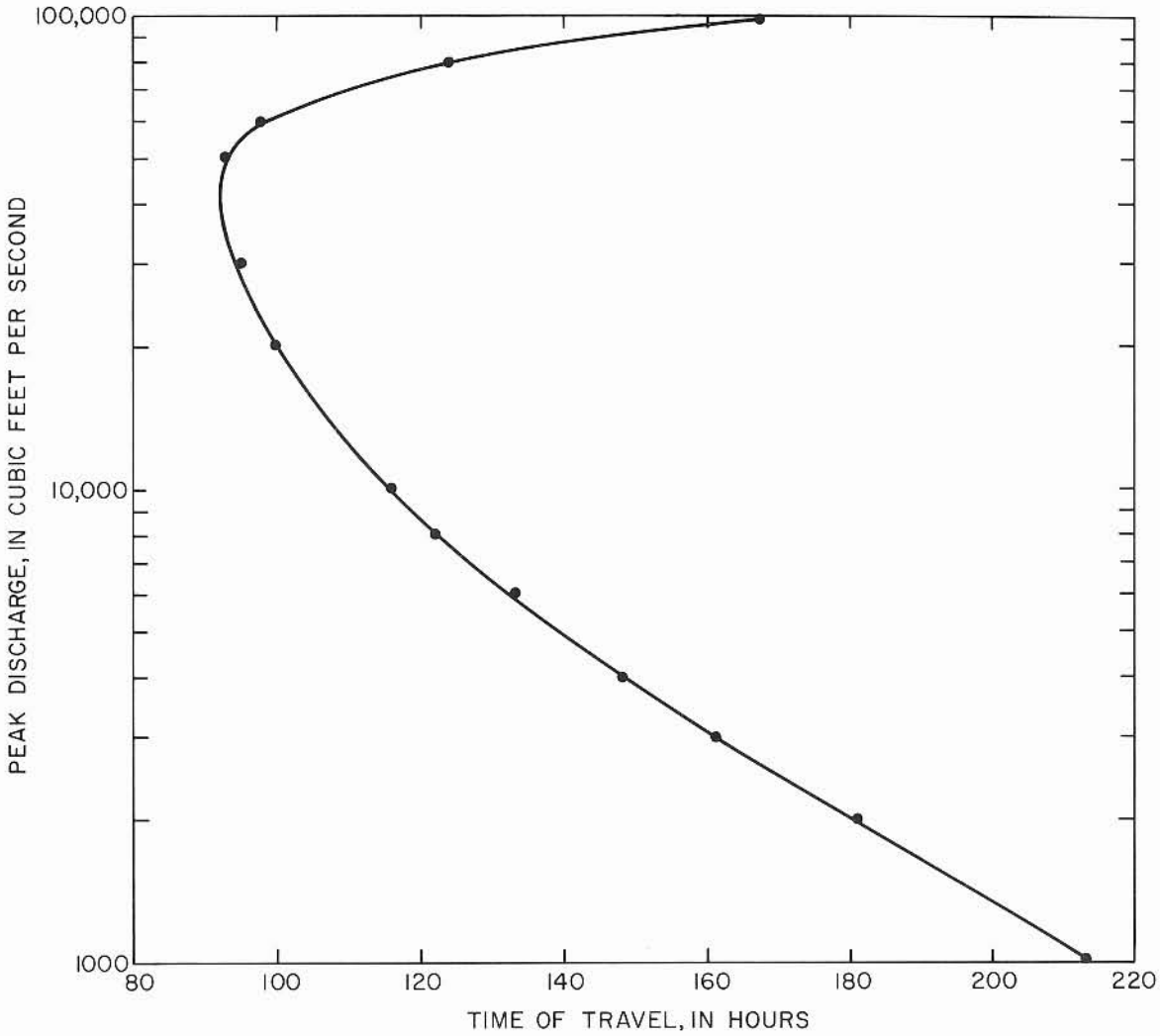


Figure 3.—Relationship of Travel Time to Peak Discharge on the Brazos River From the Whitney Gaging Station to the Richmond Gaging Station

became larger. As a result, travel time for peaks tended to be the same for all initial flows above about 60 cfs (Table 4).

The time differences of the translatory waves from Belton to Cameron for any change in flow at the Belton gage when related to the flow conditions at the Belton gage are shown on Figure 8a. Because of the scatter shown on Figure 8, a detailed study was made of the factors affecting flow in the subreaches.

Leon River near Belton to Little River at Cameron

The minimum travel times of peaks for the 82-mile reach between Leon River near Belton and Little River at Cameron varied from 57 hours for initial flow less than 15 cfs at Belton to about 42 hours for initial flow above 200 cfs at Belton (Table 4).

The gates at Belton Reservoir were opened or closed a given amount as quickly as possible. The pen trace at the Belton stream-gaging station usually started rising or falling quickly, changed in an almost vertical line, and then leveled off quickly. There was a noticeable lengthening of the time required for the stage to rise or fall as the released water moved downstream.

The time of change was determined by using the time from the beginning of change to the time when the flow became constant. The time of change at Belton was generally less than 4 hours. The change occurred in less than 5 hours 70 percent of the time, and very few changes lasted more than 8 hours, especially the time of rise.

The time of travel for translatory waves through the 19.7-mile subreach from Leon River near Belton to Little River at Little River for different initial flow conditions in the channel at Belton is shown on Figure 9 and Table 4.

The travel time of translatory waves from Belton to Cameron for different initial flow conditions in the channel at Belton are shown on Figure 10.

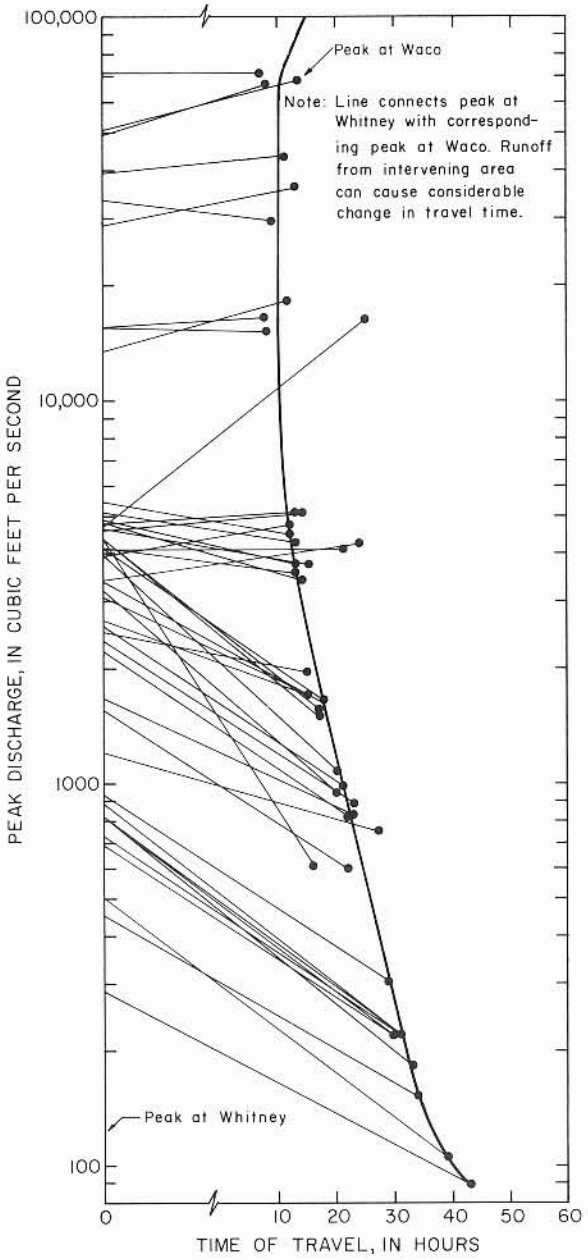


Figure 4.—Travel Time of Peak Discharge on the Brazos River From the Whitney Gaging Station to the Waco Gaging Station

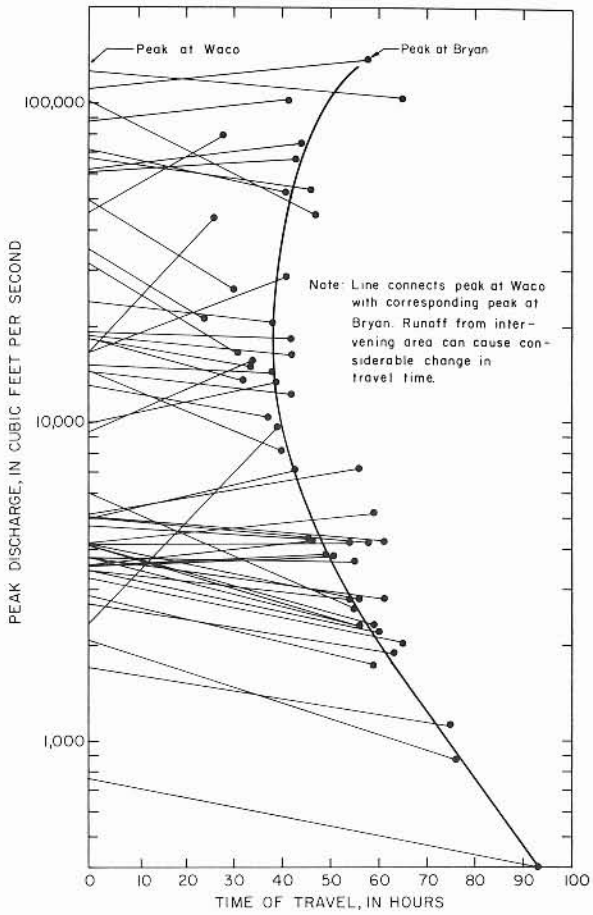


Figure 5.—Travel Time of Peak Discharge on the Brazos River From the Waco Gaging Station to the Bryan Gaging Station

The scatter of travel-time points for changes in release rates when the initial flow at Belton is less than 200 cfs is much greater than for higher initial flows (Figures 9a and 10a). Travel time is consistently longer in a channel with less initial flow. The low-flow effect begins to be less of a factor on travel time when the initial channel flow at Belton is at least 1,500 cfs (Figures 9b and 10d). Also, travel time is more consistent at greater changes in discharge.

The character of the channel is one of the major reasons for the longer time and greater spread of points in the low change of discharge range. The river bed is made up of alternating pools and riffles. At low stages, these pools and riffles cause the mean depth (d_m) to vary greatly as the wave travels downstream. Because the celerity of a wave varies in direct proportion to the square root of d_m, the riffles are in effect reducing the wave velocity. As the stage rises, d_m becomes greater and the changes in river-bed profile (which remains relatively constant) has less influence. Therefore, small changes in discharge rates in a channel with little flow causes travel time to vary widely. At about 1,500 cfs, the bed profile has little or no effect on wave velocity.

An attempt was made to relate travel time to rate of change in streamflow. No close relationship was apparent. Under the same channel conditions, a faster change would cause the translatory wave to travel downstream somewhat faster; however, initial flow in the channel had a much greater overall effect on time than did rate of change in streamflow.

Little River at Cameron to Brazos River Near Bryan

Travel time of translatory waves for the 65-mile reach between Little River at Cameron to Brazos River

Table 3.—Stream-Gaging Stations in Operation on the Leon, Little, and Brazos Rivers Reach During Period of Report

STATION NUMBER	SITE	LOCATION RIVER MILES [1]	LOCATION RIVER MILES [2]	STREAMBED ELEVATION (FEET)	GRADIENT BETWEEN STATIONS (FEET PER MILE)
8-1025	Leon River near Belton	115.9	147.0	477	
					3.83
8-1045	Little River near Little River	95.8 [3]	126.9	400	
					1.90
8-1065	Little River at Cameron	33.6 [3]	64.7	282	
					1.39
8-1090	Brazos River near Bryan	31.1	0	192	
	Study reach	—	—	—	1.94

[1] River miles were measured fromthe mouth of Little River upstream along Little River and Leon River and downstream along the Brazos River.
[2] River miles measured upstream from Brazos River near Bryan.
[3] Data furnished by U.S. Army Corps of Engineers.

near Bryan depends upon flow conditions in the channel and the flow conditions in Brazos River above Little River. A curve through the points varies from 12 hours when flow in the river at Bryan is 50,000 cfs, to 30 hours when flow is near 200 cfs (Figure 8b). These points are for travel time of translatory waves caused by troughs, beginning of rises, or recessions. Travel times for peaks vary from 30 hours at 1,000 cfs, to 22 hours at 3,500 cfs, to 25 hours for 65,000 cfs, to 34 hours for 134,000 cfs (Figure 11). The relationship of peaks at Little River at Cameron to corresponding peaks at Brazos River near Bryan are also shown on Figure 11.

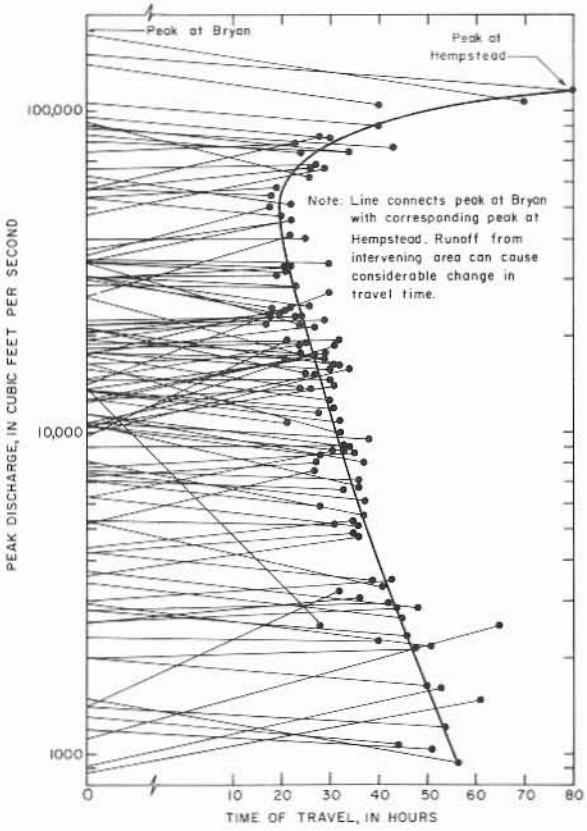


Figure 6.—Travel Time of Peak Discharge on the Brazos River From the Bryan Gaging Station to the Hempstead Gaging Station

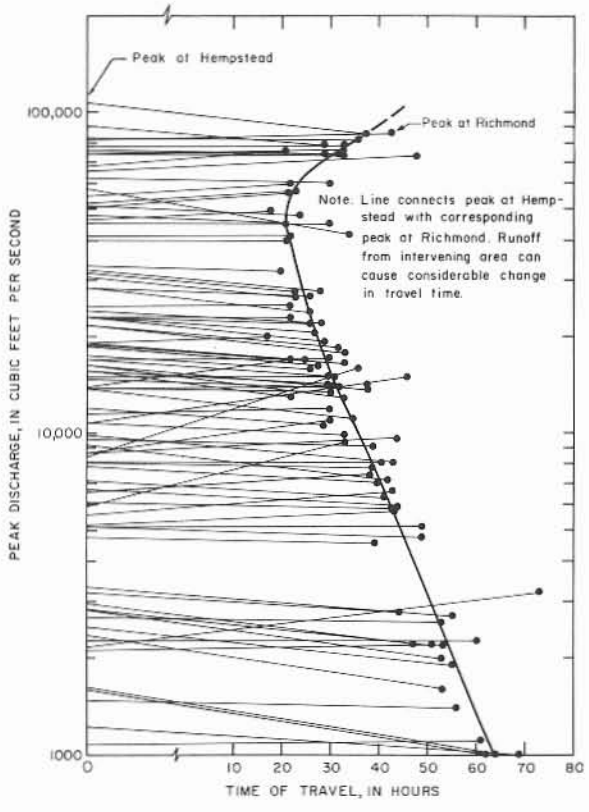


Figure 7.—Travel Time of Peak Discharge on the Brazos River From the Hempstead Gaging Station to the Richmond Gaging Station

Table 4.—Travel Times in the Subreaches From Leon River Near Belton to Little River at Cameron.

INITIAL FLOW AT BELTON (CFS)	INITIAL FLOW AT CAMERON (CFS)	CHANGE IN STREAM FLOW AT LEON RIVER NEAR BELTON	TRAVEL TIME IN HOURS 1/ BELTON TO LITTLE RIVER		BELTON TO CAMERON	
			TRANSLATORY WAVE	PEAK	TRANSLATORY WAVE	PEAK
< 15	< 200	Increased by 200 cfs or less.	14	18	52	57
< 30	< 400	Increased by 200 to 500 cfs.	12	16	44	54
<200	–	Decreased by 40 to 200 cfs.	8.5	–	36	–
< 60	about 400	Increased by 350 to 700 cfs.	8.5	12	36	50
<200	> 500	Increased by 250 to 3,000 cfs.	6.0	10	28	42
200-500	–	Changed (increased or decreased) any amount.	6.0	10	22	42
501-1,500	–	do	3.0	10	22	42
>1,500	–	do	3.0	10	20	40

1/ Hours shown are near the minimum time required for travel. See Figures 9 and 10 for spread of points.

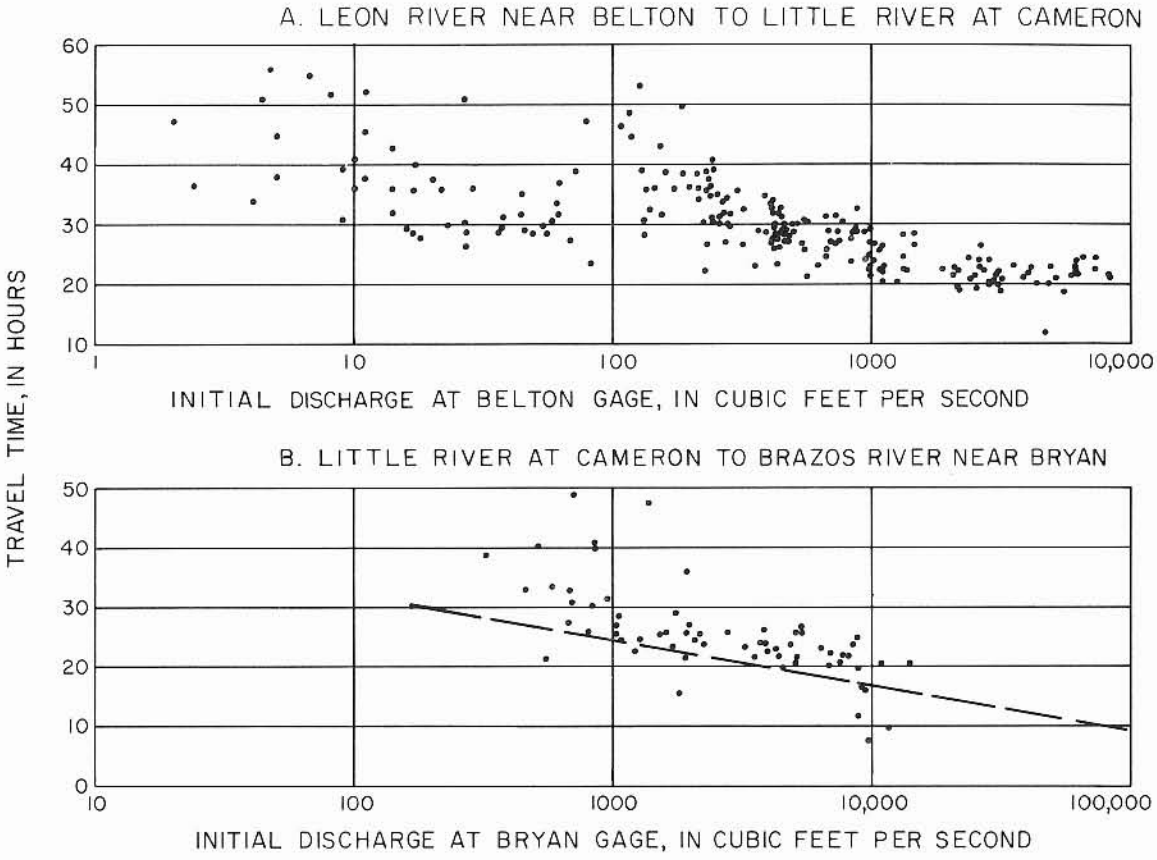


Figure 8.—Travel Time of Translatory Waves on the Leon, Little, and Brazos Rivers

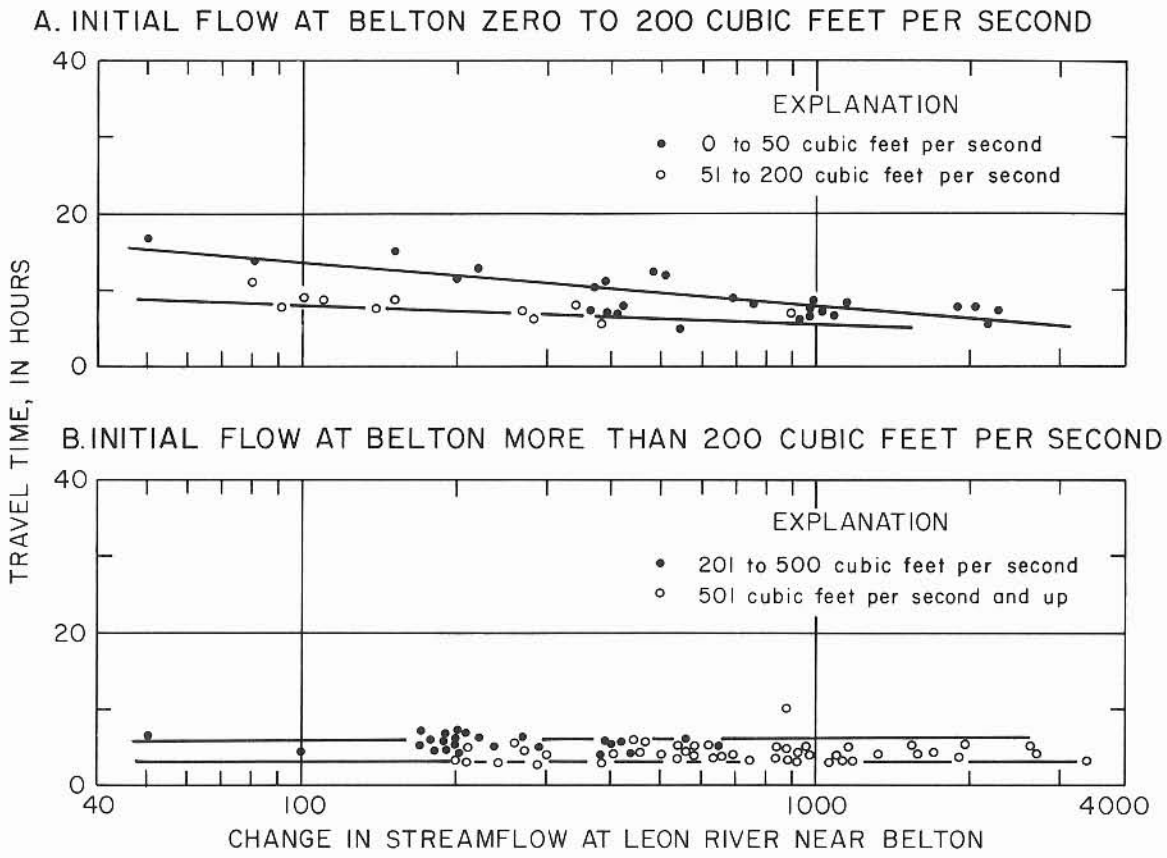


Figure 9.—Travel Time of Translatory Waves on the Leon and Little Rivers From the Belton Gaging Station to the Little River Gaging Station

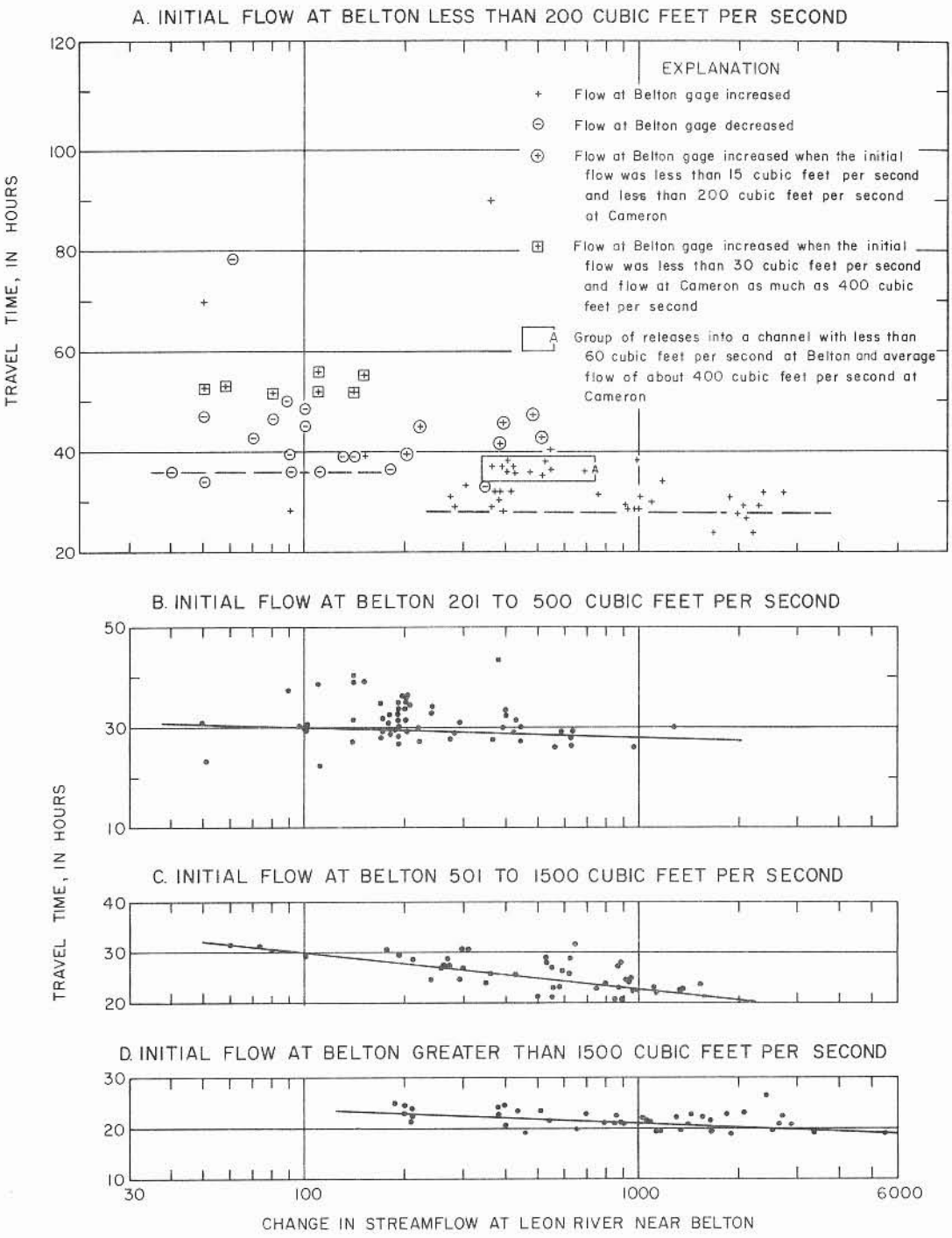


Figure 10

Travel Time of Translatory Waves on the Leon and Little Rivers From the Belton Gaging Station to the Cameron Gaging Station

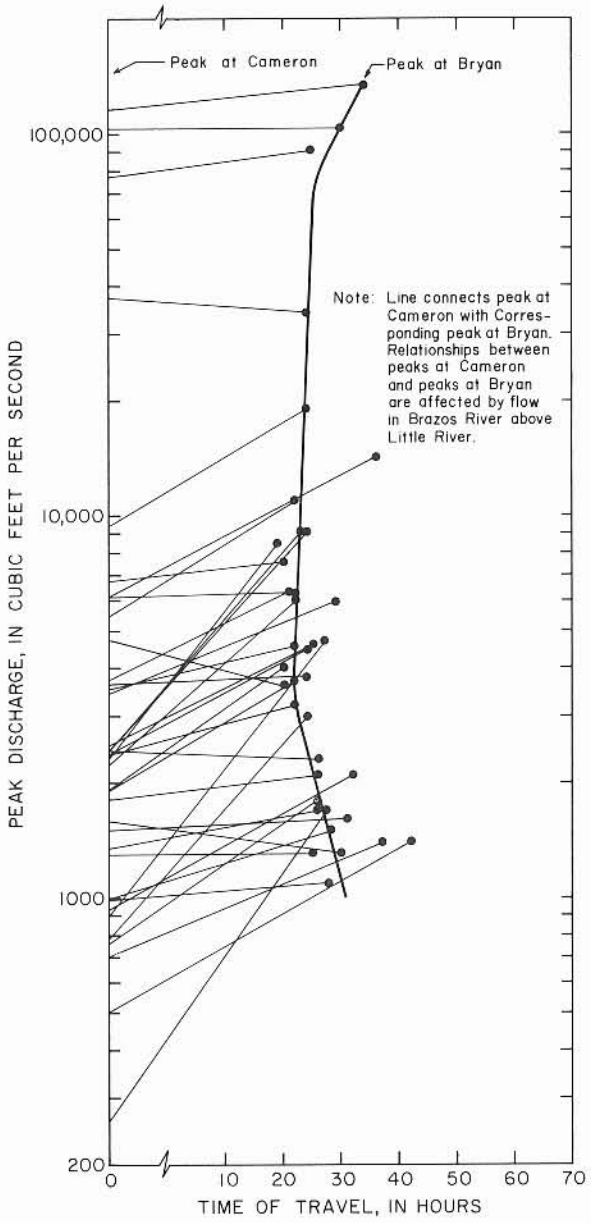


Figure 11.—Travel Time of Peak Discharge From Little River Gaging Station at Cameron to Brazos River Gaging Station Near Bryan

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