Analyses of Backwater Flooding on Long Branch at Whiteman Air Force Base, Knob Noster, Missouri

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 98–4068

Prepared in cooperation with the
U.S. DEPARTMENT OF DEFENSE
U.S. AIR FORCE
AIR COMBAT COMMAND
WHITEMAN AIR FORCE BASE

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Cover photograph: Long Branch immediately downstream from streamflow-gaging station 06907052. Photo courtesy of Scott Southern, U.S. Geological Survey.

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Rolla, Missouri
1998

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ABSTRACT

Whiteman Air Force Base in west-central Missouri has had repeated flood damage to buildings and other structures by overbank flood flows from Long Branch. A hydrologic and hydraulic study for the Long Branch Basin was conducted to define backwater flooding conditions at Whiteman Air Force Base.

A rainfall-runoff model, HEC-1, was calibrated using data collected during August 14–15 and 19, 1997, at rainfall- and streamflow-gaging stations located in the Long Branch Basin. The calibrated HEC-1 model was used to simulate peak discharges for the 100-year, 2- and 6-hour rainfall. These peak discharge data were used with a step-backwater Water-Surface PROfile (WSPRO) model to compute water-surface elevations at selected valley cross-section locations. The computed water-surface elevations were used to define the 100-year recurrence interval flood profiles for Long Branch and selected tributaries. The resulting profiles indicated that the State Highway D crossing and a pipe-arch culvert on the main channel cause constrictions to runoff from floods. A second WSPRO analysis was made without the State Highway D crossing and the pipe-arch culvert constrictions to quantify the backwater flooding from these structures.

Results of the WSPRO analyses indicated that immediately upstream from the State Highway D crossing of Long Branch about 2.7 feet of backwater may occur from a 100-year, 6-hour rainfall; backwater flooding from State Highway D was indicated to extend about 1,300 feet upstream on the main tributary. Backwater flooding from the pipe-arch culvert, on the main channel of Long Branch, was computed as about 3.2 feet immediately upstream and 0.9 foot at approximately 4,500 feet upstream from the culvert. Also, backwater flooding from State Highway D was computed as about 1.4 feet on the tributary draining the restricted-access area.

INTRODUCTION

The Long Branch Basin is 6.55 mi^2 (square miles) in west-central Missouri in Johnson County. The headwaters of Long Branch are south of Whiteman Air Force Base (fig. 1). Storm drainage along the eastern one-half of Whiteman Air Force Base property flows into the Long Branch Basin. Flooding from intense rainfall can cause Long Branch to overflow its banks, which causes damage to buildings, inundates restricted-access area, and impairs the operation of Whiteman Air Force Base. Inundation of overbank areas may be due to flows exceeding the carrying capacity of the stream channel from excess runoff and may also be due to backwater conditions from natural or man-made constrictions in a stream reach. Backwater is typically defined as water backed up or retarded

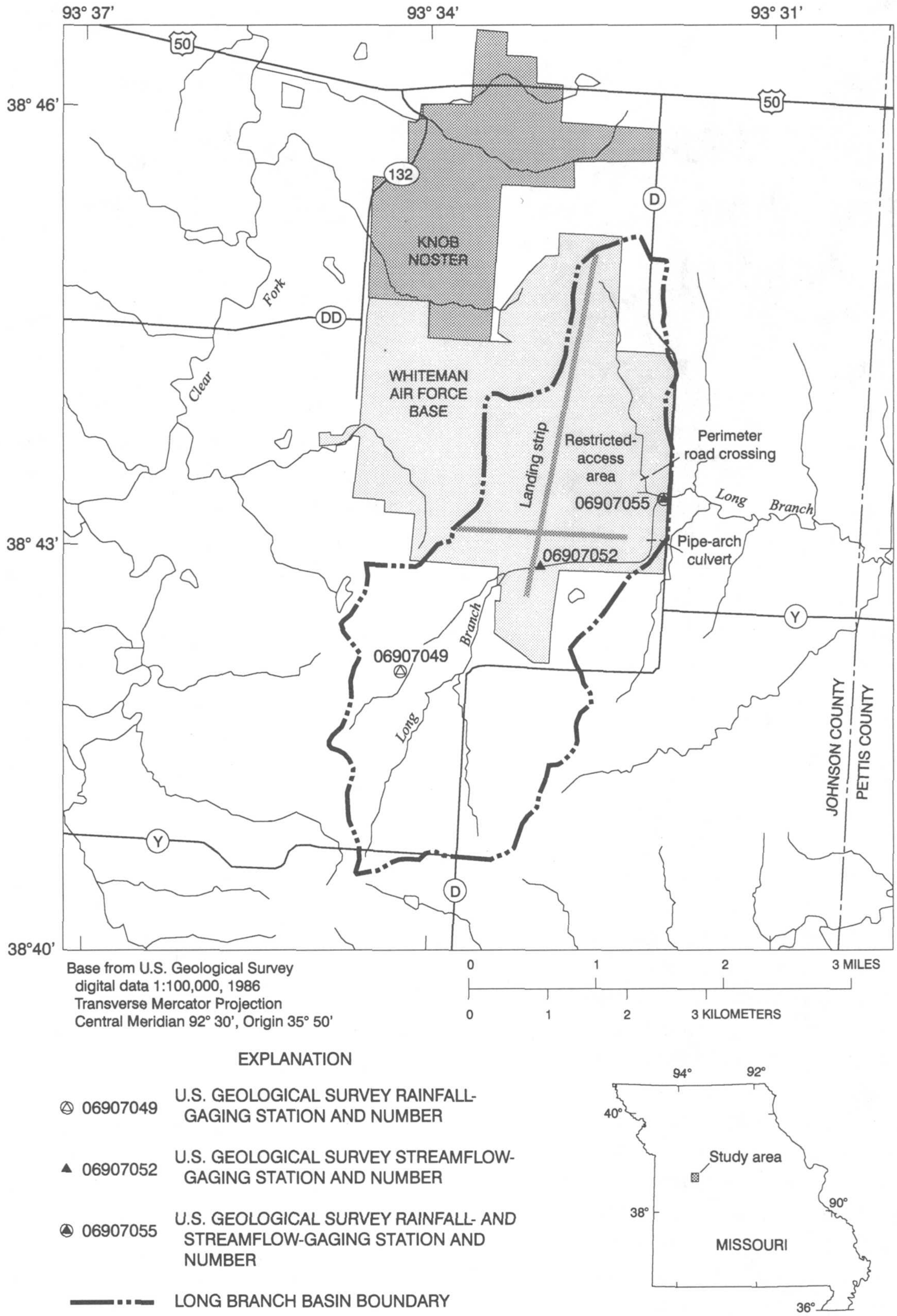

Figure 1. *Location of Long Branch Basin and selected rainfall- and streamflow-gaging stations at Whiteman Air Force Base, Knob Noster, Missouri.*

in its course as compared with its normal or natural condition of flow (Langbein and Iseri, 1960).

During 1997, the U.S. Geological Survey (USGS), in cooperation with Whiteman Air Force Base, studied the backwater flooding conditions within Long Branch Basin near the Whiteman Air Force Base property. Analyses of the flooding conditions were done in two steps. First, a rainfall-runoff model was applied to the Long Branch Basin upstream from State Highway D (the study area). Two storms were used to calibrate the rainfall-runoff model, and the 100-year, 2- and 6-hour rainfall data from Huff and Angel (1992) were used to estimate 100-year recurrence interval peak discharges (hereinafter referred to as 100-year discharges) at selected locations in the Long Branch Basin (recurrence interval is the average interval of time within which a given flood will be equaled or exceeded once). The second step was the application of a step-backwater model to the 100-year discharges obtained from the rainfall-runoff model results to determine the 100-year recurrence interval flood profiles (hereinafter referred to as 100-year flood profiles) along selected reaches of the Long Branch Basin.

This report presents analyses of backwater flooding on Long Branch at Whiteman Air Force Base. The report describes the existing hydraulic conditions, including factors causing backwater flooding conditions. Estimates are given of the possible decreases in the water-surface elevations for the 100-year flood profile by removing the State Highway D crossing and the pipe-arch culvert on the main channel of Long Branch. Results contribute to improved understanding of backwater flooding analysis.

Description of Study Area

Land use in the Long Branch Basin upstream from State Highway D (upper drainage area) is approximately one-half agricultural with large cultivated fields on nearly level slopes and smaller pasture or forested areas on the moderately sloping land surfaces. The lower one-half of the basin has a nearly level land surface and has been developed for use by Whiteman Air Force Base (fig. 1); the drainage characteristics of Long Branch have been substantially altered to control and improve runoff conditions along the base property.

The upper drainage of Long Branch enters the base property from the southwest immediately west of the landing strip (fig. 1). All stormwater runoff is routed through two large culverts located under the landing strip. Runoff from the landing strip is channeled into a combination of closed conduits and open channels. However, between the landing strip and State Highway D, Long Branch has been channelized (except for a small subreach where the channel changes directions from east to north). Land use in the tributary drainage area, east of the landing strip, primarily is agricultural. This tributary drainage system is unaltered in the headwaters, but has been channelized in its lower reach upstream from the junction with Long Branch.

Study Approach

For this study, the determination of Long Branch flood-flow characteristics required the selection of a rainfall-runoff model that can simulate discharge hydrographs resulting from known or hypothetical rainfall events. The computed peak discharges can be routed through surveyed valley cross sections to determine water-surface profiles. The water-surface profiles may then be used to identify base properties and roads that may be inundated by flooding of Long Branch.

To simulate discharge hydrographs, the rainfall-runoff model designated as HEC-1 was selected. The HEC-1 model was developed by the U.S. Army Corps of Engineers (1982) for stream hydrology computations and is widely used throughout the United States for flood peaks and volumes and drainage area analyses. To aid in calibrating the HEC-1 model, two rainfall- and two streamflow-gaging stations were installed in the Long Branch Basin (fig. 1).

Peak discharges from the HEC-1 model were routed using the step-backwater model Water-Surface PROfile (WSPRO; Shearman, 1990). The WSPRO model uses valley cross-section data and peak discharges to compute water-surface elevations at each cross section. The computed water-surface elevations, at each cross section, can be used to estimate the Long Branch water-surface profiles for both existing and modified stream conditions.

ESTIMATION OF PEAK DISCHARGES

The HEC-1 modeling technique requires the estimation of the dimensionless unit hydrograph, time of concentration, and the soil-infiltration-rate parameters for a homogeneous basin. To facilitate the estimation of these parameters, the Long Branch Basin was divided into 12 subbasins (fig. 2). Subbasins numbered 1 through 6, 8, and 12 on figure 2 were considered to be rural areas (agricultural land and natural channels); subbasins 7, 9, 10, and 11 were considered to be partially developed (urban areas) with improved drainage systems.

For each subbasin, the parameters of drainage area, time of concentration, and soil-infiltration rates were computed for use in the HEC-1 model (table 1). The drainage area for each subbasin was measured from USGS 7.5-minute topographic maps. Time of concentration, which is the time in hours between the centroid of rainfall excess and the peak discharge of the hydrograph, was estimated from the topographic maps and storm drainage maps supplied by Whiteman Air Force Base. Chow (1964) describes estimation of time of concentration based on topographic characteristics. The Soil Conservation Service (SCS) curve number method was used to estimate soil-infiltration rates. This method of relating soil loss to runoff (curve number) is a function of soil cover, land-use type, and antecedent moisture conditions (Soil Conservation Service, 1972, 1975). In the Long Branch Basin, silt loam or silty clay loam are the predominant soils, with permeability rates that range from 0.06 to 2.0 in./h (inches per hour; Allgood and Persinger, 1979). Depending on antecedent moisture, SCS curve numbers range from 60 to 95 for most modeling applications in west-central Missouri.

In this study, rainfall and discharge data were collected to calibrate the HEC-1 model. Rainfall data were collected in the upper part of the Long Branch Basin at a rainfall-gaging station (06907049) and in the lower part of the basin at a rainfall- and streamflow-gaging station (06907055). A second streamflow-gaging station was located downstream from the landing strip on the main channel of Long Branch (06907052, fig. 1).

On August 14–15, 1997, intense thunderstorms developed over the Long Branch Basin; 2.43 in. (inches) of rainfall were measured in the upper rainfall-gaging station (06907049) and 2.72 in. of rainfall were measured in the lower rainfall-gaging station (06907055). Before this rainfall, little measurable rainfall had occurred in July and August, and the soil was dry. The incremental rainfall and streamflow at each gaging station were input into the HEC-1 model for calibration. The time of concentration for each subbasin was adjusted, if necessary, to simulate the shape and timing characteristics of the observed discharge hydrographs at each streamflow-gaging station. All subbasins (fig. 2) reflected low soil moisture contents, and a SCS curve number of 64 provided the best HEC-1 simulation results (table 1). The simulated peak discharges were within 5 percent of the peak discharges at the streamflow-gaging stations; for example, the downstream gaging station (06907055) peak discharge was 291 ft^3/s (cubic feet per second) and the simulated peak discharge was 303 ft^3/s (table 2). The measured and simulated discharge hydrographs and the incremental rainfall for August 14–15, 1997, are given in figure 3.

On August 19, 1997, a second rainfall event occurred over the Long Branch Basin. The August 19 event was less intense and of longer duration than the one on August 14–15. The rainfall totals were 1.18 in. at the upstream rainfall-gaging station (06907049) and 1.19 in. at the downstream rainfall-gaging station (06907055). The soil moisture content before this storm was substantially higher than that for the August 14–15 storm; thus, a SCS curve number of 81 provides the best HEC-1 simulation results (table 1). By using slightly higher SCS curve numbers (82, 83; table 1) on the developed (urban) subbasins, the simulated discharge hydrographs more accurately represent discharge hydrographs at the streamflow-gaging stations (fig. 4). The need to increase the SCS curve numbers for the urban subbasins is because of more impervious area and less vegetation (mowed grass) as compared to the agricultural subbasins (corn and bean fields) in the upper parts of the basin. The increased impervious area decreased rainfall infiltration into the soil, and less vegetation results in less evapotranspiration, allowing for more surface runoff. The August 19 peak discharge at the downstream streamflow-gaging station (06907055) was 162 ft^3/s and the simulated peak discharge was 144 ft^3/s (table 2). The simulated peak discharge was 11 percent lower than the measured peak discharge at the downstream streamflow-gaging station and 24 percent higher at the upstream streamflow-gaging station. The increase in differences between measured and simulated peak discharges is due, in part, to simulating a smaller event with a longer duration storm and less defined flood peak.

The calibrated HEC-1 model for the Long Branch Basin can be used in conjunction with frequency and duration rainfall data to determine 100-year discharge hydrographs at selected locations within the basin. The 100-year recurrence interval rainfall totals for the 1-, 2-, 3-, 6-, and 12-hour durations (Huff and Angel, 1992) were selected for peak discharge

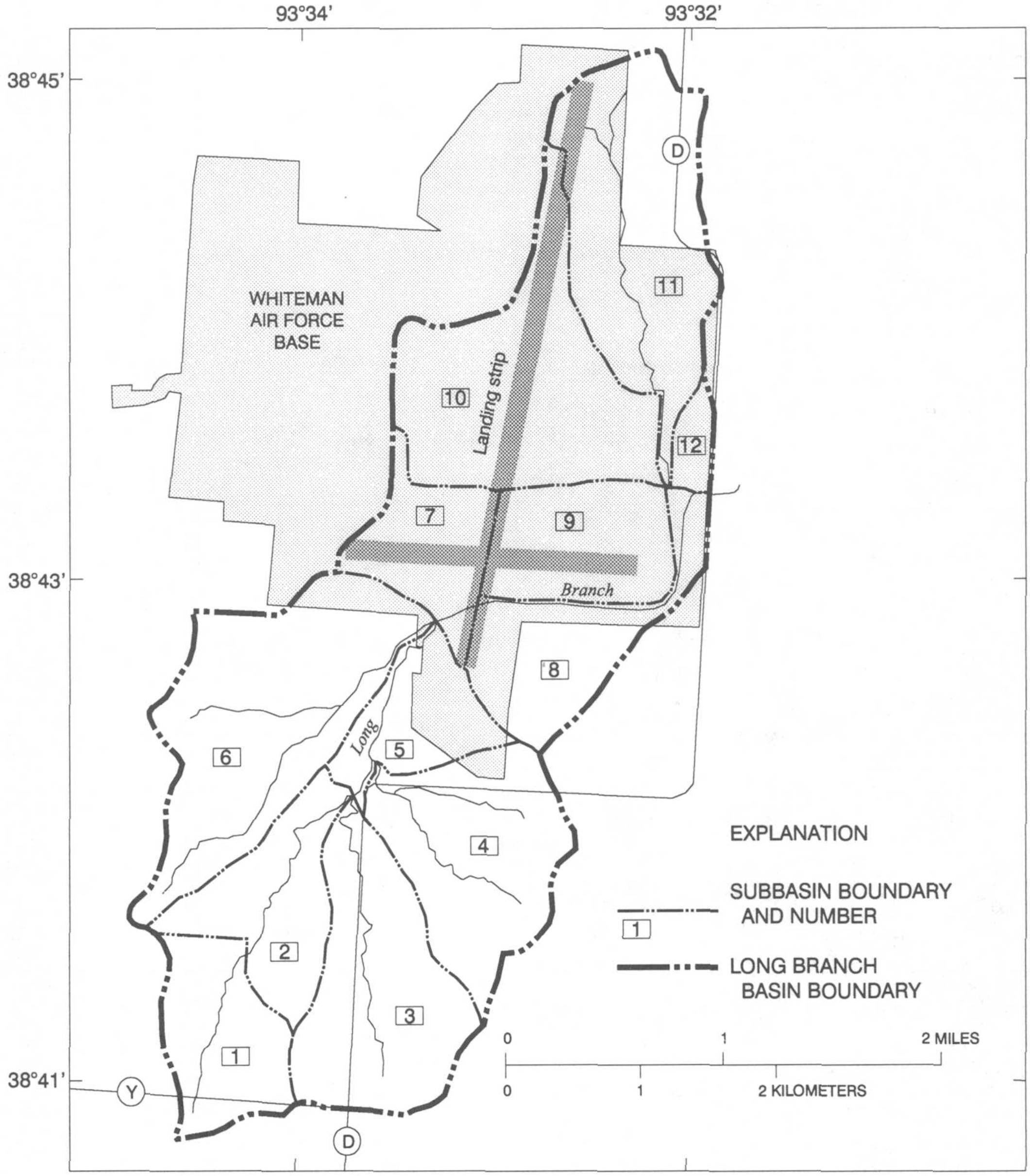

Figure 2. Drainage area subbasins used in the Long Branch Basin model at Whiteman Air Force Base, Knob Noster, Missouri.

Table 1. The HEC-1 model parameters used to simulate discharge hydrographs for August 14–15 and 19, 1997, and 100-year, 2- and 6-hour rainfall for the Long Branch Basin at Whiteman Air Force Base, Knob Noster, Missouri

[mi^2, square miles; TC, time of concentration; h, hours; SCS, Soil Conservation Service]

Subbasin number (fig. 2)	Drainage area (mi^2)	TC[1] (h)	SCS curve number		
			August 14–15, 1997	August 19, 1997	100-year, 2- and 6-hour rainfall
1	0.42	1.32	64	81	92
2	.45	1.89	64	81	92
3	.74	2.18	64	81	92
4	.70	1.64	64	81	92
5	.32	1.21	64	81	92
6	1.03	2.70	64	81	92
7	.34	.54	64	83	94
8	.48	2.60	64	81	92
9	.44	1.00	64	83	94
10	.63	1.20	64	83	94
11	.93	2.20	64	82	93
12	.07	.72	64	81	92

[1]Chow (1964, p. 21–10).

Table 2. Peak discharges for August 14–15 and 19, 1997, and 100-year, 6-hour rainfall at the two streamflow-gaging stations on Long Branch at Whiteman Air Force Base, Knob Noster, Missouri

[ft^3/s, cubic feet per second; --, no data]

Streamflow-gaging station number (fig. 1)	August 14–15, 1997		August 19, 1997		100-year, 6-hour rainfall	
	Measured (ft^3/s)	Simulated (ft^3/s)	Measured (ft^3/s)	Simulated (ft^3/s)	Measured (ft^3/s)	Simulated (ft^3/s)
06907052	182	180	66	82	--	2,760
06907055	291	303	162	144	--	4,130

analyses. These analyses indicated that the 100-year, 6-hour duration rainfall (6.00 in.) results in the highest peak discharge along the main channel of Long Branch; however, the 100-year, 2-hour duration rainfall (4.70 in.) produced the highest peak discharges along the tributary east of the landing strip. The 100-year discharge hydrographs for the streamflow-gaging stations are shown in figure 5. The simulated 100-year peak discharge at the downstream-gaging station (06907055) was 4,130 ft^3/s (table 2).

To support the applicability of the Long Branch HEC-1 model results, the simulated peak discharge from a 100-year, 6-hour rainfall at State Highway D for streamflow-gaging station 06907055 was compared to the 100-year discharge computed from flood-frequency regression equations by Becker (1986) and

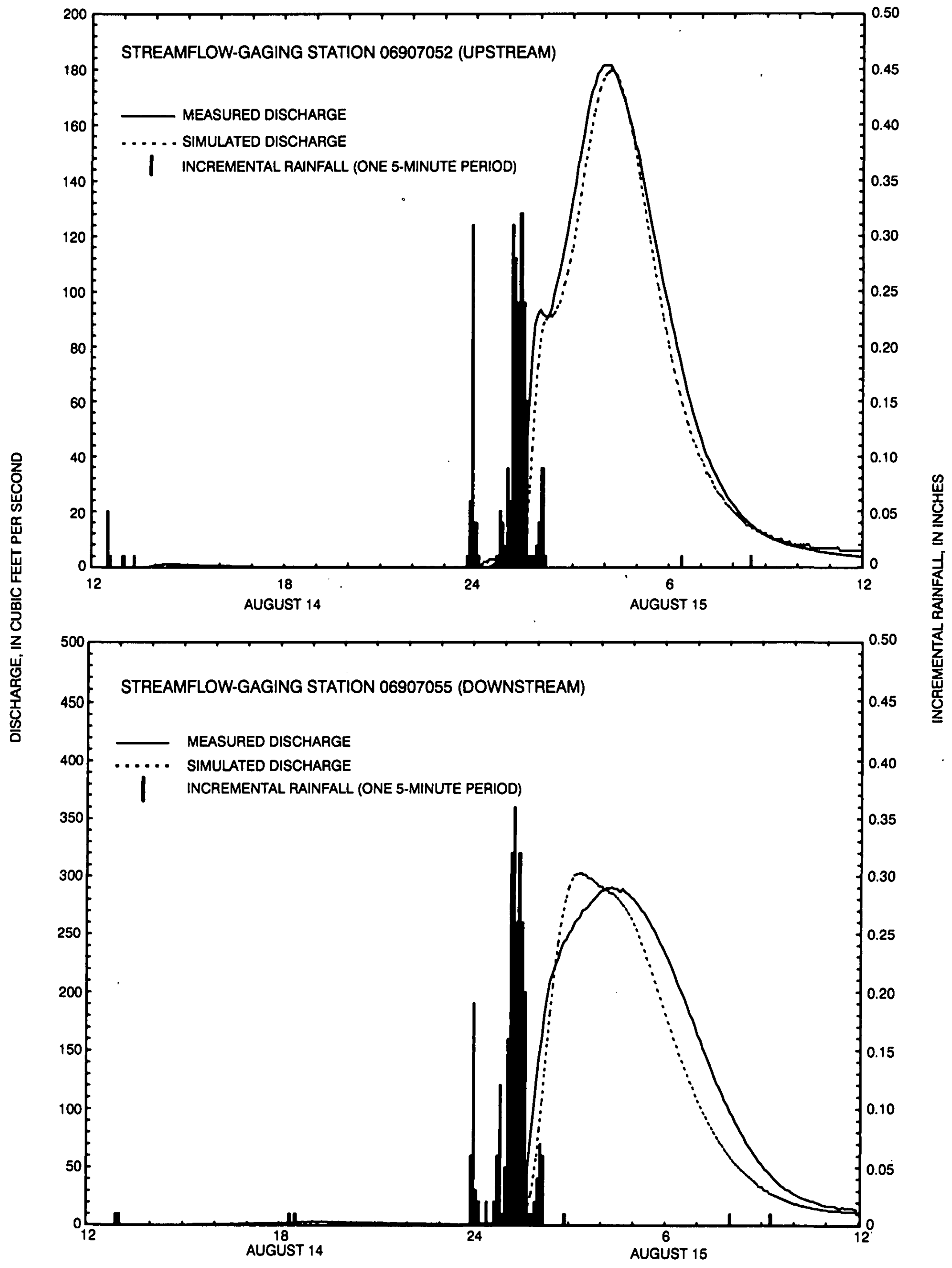

Figure 3. Discharge hydrographs and rainfall distribution for August 14–15, 1997, on Long Branch at Whiteman Air Force Base, Knob Noster, Missouri.

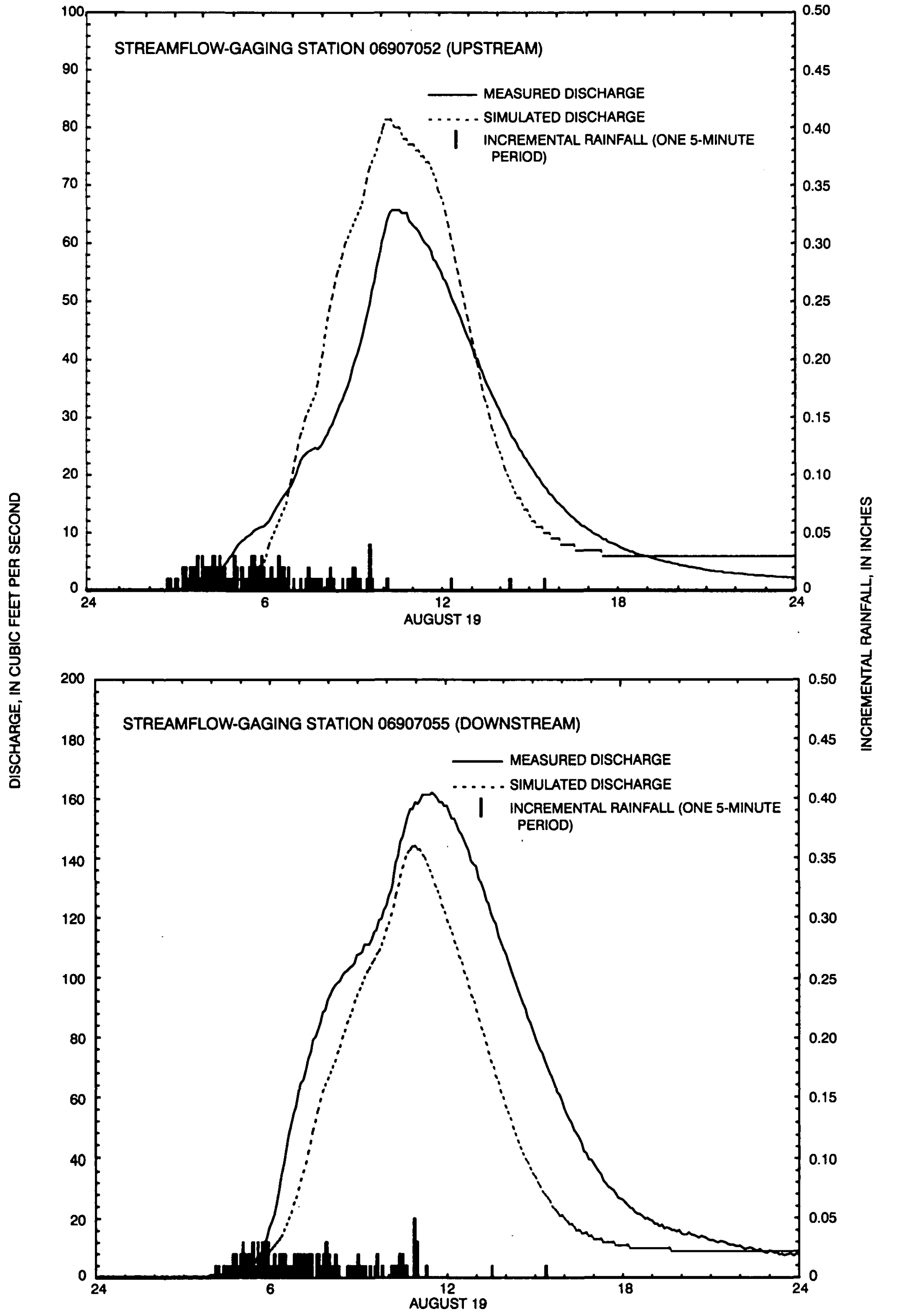

Figure 4. Discharge hydrographs and rainfall distribution for August 19, 1997, on Long Branch at Whiteman Air Force Base, Knob Noster, Missouri.

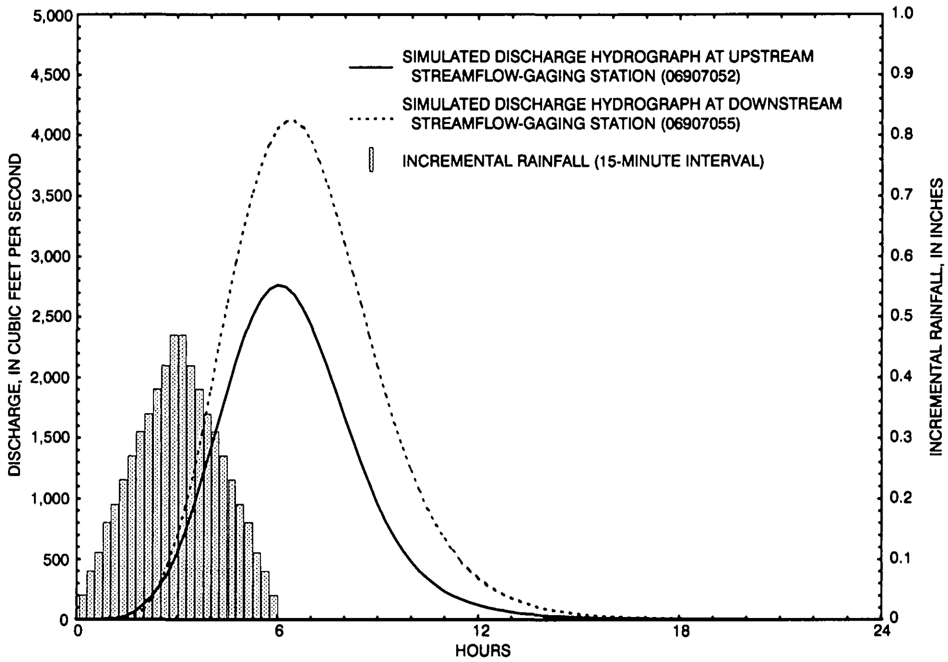

Figure 5. Discharge hydrographs and rainfall distribution for the 100-year, 6-hour rainfall on Long Branch at Whiteman Air Force Base, Knob Noster, Missouri.

Alexander and Wilson (1995). Becker developed a set of urban regression equations using basin parameters of drainage area and impervious area, whereas Alexander and Wilson developed a set of rural regression equations using drainage area and basin slope. The Long Branch drainage area is 6.55 mi^2, impervious area is 2 percent, and basin slope is 13.8 ft/mi (feet per mile). Consequently, the discharge for the 100-year urban regression equation was 5,100 ft^3/s, and the discharge for the 100-year rural regression equation was 3,180 ft^3/s (fig. 6). Because, the Long Branch Basin has some urbanization in its lower part, the simulated 100-year peak discharge of 4,130 ft^3/s above State Highway D is reasonable when compared with the discharges from the urban and rural 100-year regression equations.

ANALYSES OF BACKWATER FLOODING

Two possible causes of backwater flooding at Whiteman Air Force Base are the State Highway D crossing of Long Branch and a pipe-arch culvert about 2,400 ft (feet) upstream from State Highway D. The determination of 100-year water-surface elevations for Long Branch and its tributaries with and without these structures is necessary to evaluate backwater flooding conditions within and along base property.

Onsite data consisting of valley cross sections and structure geometries were collected by transit surveys, and valley-section roughness coefficients (Manning's n) were selected for use in WSPRO computations for the Long Branch main channel and tributary east of the landing strip. Valley cross sections 1 to 21 are on the Long Branch main channel and cross sections 22 to 30 are on the tributary drainage (fig. 7). Because tributary drainage above valley cross section 30 flows through a restricted-access area, valley cross-section data were not obtained any farther upstream in subbasins 9 and 10 (fig. 2). Long Branch has no downstream natural or man-made contraction of flow that would cause substantial backwater at the State Highway D crossing. Therefore, it was assumed that slope-conveyance methodology would be adequate for esti-

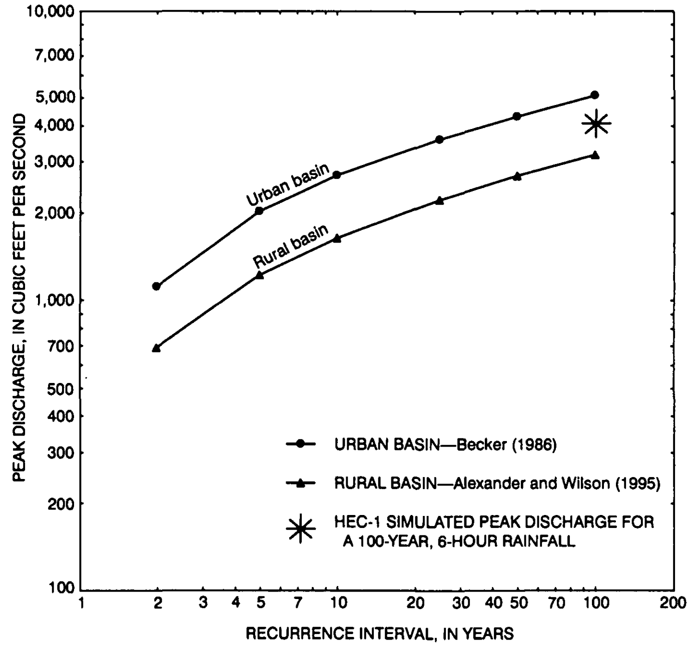

Figure 6. Regression-estimated peak discharge curves and simulated peak discharge for the 100-year, 6-hour rainfall on Long Branch at State Highway D at Whiteman Air Force Base, Knob Noster, Missouri.

mating the starting water-surface elevation for the 100-year flood-profile computations.

Because water-surface elevations at a cross section are a function of energy losses and peak discharge between cross sections, two WSPRO analyses were made to determine the maximum water-surface elevation at each cross section using the peak discharges determined from the HEC-1 model. The peak discharges for the 100-year, 2- and 6-hour rainfall (see Peak Discharges section) were analyzed for existing (1997) conditions. The highest water-surface elevation determined at each cross section was used to define the 100-year flood profile. Also, a WSPRO analysis was made with both State Highway D crossing and the pipe-arch culvert removed (table 3). Graphs of the maximum computed water-surface elevations are shown in figures 8 through 10.

For this study, backwater was computed as the difference between water-surface elevations determined from two WSPRO analyses. The first analysis included the State Highway D crossing and the pipe-arch culvert and the other excluded these hydraulic structures. The computed backwater flooding along the main channel upstream from State Highway D was about 2.7 ft at cross section 4 and decreased to 0.9 and 0.7 ft at cross sections 5 and 6. At cross section 12, the computed backwater flooding was about 3.2 ft, at the pipe-arch culvert. The effect of the pipe-arch culvert on water-surface elevations extended approximately 4,500 ft upstream (fig. 8) to the upstream streamflow-gaging station (06907052).

Backwater flooding on the main tributary, draining subbasin 11 (fig. 2), occurred for about 1,300 ft upstream from its junction with the main channel (fig. 9). The backwater flooding from State Highway D ended at the downstream side of the perimeter road embankment at cross section 24 (1.4 ft of backwater at cross section 24). Upstream from the perimeter road (cross section 25), the main tributary is deeply channelized with high embankments designed to convey large quantities of runoff. A second tributary, draining the restricted-access area, (subbasins 7, 9, and 10; fig. 2) was affected by backwater flooding from State Highway D. About 1.4 ft of backwater flooding occurred at the downstream end of the restricted-access area (cross section 30, fig. 10); therefore, water-surface elevations

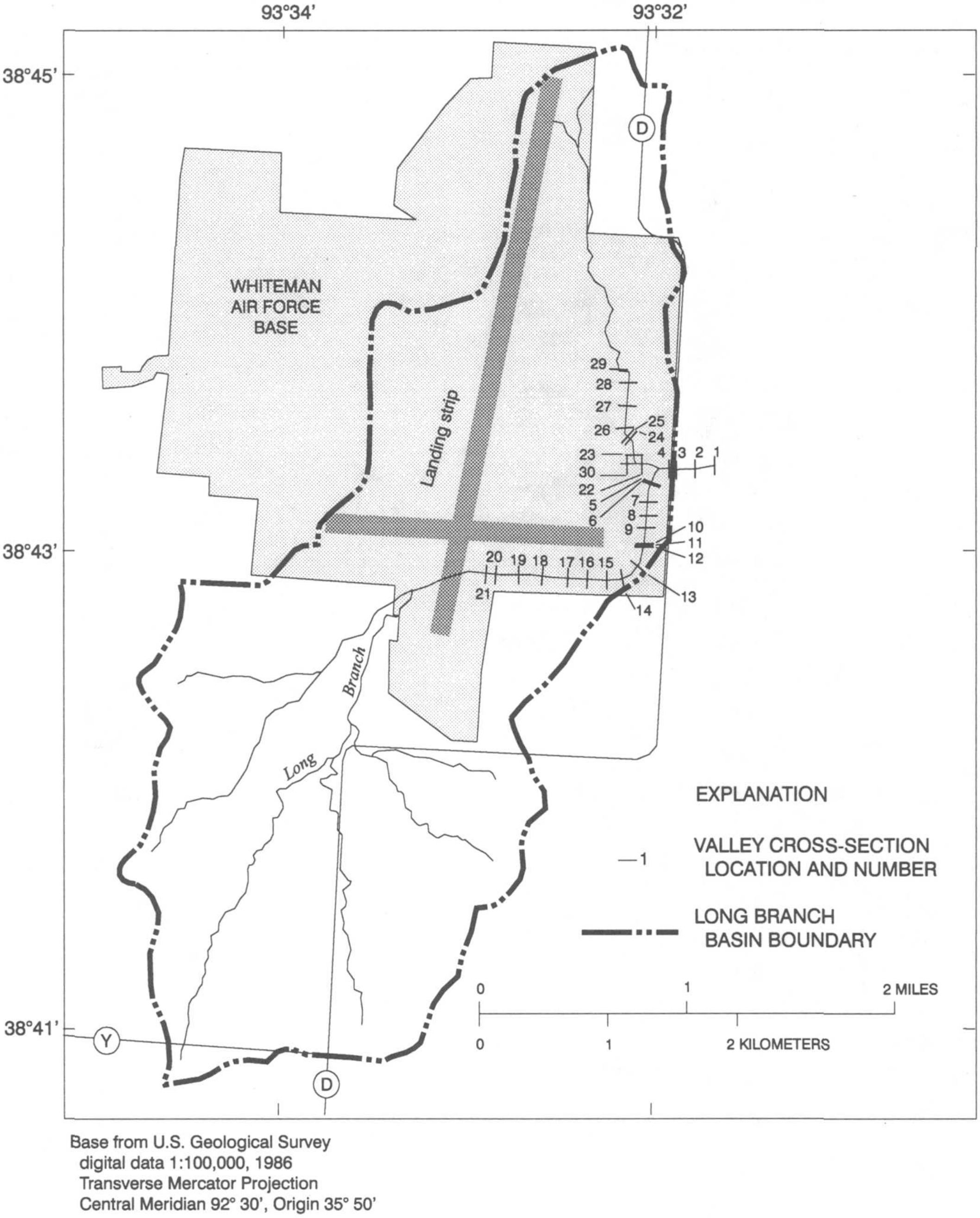

Figure 7. Location of the valley cross sections used to determine flood profiles at Whiteman Air Force Base, Knob Noster, Missouri.

Table 3. Computed 100-year water-surface elevations for Long Branch and selected tributaries at Whiteman Air Force Base, Knob Noster, Missouri

[ft, feet; ft^3/s, cubic feet per second; h, hours; --, not applicable]

Valley cross-section number (fig. 7)	Water-surface elevations[1], existing conditions (ft)	Water-surface elevations[1], with State Highway D and pipe-arch culvert removed (ft)	Backwater from State Highway D and pipe-arch culvert (ft)	Valley cross-section discharge (ft^3/s)	100-year rainfall duration (h)
1	817.0	817.0	--	4,130	6
2	817.9	817.9	--	4,130	6
3	818.9	818.9	--	4,130	6
4	822.0	819.3	2.7	4,130	6
5	822.4	821.5	.9	2,820	6
6	822.4	821.7	.7	2,820	6
7	824.8	825.1	--	2,820	6
8	826.8	827.0	--	2,820	6
9	827.3	827.5	--	2,820	6
10	828.0	828.2	--	2,820	6
11	828.2	828.4	--	2,820	6
12	831.8	828.6	3.2	2,820	6
13	831.9	828.9	3.0	2,820	6
14	832.1	829.3	2.8	2,820	6
15	832.4	830.0	2.4	2,820	6
16	832.8	830.8	2.0	2,820	6
17	833.2	831.6	1.6	2,820	6
18	833.6	832.2	1.4	2,820	6
19	834.0	832.9	1.1	2,820	6
20	834.4	833.5	.9	2,820	6
21	834.6	833.7	.9	2,820	6
22	822.2	820.7	1.5	1,320	6
23	822.2	820.8	1.4	683	6
24	822.3	820.9	1.4	683	6
25	823.1	823.0	--	747	2
26	823.2	823.0	--	747	2
27	824.0	824.0	--	747	2
28	825.9	825.8	--	747	2
29	827.1	827.1	--	747	2
30	822.2	820.8	1.4	634	6

[1] Datum is North American Vertical Datum of 1988, mathematical least squares general adjustment of the vertical control portion of the National Geodetic Reference System.

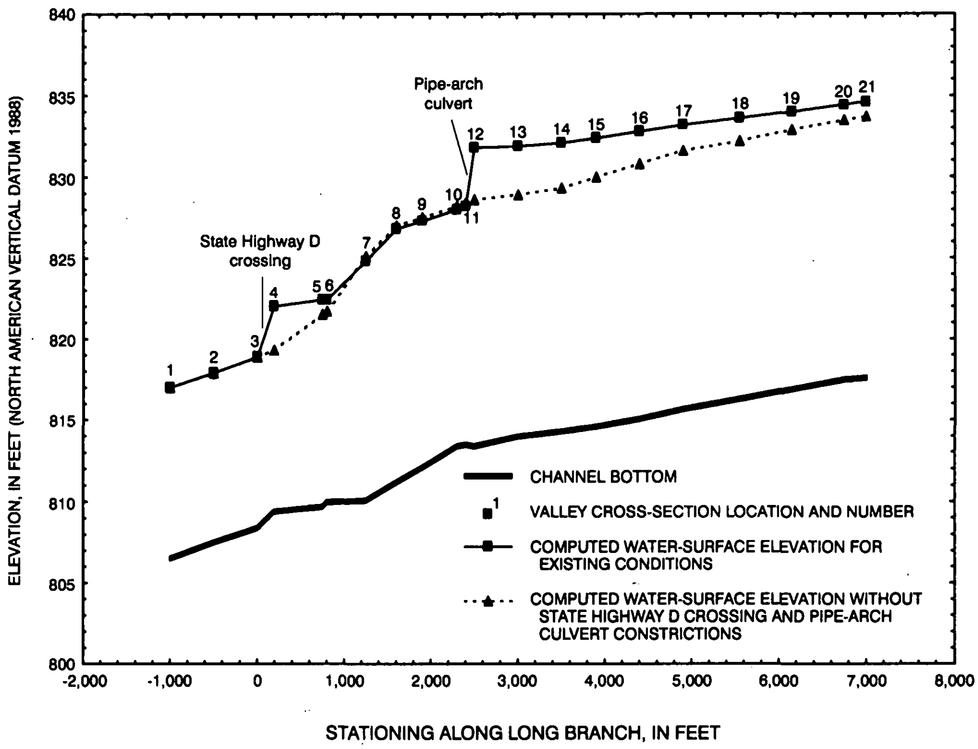

Figure 8. Computed water-surface elevations for the 100-year flood profile on Long Branch at Whiteman Air Force Base, Knob Noster, Missouri.

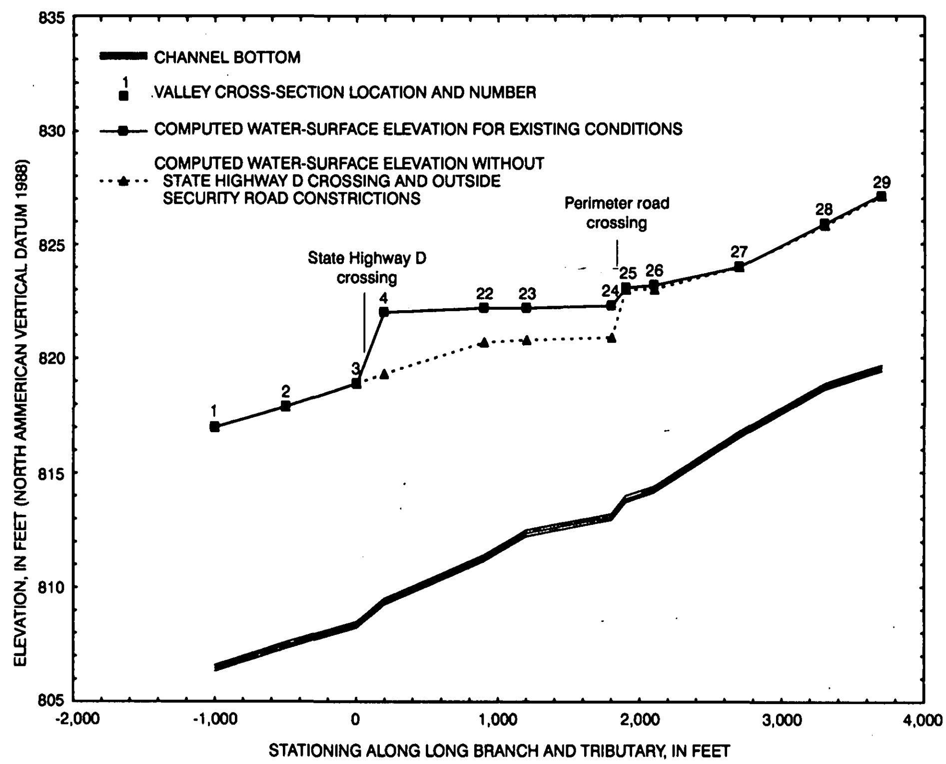

Figure 9. Computed water-surface elevations for the 100-year flood profile on the Long Branch tributary from subbasin 11 at Whiteman Air Force Base, Knob Noster, Missouri.

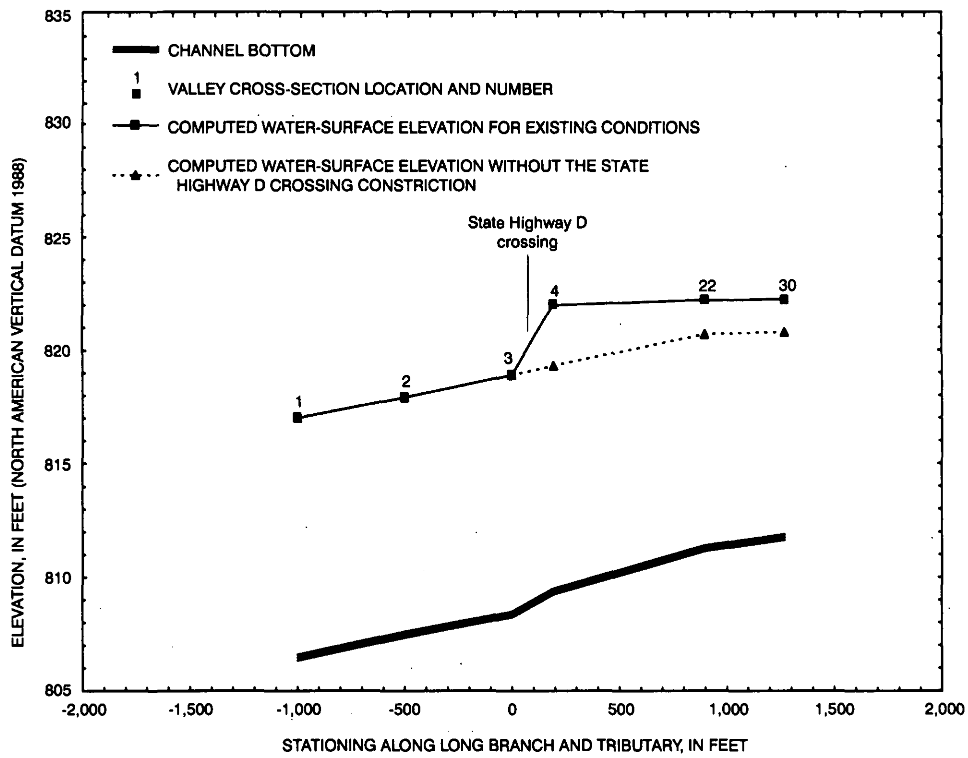

Figure 10. Computed water-surface elevations for the 100-year flood profile on the Long Branch tributary from subbasins 9 and 10 at Whiteman Air Force Base, Knob Noster, Missouri.

inside the restricted-access area are affected by backwater conditions from State Highway D.

SUMMARY

Whiteman Air Force Base is inundated by floodwaters from Long Branch during intense rainfall. To evaluate the flooding, a two-step process was used to analyze the hydrologic and hydraulic characteristics of Long Branch Basin upstream from State Highway D in the vicinity of Whiteman Air Force Base property. First, a rainfall-runoff model, HEC-1, was used to simulate 100-year discharges at selected stream locations. Second, a step-backwater Water-Surface PROfile (WSPRO) model was used to route these 100-year discharges through selected reaches for determination of the Long Branch 100-year flood profile. The model was also used to evaluate the backwater flooding that results from channel constrictions (State Highway D crossing and pipe-arch culvert) along the Long Branch main channel.

The Long Branch Basin was divided into 12 subbasins for the HEC-1 model. The time of concentration and soil-infiltration-rate parameters for the 12 subbasins were determined by collecting data at two rainfall- and two streamflow-gaging stations within the Long Branch Basin. During the study, two storms occurred—one on August 14–15, 1997, and the other on August 19, 1997. Using data from these storms to calibrate the HEC-1 model, the 100-year, 1-, 2-, 3-, 6-, and 12-hour duration rainfall data were used to determine which rainfall duration produced the peak discharges on Long Branch. The HEC-1 model results indicated the 100-year, 2- and 6-hour rainfalls caused the highest peak discharges on the tributary east of the landing strip and the Long Branch main channel, respectively.

Water-surface elevations were computed by the WSPRO model using the HEC-1 peak discharges. Valley cross sections were defined and roughness coefficients were selected onsite. The water-surface elevations at each cross section were used to define the 100-year profile for Long Branch and its tributary. Analysis of these 100-year profiles indicate that State Highway D crossing and the pipe-arch culvert on Long Branch main channel cause backwater flooding near or within the Whiteman Air Force Base property. Water-surface elevations at each cross section were computed without the State Highway D crossing and pipe-arch culvert structures to quantify possible backwater flooding upstream from these structures. About 2.7 feet of backwater was computed immediately upstream from State Highway D, and about 3.2 feet of backwater was computed immediately upstream from the pipe-arch culvert. The main tributary was affected by about 1.4 feet of computed backwater flooding from State Highway D, for a distance of approximately 1,300 feet upstream from its junction with the main channel. Also, computed backwater flooding along the tributary draining the restricted-access area was about 1.4 feet.

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