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SENSITIVITY OF OUTFLOW PEAKS AND FLOOD STAGES TO THE SELECTION OF DAM BREACH PARAMETERS AND SIMULATION MODELS

(DAM SAFETY PROGRAM)

by

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Abstract; Important breach parameters were identified and their ranges were estimated from a detailed study of historical earthdam failures due to overtopping. The U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) and the National Weather Service (NWS) dam breach models were chosen for evaluation and simulation. Both models use similar input data and breach descriptions, but the HEC uses hydrologic routing method (Modified Puls), whereas the NWS uses the St. Venant equations for routing. Information on 8 dams in Illinois was taken from the Corps of Engineers inspection reports, and surveyed cross sections of the downstream channels were supplied by the Division of Water Resources of the Illinois Department of Transportation. Various combinations of breach parameters (failure time, TF; depth of overtopping, hf; and breach size, B) were used for breach simulations by both methods with the 1.00-, 0.50-, and 0.25-PMF (probable maximum flood) inflow hydrographs. In general, the flood stage profiles predicted by the NWS were smoother and more reasonable than those predicted by the HEC. For channels with relatively steep slopes, the methods compared fairly well, whereas for the channels with mild slope, the HEC model often predicted oscillating, erratic flood stages, mainly due to its inability to route flood waves satisfactorily in non-prismatic channels. The breach outflow peaks are affected significantly by B but less so by hf. The ratio of outflow peak to inflow peak and the effect of TF on outflow decrease as the drainage area above the dam and impounded storage increase. Flood stage profiles predicted with cross sections taken from 7.5' maps compared favorably with those predicted using surveyed cross sections. For the range of breach parameters studied, the range of outflow peaks and flood stages downstream from the dam can be determined for regulatory and disaster prevention measures.

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INTRODUCTION

In August 1972, the 92nd Congress of the United States authorized the National Dam Safety Program by legislating Public Law 92-367 — The National Dam Inspection Act. This Act authorized the Secretary of the Army, acting through the Chief of Engineers, to initiate an inventory program for all dams satisfying certain size criteria, and a safety inspection of all non-federal dams in the United States that are classified as having a high hazard potential or significant hazard potential because of the existing dam conditions. A dam is defined as an impounding structure with 25 feet or more height above the streambed or with 50 or more acre-feet (ac-ft) of storage capacity at maximum water storage elevation. The Act does not apply to structures less than 6 ft high or with less than 15 ac-ft storage capacity (COE, 1980a).

The three hazards classifications considered are:

1. High hazard potential: Dam breach may cause flooding and serious damage to occupied dwellings located in the floodplain. It presents a high potential for loss of human life.
2. Significant hazard potential: Dam failure presents the possibility of loss of human life and damage to structures and facilities in the floodplain. A breach may result in substantial economic loss.
3. Low hazard potential: Dam failure has a remote possibility of loss of life, and damage to structures and facilities in the floodplain would be minor.

The Corps of Engineers (1980a) lists 920 federal and non-federal dams in Illinois meeting or exceeding the size criteria as set forth in the U.S.

Public Law 92-367. A summary of these dams by hazard potential classification, and type of dam is given below.

A. <u>Hazard Potential Classification</u>

Classification	No. of dams	%
High hazard potential	122	13
Significant hazard potential	241	26
Low hazard potential	557	61

B. <u>Type of Dam Construction</u>

Type	No. of dams	%
Earth	890	96
Gravity	23	3
Rockfilled	2	<1
Arch	1	<1
Other	4	<1

It is evident that 96% of the 920 dams inventoried are earth dams, for which the dominant causes of failure are overtopping and piping and, to a lesser extent, unsatisfactory construction and maintenance and foundation problems.

The failure by overtopping of the dams during very high inflow conditions results mainly from inadequate spillway capacity and insufficient freeboard. The Division of Water Resources of the Illinois Department of Transportation, acting on behalf of the Corps of Engineers, as well as the Corps of Engineers, have been preparing inspection reports or having them prepared by consultants and engineering companies for high-hazard-category dams. The inspection report contains the project description; engineering data for construction, operation, and maintenance; results of visual inspection; hydraulic and hydrologic evaluation of the spillway and outlet works for different inflow flood hydrographs; project plan and downstream channel; and other pertinent information.

Objectives of This Study

The objectives of this study are: 1) evaluation of breach parameters from a literature survey of historical earthdam failures, 2) evaluation and comparison of the theoretical and practical merits of two dam-break models, and 3) sensitivity analysis of important breach parameters.

The literature survey included a detailed review of historical earthdam failures due to overtopping, and identification of important breach parameters and their range. These were then used to assess the variation in the peak flow after a dam break and in the maximum flood stages downstream.

The National Weather Service (NWS) and the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) dam-break models were evaluated and compared with regard to their theoretical and practical merits. The HEC model uses the Modified Puls (MP) method for the routing of a flood wave due to dam breach. The MP method is based on the continuity equation and therefore neglects all dynamic aspects of the flood wave. The NWS model bases its routing method on the Saint venant equations and any assumptions implicit in those equations.

Eight earth dams (figure 1) were selected for breach simulation. The basic data on the dams were taken from Inspection Reports, National Dam Safety Program, published by the Department of the Army, Chicago District, Corps of Engineers (COE). The name of the dam, height of the dam above the streambed, storage at normal pool level, and peak of the probable maximum flood (PMF) inflow hydrograph are given on page 5. The information on size

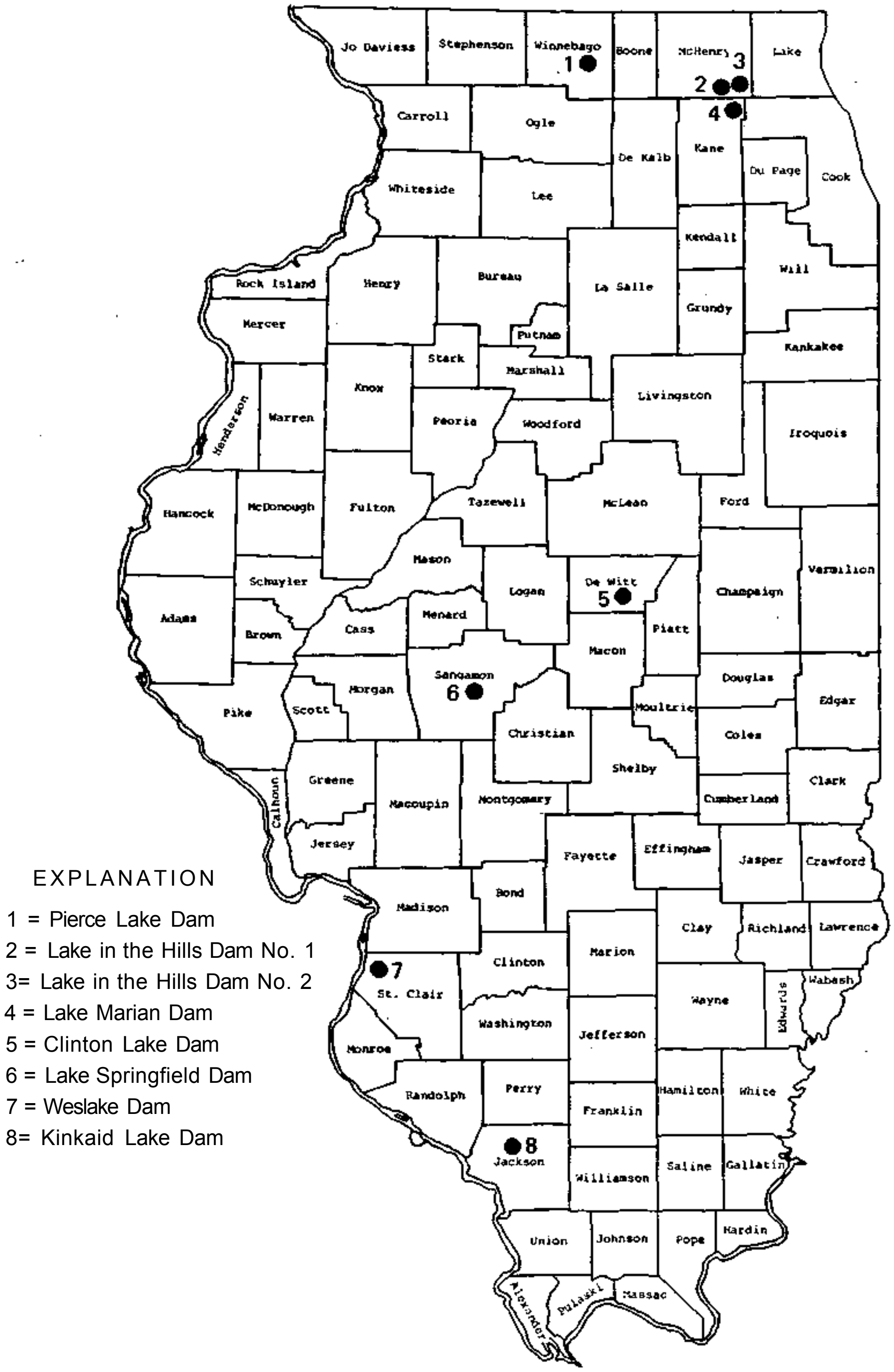

Figure 1. Location of 8 study dams

(S = small, IM = intermediate, L = large) as well as hazard (H = high) categories, as given in the Inspection Reports, is also included.

	Height of dam h_d, ft	Storage S, ac ft	Peak of PMF Q, cfs	COE Size	COE Hazard
Pierce Lake Dam	46.0	2,660	30,500	IM	H
Lake in the Hills Dam #1	40.0	598	8,400	IM	H
Lake in the Hills Dam #2	14.5	78.9	11,318	S	H
Lake Marian Dam	50.0	151	3,164	IM	H
Clinton Lake Dam	65.0	74,200	150,200	L	H
Lake Springfield Dam	48.0	53,504	121,364	L	H
Weslake Dam	48.0	224	1,243	IM	H
Kinkaid Lake Dam	92.0	78,500	71,000	L	H

A complete set of simulations on a single dam consists of the following combinations:

1) Routing of inflow hydrographs for PMF, 0.5 PMF, and 0.25 PMF floods without the existence of the reservoir.

2) Routing of the inflow hydrographs through the reservoir, but with the dam intact, even if overtopped.

3) Routing of inflow hydrographs with the failure of the dam, using 8 combinations of breach parameters.

In addition to the simulations with the HEC and the NWS models, peak outflows were calculated using the SCS procedure, which determines the peak outflow with an empirical equation relating the peak outflow to the height of the dam. The routing method of the SCS is not used for comparative purposes, since it does not develop the actual breach hydrograph, but instead assumes its shape depending on the flow conditions.

Six of the 8 dams failed by overtopping with the PMF or probable maximum flood hydrograph (and 4 of the 6 failed with 0.50 and 0.25 PMF also). Two dams, Clinton Lake Dam and Kinkaid Lake Dam, were not overtopped by the PMF. Their failure was simulated by considering a piping failure.

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DAM FAILURES — A LITERATURE SURVEY

The objectives of the literature survey are: 1) to locate, evaluate, and select references on historical breaches and failures of earth dams because of overtopping; 2) to provide a brief description of each selected dam and its failure; 3) to study the relationships between the reservoir, dam, and breach parameters; and 4) to develop a set and range of dam breach parameters for detailed breach and sensitivity analyses. Several comprehensive bibliographies are available on dam failures. A few of the more important ones are: Middlebrooks (1953), Gruner (1963, 1964), Babb and Mermel (1963), ICOLD (1973), ASCE (1975), and Jansen (1980). Other sources are engineering magazines, such as Engineering News (EN), Engineering Records (ER), and Engineering News Record (ENR), and ICOLD or International Commission on Large Dams. Of about 700-800 references on dam incidents, approximately 150 were investigated in detail. Because this investigation was concerned with overtopping of earth dams and embankments, only the dams meeting this goal are described.

Bradfield Dam: Sheffield, England; built 1859-1863; failed 1864 (Jansen, 1980, p. 128).

Bradfield Dam was an earthfill structure with rough masonry lining placed on the upstream face. Most of the embankment contained a mixture of shale and other rock excavated from the reservoir floor. This was placed loosely and compacted insufficiently. The dam failed due to cracking or piping at normal maximum storage.

Coedty Dam: Dolgarrog, North Wales, England; built 1924; failed 1925 (Gruner, 1964, p. 366; Jansen, 1980, p. 138).

Coedty Dam consisted of an embankment built from the local moraine material, with a central corewall of reinforced concrete. The dam failed due to overtopping caused by the failure of the upstream Eigiau Dam.

<u>Eigiau Dam</u>: Dolgarrog, North Wales, England; built 1908; failed 1925 (Gruner, 1964, p. 366; Jansen, 1980, p. 138).

The Eigiau Dam was a concrete gravity structure. Evidence indicates that the dam was poorly constructed. It was founded on a thick layer of soft blue clay and no attempt had been made to carry the foundation down to solid rock. Seepage under the dam induced piping which resulted in a blowout of a 70-foot wide channel to a depth of 10 feet below the original ground. The outflow peaked at about 14,000 cfs. The resulting flood wave caused overtopping and failure of the downstream Coedty Dam.

<u>Elk City Dam</u>: Elk City, Oklahoma; built 1925; failed 1936 (ENR, 1936, pp. 678 and 850).

The dam was founded on shale containing vertical fissures as well as horizontal bedding. The main dam was a rolled earthfill structure, 850 feet long, and it contained a concrete corewall extending from 30 feet below the original ground level to near the top of the dam and had a thickness of 15 inches at ground level and 8 inches at the top. The corewall was surrounded by puddled clay. The dam was built of 12-inch layers of sandy clay, wetted and rolled, as it was placed. The water side of the dam had a slope of 3 to 1 and it was paved with a 4-inch thick concrete slab. The downstream face had a slope of 2 to 1 and was sodded with Bermuda grass.

The dam failed when the spillway failed to pass a cloud-burst flood and the structure was overtopped. In addition to the main breach, the dam was nearly washed away in several other places, and the whole downstream face was badly eroded.

Erindale Power Company Dam: Credit River, Ontario, Canada; built 1910; failed 1912 (ER, 1912, p. 457).

This earth dam had a corewall of concrete masonry (18 inches wide at the top and 5 feet at the bottom) which was carried down through soft shale and gravel in the river bed to the hard argillaceous sandstone below. Successive failures of small dams upstream, caused by spring floods, led to overtopping of this dam, and washing away of earthfill on the downstream side of the corewall. This was followed immediately by a collapse of a section of the corewall and the dam.

Frias Dam: Mendoza, Argentina; built 1940; failed 1970 (Jansen, 1980, p. 143).

The dam was a homogeneous rock-fill structure, with both upstream and downstream slope of 1 to 1. The upstream face was covered with a 12-inch thick reinforced concrete slab and the downstream face by mortared rubble masonry of roughly the same thickness. The top of the dam was also paved with mortared stones. The failure of the dam was caused by overtopping of the embankment to about 3 feet in height. Possible causes of failure were undermining of the downstream foundation and erosion of the fill, causing a sudden collapse of the structure.

Grand Rapids Reservoir: Grand Rapids, Michigan; built 1874; failed 1900 (EN, July 12, 1900; ER, July 14, 1900)

The reservoir was situated on a sand hill. In plan, it was a circle 196 feet in diameter at the bottom and 271 feet at the top, the depth of 25 feet was made up of 4.5 feet excavation and 20.5 feet of embankment, which was 12 feet wide at the top and had inner and outer slopes of 1.5 to 1 and

2 to 1, respectively. The surface soil was removed and used for the outer slope. The embankment was laid in 8-inch layers, wetted and compacted by rolling. A vertical wall of clay puddle, 8 feet at the bottom and 5 feet at the top, formed the embankment core, and a 1.6-foot thick nearly horizontal layer of clay puddle extended from the wall to the upstream toe. The inner slope was paved with rubble, resting on a bed of 1-foot thick concrete. The embankment failed by overtopping because of overfilling of the reservoir. A crevasse, 40 feet wide at the top and 20 feet wide at the bottom, developed and drained the reservoir.

<u>Hatchtown Dam</u>: Sevier River, Utah; built 1908; failed 1914 (EN, January 13, 1916).

The dam was an earthen embankment containing a puddle corewall. The slope of the downstream face was 2.5 to 1. The slope of the upstream face, for a vertical distance of about 10 feet below the crest, was 1.5 to 1 and the remainder 2 to 1. The upstream face was paved with roughly cubical lava rock to a thickness of 1 to 2 feet.

The first indication of the failure was noticed by a watchman. Slight seepage had been observed previously near the bottom and on the southerly side of the downstream end of the outlet culvert. This seepage had increased to a solid stream of muddy water by 2 p.m. on May 25th. In about two hours the stream began to increase, and at 8 p.m. great wedges of earth began to slip from the face of the dam over the culvert. In this manner the embankment was quickly cut back to within about 60 feet of the crest when a section of the dam, 30 feet long on the axis, moved bodily forward, followed by a wall of water 52 feet deep. A few minutes later, the gate tower fell. The watchman estimated that 75% of the 12000 acre-feet in the reservoir escaped during the first hour after the break and that by 11 p.m. the reservoir was practically empty.

Horse Creek Dam: Holly, Colorado; built ----; failed 1935 (ENR, September 5, 1935)

The dam was an earthen dike 40 feet high, 2300 feet long, and with a storage capacity of about 2500 acre-feet. It was built for flood control and according to sound engineering principles. The dike failed when overtopped by unprecedented runoff into the reservoir during a period of two hours. A major portion of the dam was washed away. The spillway was unable to accommodate the flood, though the reservoir was practically empty at the beginning of inflow.

Kaddam Dam: India; built 1957; failed 1958 (Gruner, 1964; and ICOLD, 1973).

This earth dam was overtopped by 1.5 feet. A major breach, 450 feet wide, occurred on the left and two more breaches on the right section of the dam.

Lake Barcroft Dam: Holmes Run, Alexandria, Virginia; built 1913; failed 1972 (ASCE, 1975, p. 224).

This was a gravity, cyclopean masonry dam, with a concrete ogee spillway and with earth embankment at each end. The failure was due to overtopping after excessive rainfall during tropical storm Agnes. Shortly before 11 p.m. on June 21, 1972, a 10-foot breach developed in the right embankment. The water level remained essentially unchanged for 40 minutes before any lowering was recorded. Because of the slow erosion of the embankment, no wall of water was discharged. It has been estimated that the maximum discharge downstream was not greater than if the dam had not been in existence.

Lower Otay Dam; Otay Creek, San Diego, California; built 1897; failed 1916 (EN, February 3, 1916; and Jansen, 1980, p. 151).

The dam was a rockfill structure that had at its center a steel plate embedded in cement mortar, forming a diaphragm which was the sole reliance for water tightness. The dumped fill was allowed to establish its own natural slope.

The storm that brought the disaster was without precedent in that area. From January 15 to 27, a rainfall of 9.14 inches fell over the basin. Before the storm, the water level in the reservoir was about 26 feet below the spillway crest. At 4:45 p.m., the water level was at the top of the embankment. Shortly thereafter, the overtopping occurred and water poured down and through the downstream zone of the dam, loosening rocks in the fill. Erosion was rapid and the lower face was quickly washed out, leaving the core unsupported. At 5:05 p.m. the steel diaphragm was torn open at its middle, and the remainder of the dam gave way like a pair of swinging gates. The reservoir emptied in about 2-1/2 hours. A flood wave estimated as high as 20 feet swept through the valley at about 12 miles per hour.

Machhu II Dam: Gujarat, India; built ----; failed 1979 (Jansen, 1980, p. 154).

The dam consisted of a masonry spillway in the main river section and earthen embankments on both sides. The embankments had a 20-foot top width, slopes of 3 to 1 and 2 to 1 for upstream and downstream faces, and a clay core extending through the alluvium to rocks below. The upstream face had 2 feet of small gravel and 2 feet of hand-placed riprap. The failure of the dam was due to inadequate spillway capacity, causing overtopping of the embankments. The dam withstood overtopping for about two hours, reaching a maximum depth of about 2 feet over the embankment.

Oakford Park Dam: Jeannette, Pennsylvania; built ---; failed 1903 (ER, July 11 and 23, 1903).

The dam was built up in 8-inch layers of good puddle in embankments and a masonry spillway. The earthen embankments were 8 feet at the top and both faces had a 1-foot thick dry rubble pavement. A small masonry wall, 2 feet thick and 3 to 4 feet high, was built across the creek to prevent leakage under the dam. The failure was caused by overtopping due to inadequate spillway capacity. After erosion of most of the downstream face of the dam, a breach opened near the spillway. The embankments withstood failure for about an hour and the maximum water depth over the embankments was about 2 to 3 feet.

Canyon Lake Dam; Rapid City, South Dakota; built 1938; failed 1972 (Jansen, 1980, p. 133).

The dam was an earth embankment, 20 feet high and about 500 feet long. Due to intense rainfall, the dam was overtopped. The dam was washed out in 5 to 6 minutes, releasing a flood wave of debris-laden water toward Rapid City which was already experiencing severe flooding.

Schaffer Dam; Beaver Creek, Colorado; built ----; failed 1921 (Follansbee and Jones, 1922).

The dam was an earth embankment with the upstream slope riprapped to the top. The dam was 15 feet wide at the top and had upstream and downstream slopes of 3 to 1 and 2 to 1, respectively. It failed due to overtopping of about 75-foot length along the middle section. The dam was almost entirely washed out and the reservoir emptied in about 30 minutes.

Sherburne Dam; Sherburne, New York; built 1892; failed 1905 (EN, vol. 54, p. 274, Sept. 14, 1905).

The earth dam was built with a puddle corewall. It was overtopped by a flood in 1905. About one-half of it was entirely washed out and about one-third of the lower side of the remaining portion was also carried away along the entire length.

South Fork Dam; Johnstown, Pennsylvania; built 1853; failed 1889 (EN, vol. 47, p. 506, Jun 19, 1902; Jansen, 1980, p. 184).

The dam was an earthfill structure. The cross section of the dam was made up of impervious soil on the upstream half and of a rock, gravel and sand fill on the downstream face. Slope of the downstream face was 1.5 to 1 and of the upstream face 2 to 1, with a protection of light riprap. The failure was caused by overtopping of the dam due to inadequate spillway capacity. The downstream slope was gradually eroded until the dam became so thin at one point that it could not withstand the pressure of water behind it. After that, the dam was eroded away very rapidly.

Swift Dam; Birch Creek, Montana; built 1912; failed 1964 (ENR, June 18, 1964).

This was a rockfill dam, with a concrete slab facing on the upstream slope and a compacted earthfill facing on the downstream slope. The dam was overtopped and gave way a few minutes after the spillway capacity was exceeded. According to a witness, the water in the Swift Dam reservoir topped the upstream face and rapidly washed away the downstream rock and compacred earthfill facing. Within minutes, the south end of the dam gave way. The rest of the dam probably collapsed at almost the same time.

Winston Dam; Winston, North Carolina; built 1904; failed 1912 (EN, vol. 7, April 11, 1912).

The dam consisted of a massive rubble spillway near the center and two earthen embankments joining the spillway to the high ground. The southern embankment was provided with a 3-foot rubble core and the northern embankment was supported by a rubble retaining wall. The corewall consisted of large and small stones loosely put together. The foundation for most of the spillway and the corewall was a mica schist, which was somewhat softened by weathering. Nearly half of the corewall rested on an earth foundation, some parts of which were very soft. The earth used in the fill was disintegrated mica schist which was not suitable for earth dam construction.

The dam failed by overtopping due to a flood caused by heavy rains. The overtopping was about 12 inches. The southern embankment withstood it for about 15 minutes, after which began the rapid sloughing of the downstream face. The corewall crumbled away a stone at a time, keeping pace with the destruction of the embankment. This resulted in slow erosion of the embankment, taking 5 hours to reach the foundation bedrock.

Breach Parameters

A summary of dam, reservoir, and breach parameters is given in table 1 for the 20 historical dam failures briefly described already. Information on three breach parameters--width of breach, water depth over the dam when failure occurs by overtopping, and time taken to empty the reservoir once the dam is breached--was developed from the review of historical failures.

The approximate breach width, B, is plotted against the dam height, h_d, in figure 2. Most of the points lie between two lines, defined by $B=2h_d$ and $B=5h_d$. The information on maximum water depth over the dam during failure by overtopping, h_f, is summarized on page 18.

Table 1. Physical and Breach Parameters for 20 Historical Dam Failures

		Length	Height	Storage	H_{se}	h_f	TF	t_e	BTW	BBW	DBD	Q_{max}	R	A
		ft	ft	1000 ac-ft	ft	ft	hr	hr	ft	ft	ft	1000 cfs	inches	sq mi
1.	Bradfield Dam	1254	95	2.6	84			0.75				40		
2.	Canyon Lake Dam	500	20	0.8			0.10						10	
3.	Coedty Dam	860	36	0.252			"short"	"short"	220	60				
4.	Eigiau Dam	3253	35	3.67								14		
5.	Elk City Dam	1850	30	0.6	27.5	1-1.5			150	*	30		5.75/2	23.5
6.	Erindale Dam	700	35		29		"short"		130	*	15			450
7.	Frias Dam	204				3.0	0.25		204	*	49			
8.	Grand Rapids Dam	**	25	0.18		"small"	"short"	"short"	40	20	25			
9.	Hatchtown Dam	780	63	13	58	-10†	"short"	1.0	640	400	63			
10.	Horse Creek Dam	2300	40	2.5					†	†	†			
11.	Kaddam Dam		41 [2]	174		1.5			450	*				
12.	Lake Barcroft Dam		69	2.53		1.3	"long"	"long"	75	*	36		9.0	
13.	Lower Otay Dam	565	130	40		1-2	0.25	2.5	565	*	130		9.14	
14.	Machhu II Dam	13700	197	81.9		2.0	2.0		1768	*	197		21/21	
15.	Oakford Park Dam	350	20			2-3	1.0		75	*	10-20		5.1	
16.	Schaffer Dam	1100	90	3.19			"short"	0.5	†	†	†	153		
17.	Sherburne Dam	300	34	0.064	29				150	*		34		
18.	South Fork Dam	930	72	15.4	65	0.4	0.75	3.5	400	*			10/36	
19.	Swift Dam	740		30			"short"		†	†	†			
20.	Winston Dam	435	24	0.538	20	1.0	5.0	5.0	70	60	24		6.0	7.5

H_{se} = spillway elevation above the foundation
h_f = maximum water depth over the dam during failure by overtopping
TF = failure time from inception to completion of breach
t_e = time taken to empty reservoir after the beginning of failure
BTW = breach top width
BBW = breach bottom width
DBD = depth of breach from top of dam
Q_{max} = maximum outflow rate after dam breach
R = depth of rainfall/duration in hours (if known)

A = area of drainage basin above dam
"short" = time of few minutes, less than 0.5 hour
"long" = time of few hours, longer than 1.0 hour
"small" = depth of few inches, less than 0.5 foot
* = breach width not specified for top or bottom
† = most of the dam failed
** = circular reservoir with radius = 230 feet
† = piping failure
2 = 36 feet where embankment failed

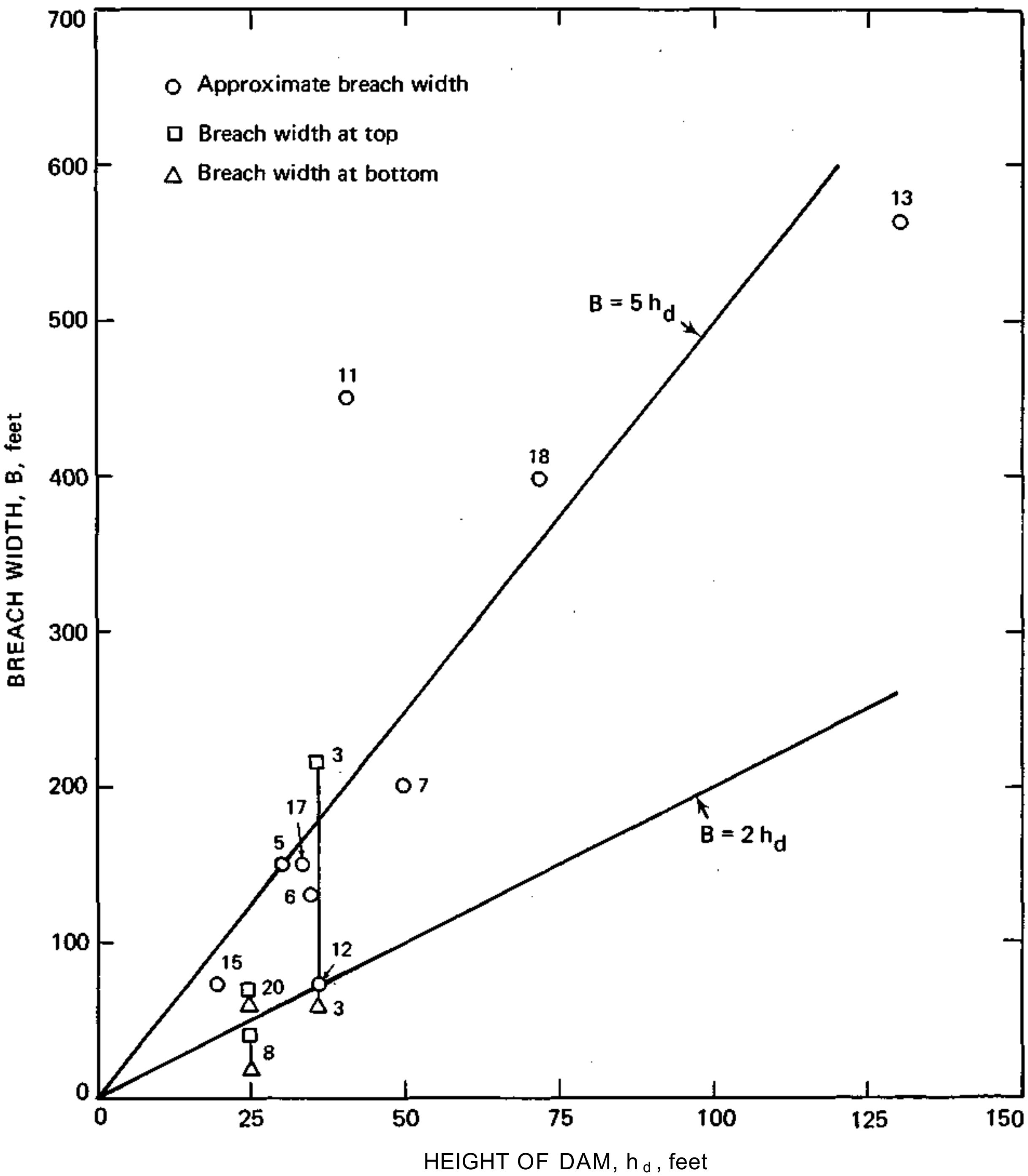


Figure 2. Breach width versus height of dam

Dam number	hf, ft
5	1-1.5
7	3.0
8	<0.5
11	1.5
12	1.3
13	1-2
14	2.0
15	2-3
18	0.4
20	1.0

The hf generally lies in the range of 0.5 to 2.0 feet. A low hf connotes either weak downstream slope (not well compacted and not covered with erosion-resistant cover) or poor maintenance. The information on failure time, TF, from inception to completion of breach is given below.

Dam number	TF, hours
2	0.10
3	<0.5
6	<0.5
7	0.25
8	<0.5
9	<0.5
12	>1.0
13	0.25
14	2.0
15	1.0
16	<0.5
18	0.75
19	<0.5
20	<5.0

The TF generally lies in the range of 0.25 to 1.0 hour. A low TF signifies either weak (not properly compacted) or faulty (undesirable earth constituents of the fill) construction.

THEORETICAL EVALUATION OF SELECTED DAM-BREAK MODELS

Two models were chosen for evaluation. These are the U.S. Army Corps of Engineers HEC-1 dam-break version, referred to as the HEC, and the National Weather Service dam-break model developed by Fread, referred to as the NWS. The Soil Conservation Service has developed an equation which estimates the peak outflow from the dam during a breach. This is based on a plot of peak outflow versus the height of dam for some historical dam failures. An outflow hydrograph with an assumed shape is then routed through the downstream channel. This is an empirical approach to the dam-break problem.

General Open-Channel Flow Equations

The general equations for open-channel flow are based on the continuity equation and Newton's second law of conservation of linear momentum. Mathematical models for various simplified and approximate special cases have been developed and applied to engineering problems (Chow, 1959; Henderson, 1966). Recently, more rigorous derivations of the general equations have been done, notably by Strelkoff (1970) and Chen and Chow (1971). In both cases, the one-dimensional incompressible open-channel flow equations were derived by the integration of the point form of the continuity equation and the Navier-Stokes equation. In a series of papers, Yen (1973, 1975) derived the equations describing an unsteady, spatially varied, turbulent, free surface flow of a viscous nonhomogeneous fluid in a channel of arbitrary cross-sectional and alignment geometry with erodible boundary. This was done rigorously by integrating the point form of continuity, momentum and energy equations over a cross-sectional area of the channel.

For incompressible fluid the integrated equation of continuity is (Yen, 1973):

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = \int_{\sigma} \hat{q}\, d\sigma \tag{1}$$

in which A is the flow cross-sectional area; Q is the discharge through A; σ is the perimeter bounding A; and q is the time rate of lateral flow per unit length of σ, having dimension of length/time, and being positive for lateral inflow and negative for outflow.

The one-dimensional momentum equation integrated over the area, A, for a gravity oriented coordinate system with depth, Y, measured vertically is (Yen, 1975):

$$\begin{aligned} &\frac{1}{gA}\frac{\partial Q}{\partial t} + \frac{1}{gA}\frac{\partial}{\partial x}\left(\frac{\beta}{A}Q^2\right) + \frac{\partial}{\partial x}(kY) + (k-k')\frac{Y}{A}\frac{\partial A}{\partial x} \\ &= S_o - S_f + \frac{1}{\gamma A}\frac{\partial T}{\partial x} + \frac{1}{gA}\int_{\sigma} \hat{q}\, u_x\, d\sigma \end{aligned} \tag{2}$$

in which g is the gravitational acceleration; S_Q is the channel slope, = tan Θ for gravity oriented coordinates, where 0 is the angle between the channel bottom and a horizontal plane; S_f is the friction slope; Y is the specific weight of the fluid; u_x is the x-component velocity of the lateral flow joining the channel flow; k and k' are pressure distribution correction factors; β is the momentum flux correction factor; and T represents the force acting normal on A due to internal stresses.

With the assumptions of constant piezometric pressure distribution over A (k=l); constant piezometric pressure distribution over non-fluctuating A and σ (k'=l); the gradient of the force due to internal stresses, $\partial T/\partial x$, being relatively small and negligible; and the velocity, u, being uniformly distributed over the area, A, (3=1); we have a set of the Saint-Venant's equations in equation 1 and modified equation 2:

$$\frac{1}{gA}\frac{\partial Q}{\partial t} + \frac{1}{gA}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + \frac{\partial Y}{\partial x} - S_o + S_f = \frac{1}{gA}\int_\sigma \hat{q}\, u_x\, d\sigma \tag{2a}$$

Equations 1 and 2a, quoting Yen (1979): "are invalid when the assumptions, particularily that on pressure distribution, are seriously violated. Thus the Saint-venant equations are unreliable when applied to the initial stage of dam breach problems, channel control sections with highly curvilinear flow, supercritcal flow with roll waves, and flow with Froude number near unity (hydraulic jump and hydraulic drop)."

The estimation of the friction slope, Sf, is usually accomplished by the use of the Manning's equation:

$$S_f = \frac{n^2 Q^2}{2.21\ A^2\ R^{4/3}} \tag{3}$$

in which n is Manning's roughness factor and R is the hydraulic radius defined as A divided by the wetted perimeter, P.

The solution of equations 1 and 2a requires two initial conditions and two boundary conditions. The initial conditions specify the state of the flow at all cross sections at the initial time. The two initial conditions are given by the discharge $Q(x,t_0)$ and depth $Y(x,t_o)$ or $A(x,t_o)$. The boundary conditions specify the time variations of the discharge $Q(x_o,t)$ and depth $Y(x_o,t)$ or area $A(x_o,t)$ of flow, or functional relationship between them at certain boundary locations, x_o. For a supercritical flow, both boundary conditions must be specified at the upstream boundary of the channel. For a subcritical flow, one boundary condition must be specified at the upstream end of the channel and the other at the downstream end (Yen, 1979).

Routing Method of the HEC Model

The HEC program offers several alternative methods for the routing of a flood wave. The modified-Puls (MP) method is recommended for the routing of a flood wave due to dam breach. The MP-method is based on the continuity equation as are all hydrologic routing methods:

$$\frac{\Delta S}{\Delta t} = I - Q \tag{4}$$

where AS/At is the change in storage during period At, I is the average inflow rate and Q is the outflow rate during the period At (Chow, 1959). The MP-method transforms the above equation to the following form (Chow, 1964):

$$\frac{1}{2}(I_1+I_2)\ \Delta t + S_1 + \frac{1}{2}Q_1\Delta t - Q_1\ t = S_2 + \frac{1}{2}Q_2\Delta t \tag{5}$$

where subscripts 1 and 2 refer to the beginning and end of time interval, At, respectively.

The HEC model employs a procedure for specifying storage-discharge data which emphasizes geometric and hydraulic characteristics of a routing reach. This technique allows the user to compute a normal depth storage-outflow relationship using a typical cross section, channel and overbank roughness, energy grade line slope, and length of the reach. The energy grade line slope may be assumed equal to the average channel bed slope. The program computes storage-discharge and discharge-elevation relationships for the routing reach using normal depth assumptions. The storage-discharge relationship is then used in the MP-method. For reservoir routing, the storage-outflow relationship for the reservoir may be input directly, or generated based on the reservoir area-capacity data and the physical characteristics of the outlet works and the dam itself (COE, 1978a). The boundary conditions for the MP-method are given by the inflow hydrograph for the reservoir routing and by the breach hydrograph for the channel routing.

The basic assumptions of the MP-method are: 1) it is based only on the continuity equation and the application of the normal flow equation, neglecting all dynamic effects which are exceedingly important for dam breach flood waves; 2) it neglects all lateral flow, both for the continuity equation and for the momentum equation; and 3) it relies on single valued, invariable discharge-storage relationships for each routing reach.

Routing Method of the NWS Model

The routing method of the NWS model is based on the Saint-Venant equations (Fread, 1977): the continuity equation

$$\frac{\partial(A+A_o)}{\partial t} + \frac{\partial Q}{\partial x} = q \qquad (6)$$

and a conservation of momentum equation

$$\frac{\partial Q}{\partial t} + \frac{\partial(\frac{Q^2}{A})}{\partial x} + gA\left(\frac{\partial h}{\partial x} + S_f + S_e\right) = 0 \qquad (7)$$

where h is the water surface elevation, A is the active cross-sectional area of flow, A_Q is the inactive (off-channel storage) cross-sectional area, x is the longitudinal distance along the channel (valley), t is the time, q is the lateral inflow or outflow per linear distance along the channel (inflow is positive and outflow is negative in sign), g is the acceleration due to gravity, S_f is the friction slope, and S_e is the expansion-contraction slope. The friction slope is evaluated from the Manning equation for uniform steady flow:

$$S_f = \frac{n^2 Q^2}{2.21 A^2 R^{4/3}} \tag{8}$$

where n is the Manning's coefficient of frictional resistance and the hydraulic radius, R,. is defined as A/B where B is the top width of the active cross-sectional area. The term S_e is defined as:

$$S_e = \frac{k \Delta (Q/A)^2}{2g \Delta x} \tag{9}$$

in which k is the expansion-contraction coefficient varying from 0.0 to 1.0 for contraction and 0.0 to -1.0 for expansion, and $A(Q/A)^2$ is the difference in term $(Q/A)^2$ at two adjacent cross sections separated by the distance, Ax.

The basic assumptions of the NWS model are the same as those for the Saint-Venant equations discussed in the previous section. In addition, in equation 6, the lateral flow, q, is assumed constant along the boundary, or q represents the quantity $\int_\sigma \hat{q}\, d\sigma$ in equation 1. Equation 6 modifies also the representation of the area to include inactive flow area. Presumably on the basis of this modification, the hydraulic radius is defined as A/B in equation 8, which is a good approximation when inactive area is taken into account and also when the ratio of depth to the width of the channel is small. When comparison is made between equation 2a and equation 7 the assumption of negligible effects of the momentum of the lateral inflow is made, which is good when no major stream confluences occur. It should be noted that the change in the water surface elevation is equal to the change in the water depth minus the channel slope S_o, i.e. $\frac{\partial h}{\partial x} = \frac{\partial Y}{\partial x} - S_o$.

The numerical solution of the set of the hyperbolic equations 6 and 7 is accomplished in two basic steps (Fread, 1977). First the partial differential equations are represented by a corresponding set of finite difference algebraic equations; and second, the system of the algebraic equations is solved in conformity with the given initial and boundary conditions. The finite difference scheme that is employed is a nonlinear weighted four-point implicit scheme. The numerical properties of this scheme are analyzed by Fread (1974, 1975). The scheme is shown to be stable and accurate for suggested weighting factors. This has been confirmed in several case studies (Fread, 1977; Land, 1980). The resulting system of 2N nonlinear equations and the same number of unknowns (for N points finite difference scheme) is solved by a functional iterative procedure, the Newton-Raphson method (Fread, 1977, 1979).

The initial conditions are given by known steady discharge at the dam from which the discharge at each cross section is calculated:

$$Q_i = Q_{i-1} + q_{i-1} \Delta x_{i-1} \qquad i = 2, \ldots, N \tag{10}$$

where Q_1 is known, and q is any lateral inflow. The water surface elevation associated with the steady state flow is computed by solving the steady state non-uniform flow equation by the Newton-Raphson algorithm. The boundary condition at the upstream boundary is the reservoir outflow hydrograph, which is routed either by dynamic or storage routing through the reservoir. The breach hydrograph is the upstream boundary condition for the channel routing. At the downstream boundary, the following equation is used if the flow is controlled by the channel:

$$Q_N = \frac{1.49}{n} \; A_N^{5/3} / \; B_N^{2/3} \left(\frac{h_{N-1} - h_N}{\Delta x_{N-1}} \right)^{1/2} \tag{11}$$

This equation reproduces a loop-rating curve. Otherwise, a single-valued rating curve is used for the downstream boundary. For supercritical flow, similar procedures are applied at the upstream boundary.

BREACH PARAMETERS AND FIELD DATA FOR DAM BREAK MODELS

The peak and shape of a hydrograph due to dam breach are governed largely by the geometry of the breach and the development of the breach with time. Often a complete and instantaneous failure is assumed, but for earthen dams the failure is generally a gradual process as shown in the historical study. The flooding downstream due to a dam failure is basically dependent on the channel and overbank geometry and artificial constrictions of the channel, along with the roughness of the floodway.

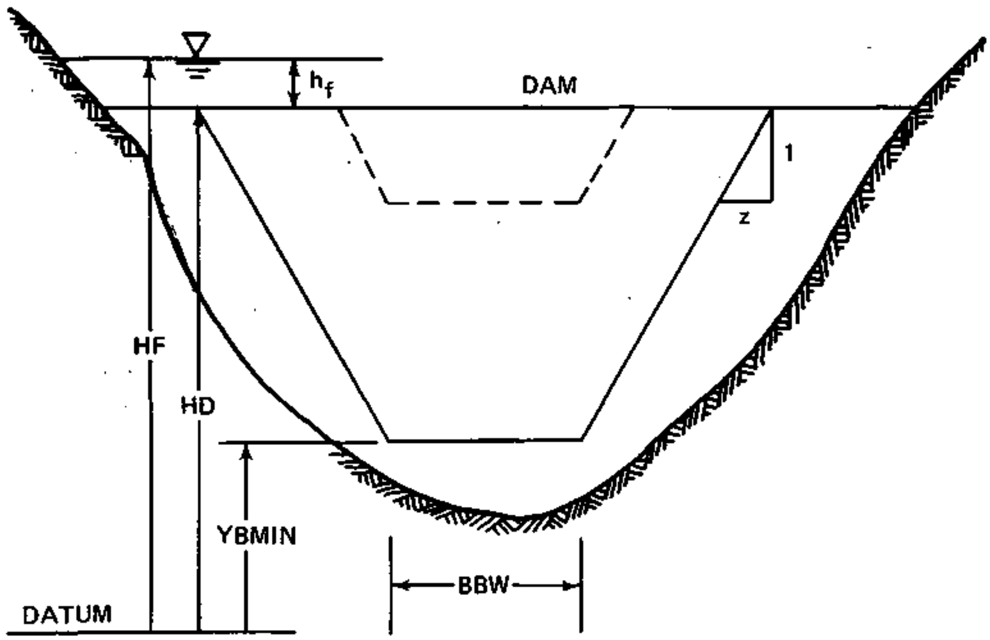
Breach Formation

The breach formation in an earthen embankment is a quite complex process, depending on various hydrologic, hydraulic, and structural factors and parameters. If breach is due to overtopping, the water will probably erode a notch that both widens and deepens as the erosion progresses. The overtopping water is also likely to erode first the downstream side of the dam, especially near the toe of the dam, where velocities are the highest. This erosion of the downstream face of the dam can cause rapid erosion of the breach itself. If the failure proceeds in this way, it is clear that the breach formation is a highly nonlinear process. In the beginning the erosion will be relatively slow. As the depth and velocities in the breach section increase and the downstream side erodes, the erosion in the breach is accelerated, resulting in a possible partial collapse of the dam. As the tailwater increases, the velocities slow down and the erosion rate decreases again. All this will depend on the structure, construction, location, and the material of the dam. The erosion rates thus may vary within certain limits.

Breach Parameters

Both HEC and NWS use the same breach parameters for description of the breach formation. The five basic breach parameters are the side slope of the breach section, z; the final bottom width of the breach, BBW; the final bottom elevation of the breach, YBMIN; the time of failure, TF; and the failure elevation, HF, as shown in figure 3. In this study, the range of the parameters was chosen so as to reflect historical observed values. The elevation of the breach bottom, YBMIN, was usually taken to be the channel bottom or the dominant ground elevation at the dam, except when this was not physically justifiable due to backwater effects. The slope, z, was considered to be 0.5, except for piping failures, where it was set at 0.0. In one case the slope was varied from 0.0 to 1.0 to investigate the effect of the slope on the breach hydrograph. The final breach bottom width, BBW, was chosen to be $2h_d$ and $4h_d$, which combined with slope of 0.5 gave a range of breach widths of $2h_d$ to $4h_d$ at the bottom to a maximum of $5h_d$ at the top. In one case the BBW was allowed to vary from $2h_d$ to $16h_d$ in order to assess the effect of BBW on the breach hydrograph. The overtopping depth, h_f or HF-HD (i.e., the water depth over the dam when failure starts), was taken as 0.5 foot or 2.0 feet. The time of failure was chosen to be 0.25 hour, 0.50 hour, and 1.00 hour. In one case a failure rime of three hours was also considered in order to assess the effect of a higher time of failure on the breach hydrograph. These ranges of breach parameters cover reasonably well the values obtained from historical earthen dam failures.

Breach formation for the HEC model



Breach formation for the NWS model

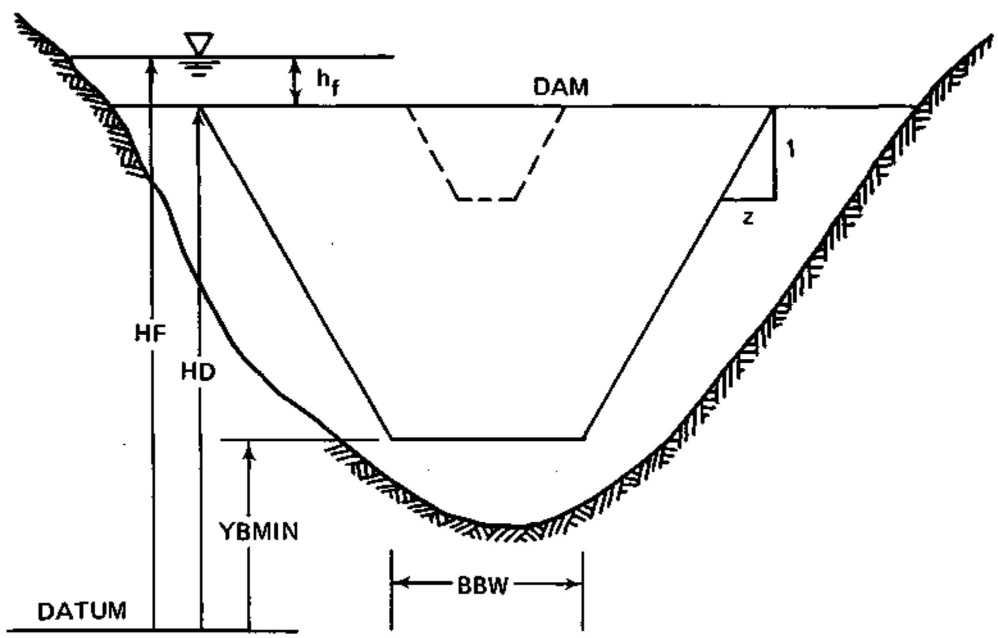


Figure 3. Breach formation for the HEC and NWS

Comparison of HEC and NWS; Breach Hydrograph Computation

Both programs use breach formation based on a procedure by Fread and Harbaugh (1973). The NWS model assumes the breach starts at a point and both the breach width and depth increase at a linear rate over the failure time, TF, until the terminal width, BBW, is attained and the breach bottom has eroded to the elevation YBMIN which is usually, but not necessarily, the bottom of the outlet channel. If TF is less than ten minutes, the width of the breach starts at a value of BBW rather than at a point. This latter version is the one used by the HEC program for all breach formations. This difference in procedures results in different breach outflow hydrographs from the two models, usually resulting in higher peak discharge for the NWS since at maximum breach size it has retained more water in the reservoir and thus higher water levels.

During the simulation of a dam failure, the actual breach formation commences when the reservoir surface elevation exceeds a specific value, HF, or the failure elevation. This feature permits the simulation of both an overtopping and piping failure depending on the specified value of HF.

The reservoir outflow discharge, Q, consists of broad-crested weir flow through the breach, Q_b, and flow over the dam and through any outlets or spillways of the dam, Q_s:

$$Q = Q_b + Q_s$$

The details are given in Fread (1977, 1979) and COE (1978a). It suffices to point out that Q_s can be presented entirely or partly by a rating curve.

The NWS program requires cross-sectional information immediately downstream of the dam in order to calculate tailwater elevations for any needed correction for partial submergence. The program also corrects for the velocity of approach. The HEC ignores both the effects of partial submergence and velocity of approach.

Field and Other Data

It is of considerable economic and social interest to assess the extent of flooding due to dam failures. This task is based on the availability and accuracy of field data, especially cross-sectional data. Three sets of cross-sectional data were used when available. The first set consisted of 5-9 surveyed cross sections, and the second set consisted of every other surveyed cross section available. The third set consisted of 5-9 cross sections taken from the 7.5' topographic maps published by the USGS. These three sets of cross-sectional data should reveal the difference between peak flows in the downstream channel with easily accessible cross sections from the topographic maps and with the surveyed cross sections. The variation in flood levels with the number of cross sections is also investigated.

The set of inflow hydrographs used in the simulation consisted of the probable maximum flood (PMF) hydrograph based on 24-hour rainfall duration supplied by the DOWR. The flood hydrogaphs corresponding to 0.50 PMF and 0.25 PMF were also used.

Sets of Parameters

A complete set of simulations on a single dam consists of the following combinations:

1) Routing of inflow hydrographs for PMF, 0.50 PMF, and 0.25 PMF floods without the existence of the reservoir
2) Routing of the inflow hydrographs through the reservoir, but with the dam intact, even if overtopped

3) Routing of inflow hydrographs with the failure of the dam. The general case consisted of 8 combinations of the breach parameters, fixing the slope, z, at 0.5 for the overtopping failure and 0.0 for the piping failure. The bottom elevation of the breach was determined from actual physical circumstances. Two failure elevations were used, one of 0.5 ft and the other 2.0 ft above the top of the dam for overtopping failures; but for piping failures the approximate maximum elevation in the reservoir was chosen as one failure elevation and the other was chosen 1.5 ft lower. For both failure elevations, two values of the bottom width of the breach were chosen, one of $2h_d$ and the other of $4h_d$. The time of failure was chosen to be 0.5 hr for the lower failure elevation, but 0.25 hr, 0.50 hr, and 1.00 hr for the higher failure elevation. The above combinations were used for the three sets of cross sections, where available.

ANALYSES AND RESULTS FROM EIGHT SELECTED EARTH DAMS

Eight earth dams (figure 1) were selected for breach simulation. The basic data on the dams were taken from Inspection Reports, National Dam Safety Program, published by the Department of the Array, Chicago District, Corps of Engineers. Available surveyed profiles for the downstream channel and detailed contour maps were supplied by DOWR. The name of the dam, height of dam above streambed, storage at normal pool level, and the peak discharge of the probable maximum flood, PMF, inflow hydrograph are given below. The information on size (S = small, IM = intermediate, L = large) as well as hazard (H = high) categories, as given in the Inspection Reports by the Corps of Engineers, COE, is also included.

		Height of dam hd, ft	Storage S, ac ft	Peak of PMF Q, cfs	COE Size	COE Hazard
I	Pierce Lake Dam	46.0	2,660	30,500	IM	H
II	Lake in the Hills Dam #1	40.0	598	8,400	IM	H
III	Lake in the Hills Dam #2	14.5	78.9	11,318	S	H
IV	Lake Marian Dam	50.0	151	3,164	IM	H
V	Clinton Lake Dam	65.0	74,200	150,200	L	H
VI	Lake Springfield Dam	48.0	53,504	121,364	L	H
VII	Weslake Dam	48.0	224	1,243	IM	H
VIII	Kinkaid Lake Dam	92.0	78,500	71,000	L	H

The dams vary in height from 14.5 to 92.0 ft and in storage from 78.9 to 78,500 ac ft. The inflow peak (PMF hydrograph) varies from 1,243 to 150,200 cfs. Thus the size categories vary from small to large, whereas all the dams are classified in the high hazard category.

The procedure of simulations with the NWS and HEC models follows the guidelines established previously. Calculation of the peak outflow with the SCS method follows the guidelines given in Technical Release No. 66, Simplified Dam Breach Routing Procedure (SCS, 1979). The maximum outflow from the breach is based on an empirical equation of the form:

$$Q_{max} = 65\ H^{1.85}$$

where H is equal to the depth of water at the dam at the time of failure, as calculated by reservoir routing of the inflow hydrograph. Thus, H = h_d + (HF-HD) where HF is the maximum water level in the reservoir with no-failure condition.

I. Pierce Lake Dam

Pierce Lake Dam (figure 4) is located on Willow Creek near Rockford in Winnebago County, Illinois. It is an earth embankment, approximately 46 ft high and 470 ft long. The appurtenant works consist of an uncontrolled ogee-crest spillway discharging into a concrete chute with a Saint Anthony Falls type stilling basin at the bottom and an auxiliary spillway consisting of an overflow drop inlet discharging into a 48" diameter concrete pipe which flows into a stilling basin. A 24" diameter dewatering conduit is connected to the vertical drop inlet tower with a sluice gate. An 80-ft wide paved emergency spillway is located to the right of the principal spillway. The watershed is steeply rolling, mainly cultivated land with some light residential development. Basin elevations range from 826 to 950 ft msl.

The dam is classified in the intermediate size and high hazard potential category because the park areas below the dam are used daily by the park visitors. There are also housing subdivisions and a school approximately two miles downstream from the dam. Failure of the dam can

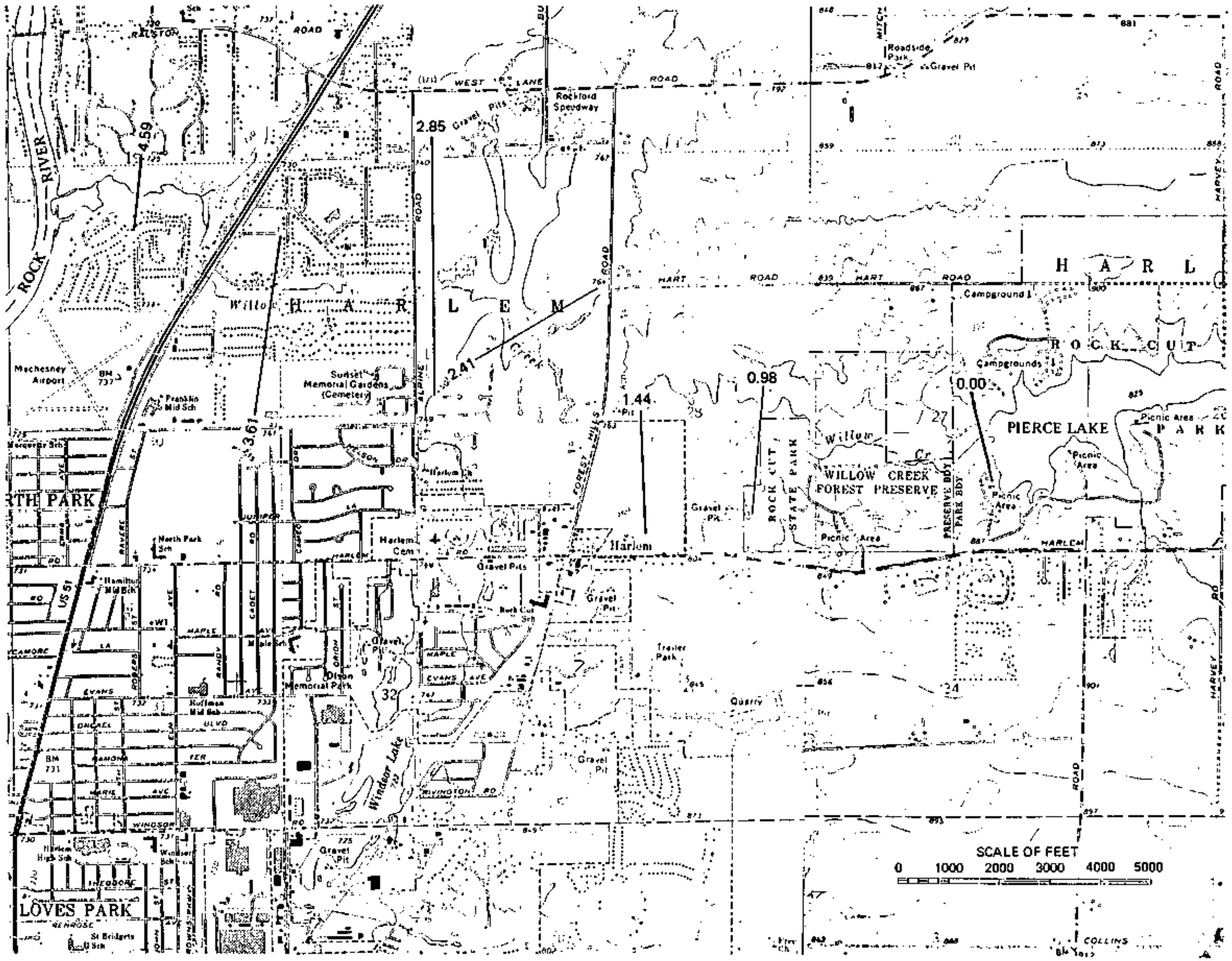


Figure 4. Location of Pierce Lake Dam and downstream channel cross sections

damage buildings and endanger human lives. Pertinent data about the dam and reservoir are given below.

Pertinent data - Pierce Lake Dam

Drainage area	13.13 sq mi
Dam	
Elevation, top of dam	836.5 ft msl
Height above streambed	46.0 ft
Length	470.0 ft
Reservoir	
Elevation, normal pool*	826.0 ft msl
Area, normal pool	162.0 ac
Capacity, normal pool	2,660 ac ft
Length, normal pool	1.17 mi
Principal spillway	
Type	Uncontrolled, ogee-crested concrete weir
Elevation, spillway crest	826.0 ft msl
Length of crest	100.0 ft
Emergency spillway	
Type	Earthcut with paved surface
Elevation, crest	830.85 ft msl
Crest length	80.0 ft
Side slopes	2:1 horiz:vert
Freeboard	
Normal pool	10.5 ft

*Based on principal spillway crest level

The basic hydrologic and hydraulic data in table 2 consist of the PMF hydrograph generated by the HEC-1 program and information on reservoir area and capacity and combined spillway discharge versus elevation. Flow over the top of the dam was determined with the weir equation:

$$Q = C\ L\ H^{3/2}$$

Table 2. PMF Hydrograph and Elevation-Area-Storage-Discharge Data: Pierce Lake Dam

a. PMF Inflow Hydrograph

Time (hr)	0	0.5	1.0	1.5	2.0	2.5
Inflow (cfs)	2,080	2,288	2,500	4,000	5,500	7,700
Time (hr)	3.0	3.5	4.0	4.5	5.0	5.5
Inflow (cfs)	8,500	10,000	11,500	13,000	14,500	19,833
Time (hr)	6.0	6.5	7.0	7.5	8.0	8.5
Inflow (cfs)	25,166	30,500	28,625	26,750	30,500	27,000
Time (hr)	9.0	9.5	10.0	10.5	11.0	11.5
Inflow (cfs)	23,500	20,000	16,500	13,000	10,000	9,000
Time (hr)	12.0	12.5	13.0	13.5	14.0	14.5
Inflow (cfs)	7,000	5,000	3,000	2,750	2,500	2,250

b. Elevation-Area-Storage-Discharge Data

Elevation (ft msl)	Area (ac)	Storage (ac ft)	Discharge* (cfs)
790.0	0	0	0
826.0	162	2,660	0
826.8			281
827.0	163	2,823	
827.5			756
828.5			1,655
830.0			3,246
832.5			7,357
835.0	229	4,420	
835.5			14,103
840.0	258	5,637	27,855

*combined spillway discharge

where Q is flow over the top of the dam (cfs); L is the effective length of the top of the dam, L = 470 ft; H is the depth of water over the top of the dam; and C is the discharge coefficient assumed to be 3.05, based on the condition and the shape of the top of the dam. The information presented above follows the Pierce Lake Dam Inspection Report (COE, 1979c).

The surveyed cross sections were supplied by the DOWR. Cross sections were also developed from 7.5' quadrangle maps. The location of the surveyed and the map cross sections are shown in figure 4. The Manning's roughness coefficient, n, was supplied by the DOWR and varied from 0.035 for the channel to 0.065 for the overbank flow.

Analyses **and** Results

Below the Pierce Lake Dam, Willow Creek flows in a westerly direction for about 5 miles to its confluence with the Rock River. The floodplain for the first 1-1/2 miles downstream of the dam consists of forested park land. The floodplain is quite narrow in this region, but it spreads out rapidly downstream so that no clear boundaries exist. U.S. 51 crosses the channel at about 4 miles downstream of the dam, and below it the floodplain is well defined.

The breach parameters were chosen on the basis of the guidelines established previously. The bottom of the breach, YBMIN, was set at the channel bottom elevation of 790.5 ft for the smaller breach size (bottom breach width, BBW = 92 ft), but at 793.5 ft for the larger breach size (BBW = 175 ft). The time from the inception of the breach to its completion, TF, has been taken as 0.25, 0.50, or 1.00 hour. The depth of overtopping when the breach starts, or h_f equal to HF-HD, has been taken as 0.5 or 2.0 ft; the HF and HD denote the water level at the beginning of the breach or the failure elevation and elevation of the top of the dam, respectively.

Resulrs from the simulation of floods are given in tables 3-A to 3-C for no-reservoir condition and in tables 3-D to 3-F with the reservoir and dam intact. It is apparent that only the PMF flood will overtop the dam and will break it for both failure elevations. Results from 8 combinations of breach parameters with the PMF flood hydrograph are given in tables 3-G to 3-N.

The peak discharges for both methods and all combinations of breach parameters along with peak discharge as determined by the SCS method are shown in table 4. The peak discharges for no-reservoir condition are taken after the inflow hydrographs have been routed from the upstream end of the reservoir to the site of the dam. Slight differences in these discharges, with the NWS and HEC, are due to differences in routing. The peak discharge, with the reservoir intact, are only slightly lower than with the no-reservoir condition because of small storage in the reservoir. The peak outflows due to the failure of the dam are about 10% higher with the NWS for all conditions. This is due to the difference in the mode of breach formation as discussed previously. Increase in peak discharge due to higher failure elevation is only about 2 to 4%, whereas it is 13-30% with a 50% reduction in failure time. Bigger breach size results in an increase of about 20 to 30%. The peak discharge, in general, varies from less than three times to more than five times the PMF peak. The peak outflow determined with the SCS method is close to the lowest value of peak discharge from various combinations of breach parameters in tables 3-G to 3-N.

Table 3. Summary of Results for Pierce Lake Dam

A. 1.00 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	30499	30500	30499	30500	30406	30500
	H	803-41	---	804.37	---	801.15	---
0.980	Q	30187	29679	---	---	30206	29875
	H	774.75	771.90	---	---	771.95	769.70
1.440	Q	29932	29540	29974	29417	30042	29783
	H	769.18	767.90	770.67	767.30	764.88	763.10
2.410	Q	29669	29051	---	---	29683	29176
	H	753.90	753.50	---	---	750.92	751.40
2.850	Q	29467	28992	29522	28917	29599	28988
	H	745.18	740.80	744.22	741.20	741.95	741.40
3.610	Q	29060	28788	---	---	28993	28925
	H	737.27	735.40	---	---	732.56	729.70
4.590	Q	28894	28698	28986	28682	28904	28820
	H	716.18	716.10	716.65	716.10	712.30	712.10

B. 0.50 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	15203	15250	15249	15250	15212	15250
	H	799.16	---	799.68	---	798.00	---
0.980	Q	15072	14751	---	---	15096	14890
	H	772.30	770.30	---	---	768.98	767.60
1.440	Q	14951	14673	15002	14671	14962	14821
	H	766.48	765.20	766.41	764.80	762.90	761.80
2.410	Q	14809	14440	---	---	14748	14607
	H	751.76	751.10	---	---	747.85	748.50
2.850	Q	14663	14421	14676	14461	14688	14510
	H	742.56	738.40	741.10	738.80	741.21	740.80
3.610	Q	14324	14359	---	---	14463	14464
	H	733.18	732.50	---	---	728.54	726.90
4.590	Q	14238	14302	14469	14302	14434	14386
	H	714.04	714.10	714.31	714.20	710.31	710.20

Table 3. Continued

C. 0.25 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	7601	7625	7624	7625	7624	7625
	H	796.35	---	796.64	---	795.80	---
0.980	Q	7532	7309	---	---	7546	7416
	H	770.68	768.80	---	---	766.89	766.00
1.440	Q	7473	7273	7500	7279	7450	7356
	H	764.46	763.20	764.41	762.80	761.61	760.80
2.410	Q	7368	7179	---	---	7347	7258
	H	749.72	749.00	---	---	745.85	746.10
2.850	Q	7273	7173	7252	7209	7303	6990
	H	738.72	736.30	736.88	736.70	740.77	740.30
3.610	Q	7177	7157	---	---	7243	6977
	H	728.69	729.70	---	---	725.74	724.70
4.590	Q	7169	7125	7216	7096	7225	6941
	H	712.71	712.80	712.85	712.90	708.87	708.80

D. 1.00 PMF, HF = maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	836.50	790.50	838.74

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	28828	28861	28749	28861	28828	28861
	H	803.02	---	803.93	---	800.87	---
0.980	Q	28797	28685	---	---	28800	28751
	H	774.57	771.80	---	---	771.74	769.60
1.440	Q	28742	28639	28556	28567	28765	28719
	H	769.01	767.80	768.87	767.20	764.74	763.10
2.410	Q	28657	28387	---	---	28660	28456
	H	753.78	753.50	---	---	750.83	751.30
2.850	Q	28595	28356	28319	28277	28627	28353
	H	745.08	740.70	744.06	741.20	741.91	741.40
3.610	Q	28421	28205	---	---	28414	28318
	H	737.17	735.40	---	---	732.40	729.60
4.590	Q	28337	28135	28132	28066	28374	28245
	H	716.10	716.00	716.56	716.10	712.23	712.00

Table 3. Continued

E. 0.50 PMF, HF = maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	836.50	790.50	835.18

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	13357	13482	13333	13482	13311	13482
	H	798.55	---	798.99	---	797.52	---
0.980	Q	13319	13353	---	---	13326	13451
	H	771.97	770.10	---	---	768.56	767.40
1.440	Q	13316	13341	13323	13359	13300	13441
	H	766.11	764.90	766.03	764.50	762.65	761.70
2.410	Q	13273	13229	---	---	13247	13390
	H	751.51	750.90	---	---	747.47	748.20
2.850	Q	13206	13222	13238	13278	13214	13357
	H	742.16	738.10	740.64	738.50	741.13	740.80
3.610	Q	13101	13190	---	---	13152	13340
	H	730.84	732.20	---	---	728.09	726.60
4.590	Q	13067	13151	13143	13151	13120	13297
	H	713.84	714.00	714.06	714.00	710.11	710.10

F. 0.25 PMF, HF = maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	836.50	790.50	831.88

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	6390	6351	6383	6351	6399	6351
	H	795.82	---	796.06	---	795.37	---
0.980	Q	6384	6299	---	---	6384	6333
	H	770.39	768.60	---	---	766.50	765.80
1.440	Q	6370	6288	6372	6272	6380	6325
	H	764.07	762.80	764.02	762.40	761.40	760.70
2.410	Q	6346	6229	---	---	6350	6292
	H	749.16	748.70	---	---	745.52	745.70
2.850	Q	6323	6227	6316	6237	6332	6059
	H	737.36	735.90	736.47	736.20	740.70	740.00
3.610	Q	6316	6216	---	---	6313	6051
	H	728.28	729.20	---	---	725.29	724.30
4.590	Q	6301	6176	6306	6103	6298	6027
	H	712.50	712.60	712.62	712.70	708.62	708.50

Table 3. Continued

G. 1.00 PMF, breach parameters: TF=0.50, BBW=92, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	790.50	92.00	0.50	836.50	790.50	837.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	106595	97577	107127	97577	106595	97577
	H	815.90	---	818.37	---	810.57	---
0.980	Q	98163	82427	---	---	98961	88419
	H	781.08	775.60	---	---	778.66	773.80
1.440	Q	91650	80320	93199	76698	94556	86307
	H	775.15	773.40	775.25	772.10	770.07	766.50
2.410	Q	84718	69542	---	---	85872	74032
	H	758.05	757.30	---	---	754.50	755.40
2.850	Q	80510	68564	81706	65032	83602	71892
	H	749.37	744.60	748.70	744.90	743.86	742.60
3.610	Q	71870	64207	---	---	64293	70507
	H	741.06	739.30	---	---	738.00	734.00
4.590	Q	66718	63143	65823	61578	62087	68851
	H	720.25	719.40	721.21	719.40	715.80	715.50

H. 1.00 PMF, breach parameters: TF=0.50, BBW=92, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	790.50	92.00	0.50	836.50	790.50	838.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	111184	99077	108786	99077	111184	99077
	H	816.33	---	818.84	---	811.01	---
0.980	Q	101022	85034	---	---	101913	90444
	H	781.30	775.70	---	---	778.85	773.90
1.440	Q	94623	82741	95773	79343	97546	87953
	H	775.36	773.60	775.44	772.30	770.26	766.60
2.410	Q	87666	72640	---	---	88922	76847
	H	758.21	757.50	---	---	754.65	755.60
2.850	Q	83621	71620	84531	67900	86768	74938
	H	749.61	744.80	748.90	745.10	743.95	742.60
3.610	Q	75642	67311	---	---	67945	73519
	H	741.31	739.50	---	---	738.36	734.30
4.590	Q	70733	66300	69030	64621	65462	71909
	H	720.63	719.60	721.56	719.60	716.12	715.80

Table 3. Continued

I. 1.00 PMF, breach parameters: TF=0.25, BBW=92. HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	790.50	92.00	0.50	836.50	790.50	838.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	124599	115361	124497	115361	124599	115361
	H	817.49	---	819.98	---	812.10	---
0.980	Q	108583	89551	---	---	109487	98198
	H	781.67	776.00	---	---	779.28	774.30
1.440	Q	99483	86565	101517	82131	103635	94501
	H	775.66	773.90	775.80	772.60	770.54	766.90
2.410	Q	90863	73970	---	---	92236	79050
	H	758.38	757.60	---	---	754.79	755.80
2.850	Q	86000	72787	87258	68642	89633	76591
	H	749.70	744.90	749.03	745.10	744.04	742.60
3.610	Q	76694	67943	---	---	68212	74854
	H	741.36	739.60	---	---	738.38	734.40
4.590	Q	71239	66787	69649	65015	65507	72965
	H	720.67	719.70	721.65	719.60	716.12	715.90

J. 1.00 PMF, breach parameters: TF=1.00, BBW=92, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	790.50	92.00	0.50	836.50	790.50	838.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	90198	81534	91691	81534	90198	81534
	H	814.09	---	816.57	---	809.02	---
0.980	Q	87348	75602	---	---	87903	77918
	H	780.50	775.20	---	---	777.91	773.20
1.440	Q	84043	74304	85077	72719	85737	76800
	H	774.68	772.90	774.68	771.80	769.64	766.10
2.410	Q	80227	68552	---	---	80948	71279
	H	757.79	757.20	---	---	754.27	755.20
2.850	Q	77572	67816	78029	65144	79598	70026
	H	749.31	744.50	748.57	744.90	743.74	742.50
3.610	Q	72056	64766	---	---	66189	69087
	H	741.11	739.30	---	---	738.21	733.90
4.590	Q	68317	63917	66925	62591	64297	68018
	H	720.45	719.40	721.38	719.40	716.06	715.50

Table 3. Continued

K. 1.00 PMF, breach parameters: TF=0.50, BBW=175, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	793.50	175.00	0.50	836.50	790.50	837.00

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	139724	125864	134371	125864	139938	125864
	H	819.82	---	822.30	---	813.63	---
0.980	Q	126322	106672	---	---	127483	114636
	H	782.83	776.90	---	---	780.31	775.20
1.440	Q	116193	102878	115677	97639	121021	111182
	H	776.71	775.10	776.72	773.70	771.52	767.70
2.410	Q	104396	86740	---	---	106621	93804
	H	759.05	758.40	---	---	755.40	756.70
2.850	Q	97544	84711	97197	78850	102509	90545
	H	750.26	745.60	749.54	745.80	744.39	742.90
3.610	Q	84354	76847	---	---	73440	87645
	H	741.77	740.20	---	---	738.80	735.40
4.590	Q	76660	74775	75448	72456	68653	84903
	H	720.81	720.30	721.61	720.20	716.41	716.70

L. 1.00 PMF, breach parameters: TF=0.50, BBW=175, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	793.50	175.00	0.50	836.50	790.50	838.50

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	143175	127183	137880	127183	143413	127183
	H	820.29	---	822.73	---	813.94	---
0.980	Q	129794	108983	---	---	131585	116481
	H	783.10	777.00	---	---	780.51	775.30
1.440	Q	120283	105681	118461	100377	125085	113168
	H	776.95	775.30	776.90	773.90	771.74	767.80
2.410	Q	108288	903611	---	---	10561	96988
	H	759.22	758.60	---	---	755.58	756.90
2.850	Q	101532	88546	100953	82567	106623	93793
	H	750.52	745.90	749.77	746.10	744.51	743.00
3.610	Q	89061	810207	---	---	8016	91039
	H	742.05	740.50	---	---	739.17	735.60
4.590	Q	81096	79009	79471	76544	73399	88595
	H	720.81	720.60	721.62	720.60	716.83	716.90

Table 3. Concluded

M. 1.00 PMF, breach parameters: TF=0.25, BBW=175, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	793.50	175.00	0.50	836.50	790.50	838.50

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	166314	156532	160338	156532	166626	156532
	H	821.89	---	824.17	---	815.68	---
0.980	Q	140573	118267	---	---	142117	130242
	H	783.51	777.50	---	---	781.01	775.90
1.440	Q	126589	113424	126074	106041	133244	125695
	H	777.28	775.90	777.31	774.30	772.05	768.30
2.410	Q	112184	93087	---	---	114843	101377
	H	759.41	758.80	---	---	755.74	757.10
2.850	Q	104228	90840	104200	84142	109958	97369
	H	750.60	746.00	749.90	746.20	744.59	743.10
3.610	Q	89802	82273	---	---	77888	93888
	H	742.07	740.60	---	---	739.15	735.80
4.590	Q	80986	80144	79503	77501	73038	90978
	H	720.71	720.70	721.53	720.60	716.79	717.10

N. 1.00 PMF, breach parameters: TF=1.00, BBW-175, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	793.50	175-00	0.50	836.50	790.50	838.50

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	111685	98076	108837	98076	111797	98076
	H	816.87	---	819.63	---	811.16	---
0.980	Q	105317	91487	---	---	106125	93832
	H	781.75	776.10	---	---	779.15	774.10
1.440	Q	101047	89720	101251	87709	102992	92327
	H	775.81	774.20	775.86	773.00	770.70	766.80
2.410	Q	94988	82228	---	---	96090	86109
	H	758.57	758.10	---	---	754.99	756.20
2.850	Q	91252	80973	91228	77050	93919	84272
	H	750.10	745.40	749.34	745.70	744.19	742.80
3.610	Q	83505	75924	---	---	75366	82585
	H	741.78	740.20	---	---	738.99	735.00
4.590	Q	78132	74547	76930	72647	71445	81041
	H	720.96	720.30	721.82	720.30	716.72	716.40

Table 4. Peak Outflows: Pierce Lake Dam

Table 3-	Item	Inflow flood*	Breach parameters YBMIN	BBW	TF	HF	Peak outflow, cfs NWS	HEC
A	No-reservoir conditions	1.00	-	-	-	-	30,499	30,500
B	"	0.50	-	-	-	-	5,203	15,250
C	"	0.25	-	-	-	-	7,601	7,625
D	No-failure conditions	1.00	-	-	-	-	8,828	28,861
E	"	0.50	-	-	-	-	3,357	13,482
F	"	0.25	-	-	-	-	6,390	6,351
G	Failure conditions	1.00	790.5	92	0.50	837.0	106,595	97,577
H	"	"	"	"	0.50	838.5	111,184	99,077
I	"	"	"	"	0.25	"	124,599	115,361
J	"	"	"	"	1.00	"	90,198	81,534
K	"	"	793.5	175	0.50	837.0	139,724	125,864
L	"	"	"	"	0.50	838.5	143,175	127,183
M	"	"	"	"	0.25	"	166,314	156,532
N	"	"	"	"	1.00	"	111,685	98,076
	SCS method	1.00	Q_p = 84,570 cfs			838.74		

*Inflow flood hydrograph corresponds to 0.25, 0.50, or 1.00 times the probable maximum flood, or PMF, hydrograph

The peak flows, Q_p, and maximum water stages, H , in the 4.5-mile downstream channel are shown in figure 5 for TF = 0.5 hr, BBW = 175 ft, HF-HD = 0.5 ft. The peak outflows with the NWS are higher than with the HEC, though the difference decreases downstream. The PMF hydrograph for rhe no-reservoir condition is translated downstream with only minimum attenuation because the PMF crest lasts more than the travel time in the 4.5-mile reach. The maximum flood stages with the NWS are higher than with the HEC. The flood stage profile with the HEC seems less reasonable (because of significant undulations in levels) than with the NWS. The flood stage with the PMF and no-reservoir condition, just below the dam, is about 16 ft lower than with the NWS and breach parameters under consideration. The difference in flood stage decreases downstream to a minimum of 6 ft.

The whole range of peak flows and maximum water stages in the 4.5-mile downstream channel are shown in figure 6. The peak outflow below the dam varies from 166,314 to 81,534 cfs and at the end of the 4.5-mile reach, from 80,986 to 63,917 cfs. Thus the flow range narrows with distance downstream. The flood stages in figure 6 follow the same pattern as in figure 5.

The effect of three different sets of cross sections (6 surveyed sections, 3 surveyed sections, and 6 sections from 7.5' quadrangle maps) on the peak discharges and maximum flood stages in the downstream channel is shown in figure 7. The variation in peak discharges is about 0 to 10%. The maximum flood stages with the NWS are similar for 6 and 3 surveyed cross sections and are consistently higher than with the 7.5' map cross

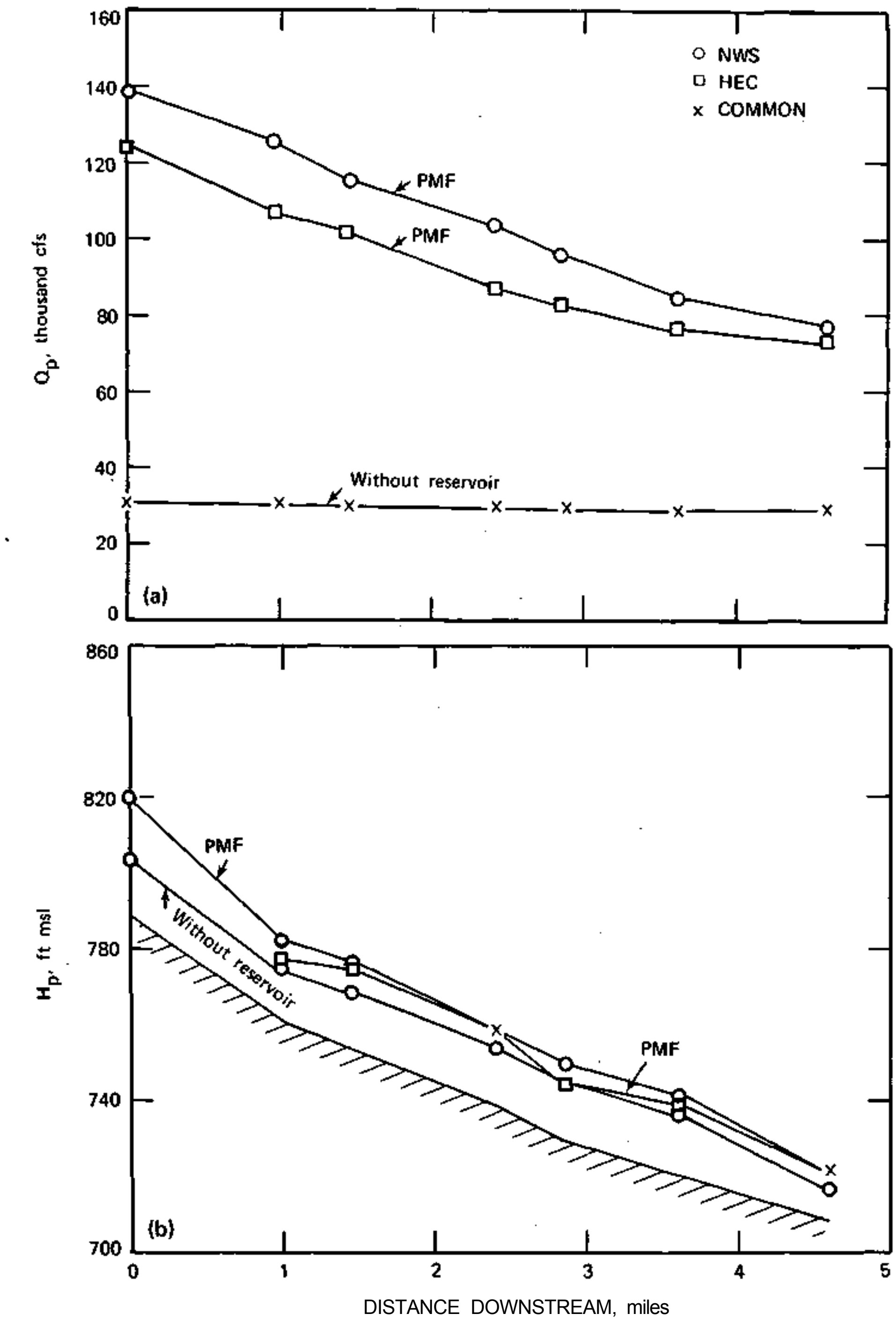


Figure 5. Peak flows and flood stages downstream of Pierce Lake Dam (PMF, BBW = 175 ft, TF = 0.50 hour, h_f = 0.5 ft)

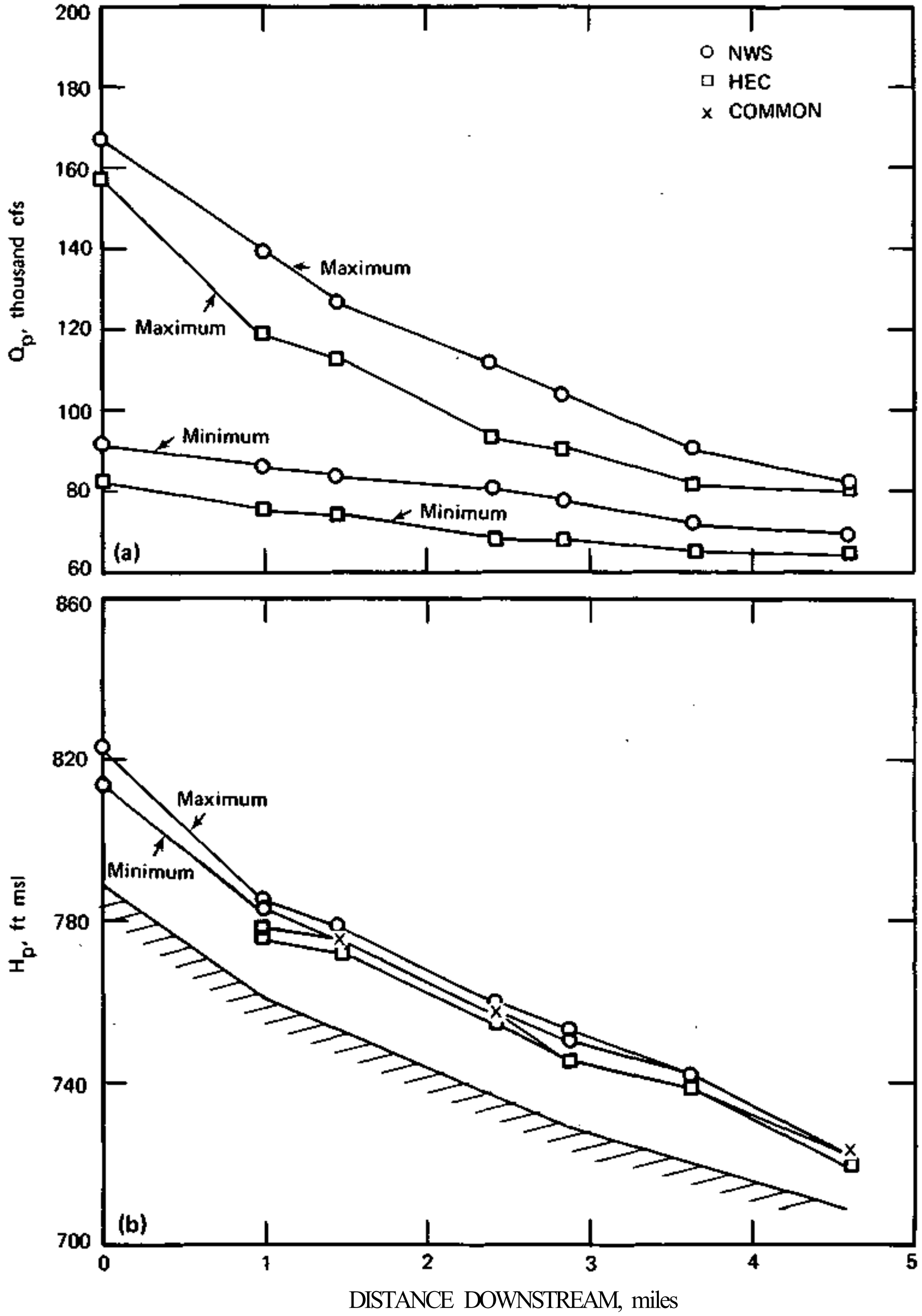


Figure 6. Maximum and minimum flood peaks and stages: Pierce Lake Dam

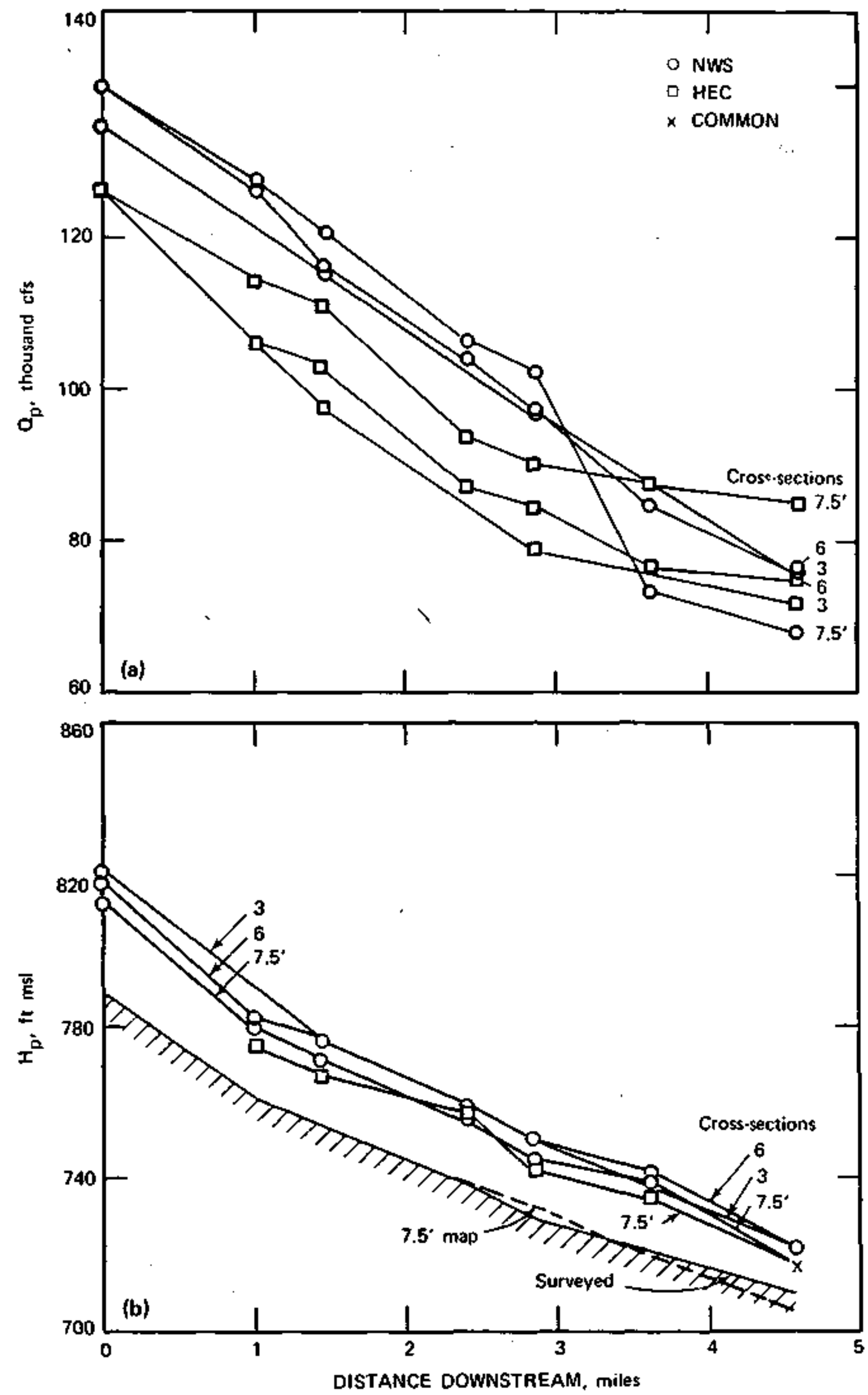


Figure 7. Peak flows and flood stages downstream of Pierce Lake Dam with surveyed and 7.5' map cross sections

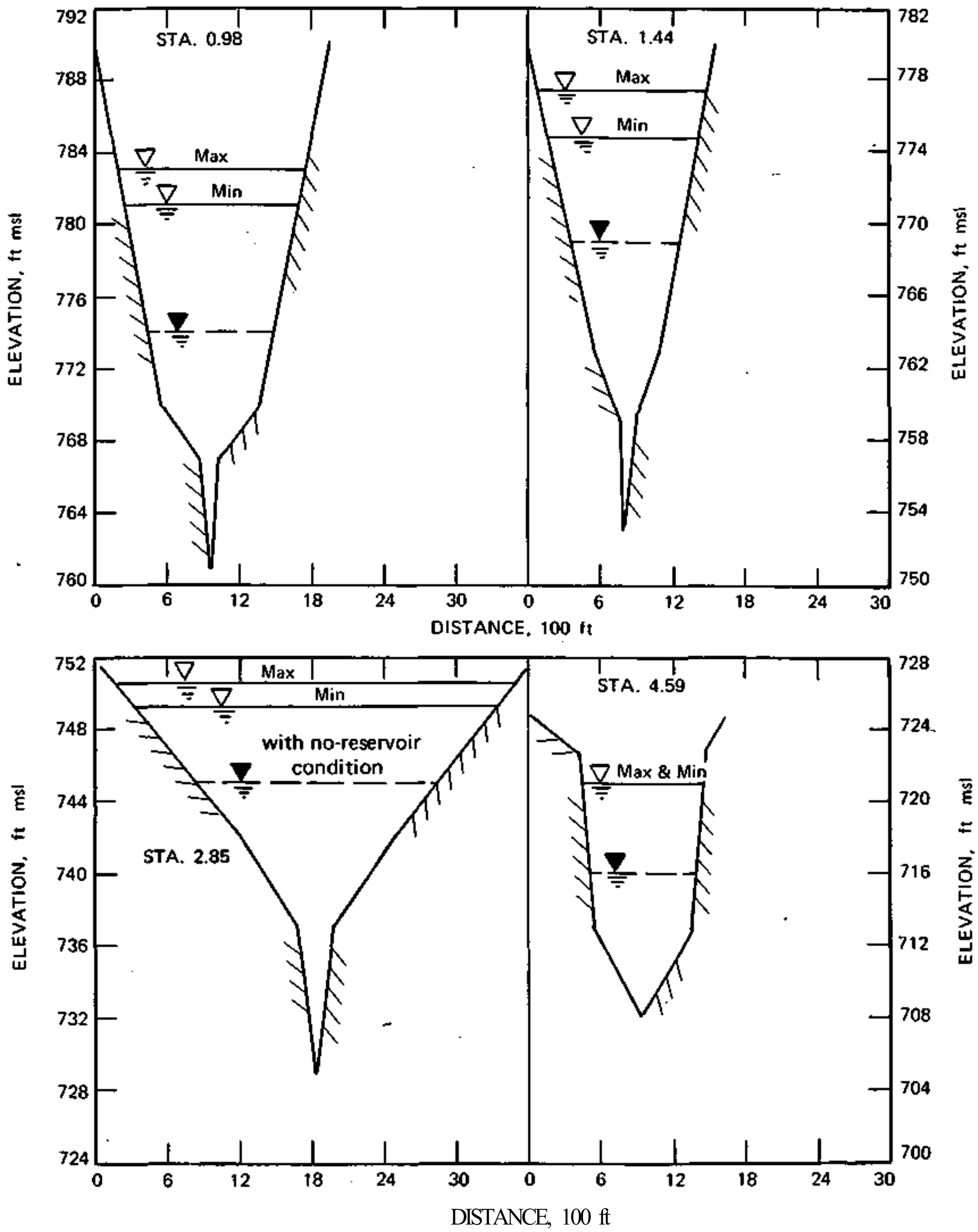


Figure 8. Range of peak flood stages downstream of Pierce Lake Dam

sections. The same holds true for the HEC, but only the results with the 7.5' map cross sections are shown.

The maximum and minimum flood stages with the breach and with those for the PMF and no-reservoir condition are shown in figure 8 for four selected surveyed cross sections along the downstream channel, as calculated by the NWS.

The actual extent of flooding in the floodplain downstream of the dam is difficult to assess when the floodplain boundaries are not well defined. The programs are not designed to handle flow that is so clearly two-dimensional, and even if the NWS allows for lateral losses (e.g. flood waters spilling to the adjoining basin/basins and storage along the channel), these losses are difficult to estimate. The flow resistance in the floodplain is also difficult to simulate because at flood levels as high as the simulations predict, residential areas with houses and other structures will change the flow pattern significantly.

II. Lake in the Hills Dam #1

Lake in the Hills Dam #1 (figure 9) is located on Woods Creek, a tributary to the Fox River, McHenry County, Illinois. It is an earthfill structure, approximately 40 ft high and 780 ft long. The appurtenant works consist of a concrete chute spillway adjacent to the right abutment and outlet works. The watershed is predominantly cultivated farmland with urban residential area around the lake. Basin elevations range from 820 to 930 ft msl.

The dam is classified in the intermediate size and high hazard potential category. A residential subdivision is located just downsteam of

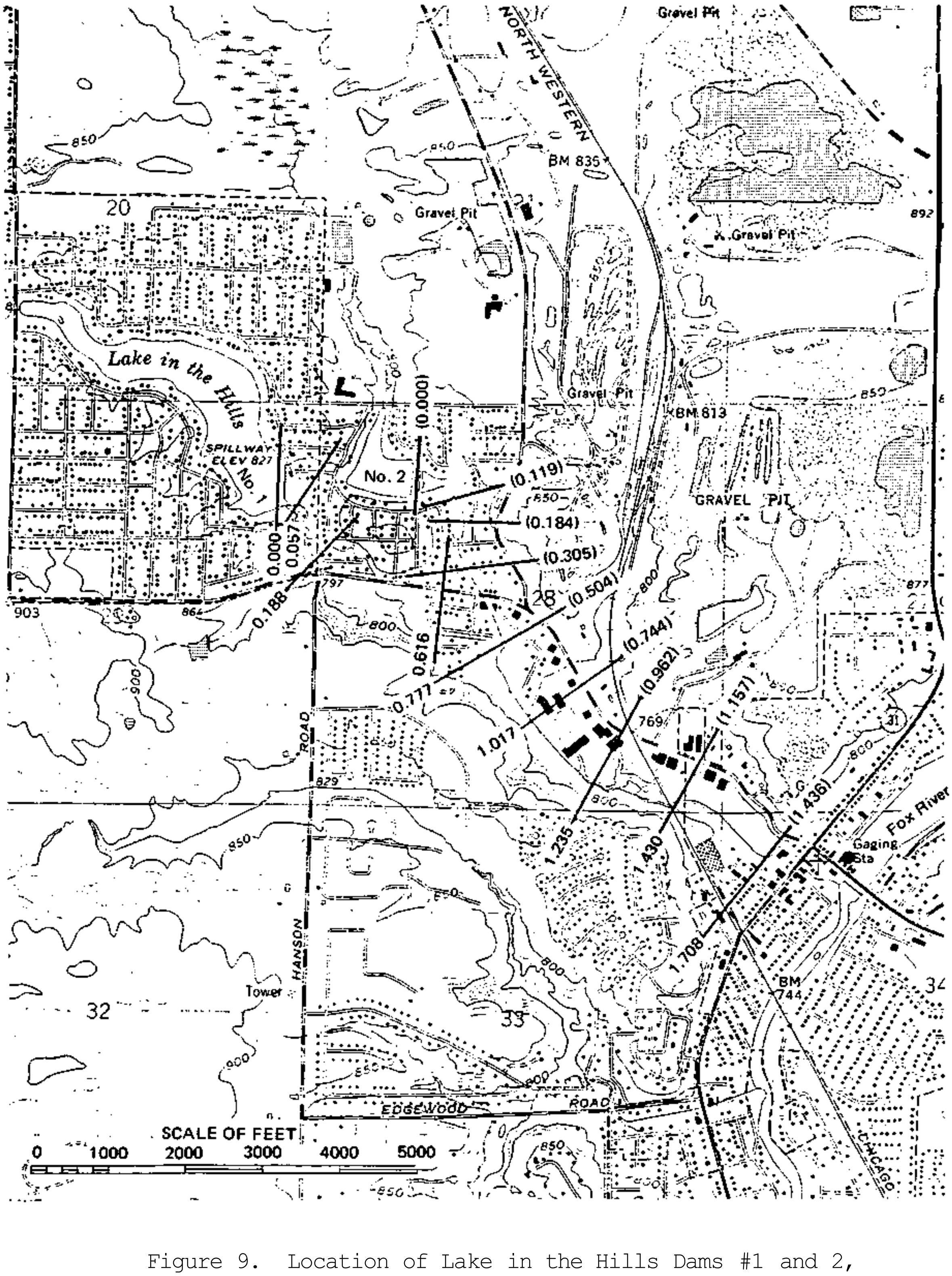


Figure 9. Location of Lake in the Hills Dams #1 and 2, and downstream channel cross sections

the dam, so its failure can cause extensive property damage and endanger human lives. Pertinent data about the dam, spillway and reservoir are given below.

Pertinent data - Lake in the Hills Dam #1

Drainage area	8.52 sq mi
Dam	
Elevation, top of dam	827.0 ft msl
Height above streambed	40.0 ft
Length	780.0 ft
Type	Earth embankment
Reservoir	
Elevation, normal pool*	822.0 ft msl
Area, normal pool	53.0 ac
Capacity, normal pool	598 ac ft
Length, normal pool	0.8 mi
Spillway	
Elevation, weir crest	822.0 ft msl
Length, crest	29.8 ft
Type	Concrete broad-crested weir
Freeboard	
With normal pool	5.0 ft
With 10-year flood event	1.0 ft

*Top of spillway crest

The basic hydrologic and hydraulic data in table 5 consist of the PMF hydrograph generated by the HEC-1 program and information on reservoir area and capacity and combined discharge versus elevation. The information presented above follows the Lake in the Hills Dam #1 Inspection Report (COE, 1978b).

The surveyed cross sections were supplied by the DOWR. Cross sections were also developed from 7.5' quadrangle maps. The location of the

Table 5. PMF Hydrograph and Elevation-Area-Storage-Discharge Data: Lake in the Hills Dam #1

a. PMF Inflow Hydrograph

Time (hr)	0	0.5	1.0	1.5	2.0	2.5
Inflow (cfs)	2,000	2,400	2,800	3,500	4,100	5,100
Time (hr)	3.0	3.5	4.0	4.5	5.0	5.5
Inflow (cfs)	6,100	7,000	7,600	8,100	8,270	8,330
Time (hr)	6.0	6.5	7.0	7.5	8.0	8.5
Inflow (cfs)	8,370	8,400	8,390	8,300	8,000	7,600
Time (hr)	9.0	9.5	10.0	10.5	11.0	11.5
Inflow (cfs)	7,200	6,800	6,400	6,000	5,700	5,400
Time (hr)	12.0	12.5	13.0	13.5	14.0	14.5
Inflow (cfs)	5,100	4,800	4,600	4,300	4,000	3,800
Time (hr)	15.0	15.5	16.0	16.5	17.0	17.5
Inflow (cfs)	3,600	3,350	3,200	3,000	2,800	2,650
Time (hr)	18.0	18.5	19.0	19.5	20.0	20.5
Inflow (cfs)	2,500	2,350	2,250	2,200	2,100	2,050

b. Elevation-Area-Storage-Discharge Data

Elevation (ft msl)	Area (ac)	Storage (ac ft)	Discharge (cfs)
787.0	0	0	0
822.0	53	598	0
822.8	59	643	50
824.5	73	755	284
826.0	88	876	627
827.0	99	969	876
827.5	105	1,020	1,807
828.0	111	1,074	3,403
829.0	127	1,194	7,817
830.0	141	1,327	13,468
831.0	158	1,477	20,121

surveyed and the map cross sections are shown in figure 9. The Manning's roughness coefficient, n, was estimated by visual observation to be 0.05 for the channel and 0.07 for the overbank flow (COE, 1978b).

Analyses and Results

Below the Lake in the Hills Dam #1, Woods Creek flows in a southeasterly direction for about 2 miles to its confluence with the Fox River. The channel and the overbanks are steep and narrow close to the dam, becoming wider and flatter about 0.4 mile downstream. At about 0.8 mile downstream of the dam, Woods Creek joins with Crystal Lake Creek which is dammed by the Lake in the Hills Dam #2 about 0.4 mile upstream of the confluence. Residential and industrial areas exist in the floodplain.

The breach parameters were chosen on the basis of the guidelines established previously. The bbttom elevation of the breach, YBMIN, was set at 789.0 ft which is about 2 ft above the channel bottom elevation. The bottom breach width, BBW, was set at 80 and 160 ft for the small and large breach, respectively. The time from the inception of the breach to its completion, TF, has been taken as 0.25, 0.50, or 1.00 hour. The depth of overtopping when the breach starts, or h_f equal to HF-HD, has been taken as 0.5 or 2.0 ft; the HF and HD denote the failure elevation and elevation of the top of the dam, respectively.

Results from the simulations of floods are given in tables 6-A to 6-C for no-reservoir condition and in tables 6-D to 6-F with the reservoir and dam intact. It is apparent that all floods (1.00 PMF, 0.50 PMF, and 0.25 PMF) will overtop the dam, with the PMF breaching it for both failure elevations and the 0.50 PMF and 0.25 PMF breaching it for the lower failure

Table 6. Summary of Results for Lake in the Hills Dam #1

A. 1.00 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	8399	8399	8399	8399	8399	8399
	H	797.31	---	794.19	---	795.03	---
0.057	0	8399	8399	---	---	8399	8399
	H	796.33	795.20	---	---	794.01	792.30
0.188	Q	8399	8399	8399	8399	8399	8399
	H	791.11	789.20	790.76	789.40	788.81	787.90
0.616	Q	8398	8397	---	---	8398	8397
	H	775.45	776.90	---	---	775.44	775.80
0.777	Q	8398	8397	8397	8396	8398	8397
	H	769.26	767.50	768.57	767.90	767.30	766.70
1.017	Q	8397	8396	---	---	8397	8396
	H	763.51	763.10	---	---	759.78	760.20
1.235	Q	8397	8396	8397	8395	8397	8396
	H	755.04	755.10	755.73	755.00	751.75	750.90
1.430	Q	8397	8396	---	---	8397	8396
	H	746.94	745.90	---	---	747.45	746.90
1.708	Q	8396	8396	8396	8394	8396	'8396
	K	738.68	738.40	738.30	738.10	740.66	740.20

B. 0.50 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	4199	4200	4199	4200	4 1 9 9	4 2 0 0
	H	795.12	---	792.04	---	792.93	---
0.057	Q	4199	4200	---	---	4199	4200
	H	794.40	793.70	---	---	792.01	790.80
0.188	Q	4199	4199	4199	4199	4199	4199
	H	789.27	787.80	788.99	787.90	786.54	785.90
0.616	Q	4199	4198	---	---	4198	4197
	H	774.73	775.60	---	---	773.11	774.40
0.777	Q	4198	4198	4198	4197	4198	4197
	H	767.73	766.40	767.23	766.70	765.86	765.30
1.017	Q	4198	4197	---	---	4198	4197
	H	762.58	762.00	---	---	758.90	759.00
1.235	Q	4198	4197	4198	4197	4198	4197
	H	753.03	753.10	753.50	753.00	750.45	750.00
1.430	Q	4198	4197	---	---	4198	4197
	H	745.29	744.30	---	---	745.65	745.20
1.708	Q	4198	4197	4198	4196	4198	4197
	H	736.55	736.50	736.41	736.30	738.57	738.60

Table 6. Continued

C. 0.25 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	---	---	---

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	2099	2100	2099	2100	2099	2100
	H	793.38	---	790.73	---	791.29	---
0.057	Q	2099	2100	---	---	2099	2100
	H	792.86	792.40	---	---	789.99	789.40
0.188	Q	2099	2100	2099	2100	2099	2100
	H	787.92	786.80	787.70	786.90	781.82	784.20
0.616	Q	2099	2099	---	---	2099	2099
	H	771.93	771.70	---	---	772.21	773.10
0.777	Q	2099	2098	2099	2098	2099	2099
	H	766.31	765.50	766.07	765.70	761.70	761.30
1.017	Q	2099	2098	---	---	2099	2098
	H	761.09	760.10	---	---	757.95	758.00
1.235	Q	2099	2098	2099	2098	2099	2098
	H	752.44	751.90	752.22	751.90	719.61	749.10
1.430	Q	2099	2098	---	---	2099	2098
	H	713.64	743.00	---	---	711.26	713.80
1.708	Q	2098	2098	2099	2098	2099	2098
	H	735.20	735.10	735.16	735.00	737.23	737.20

D. 1.00 PMF. HF=maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	827.00	789.00	829.09

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	8392	8392	8392	8392	8392	8392
	H	797.33	---	791.18	---	795.03	---
0.057	Q	8392	8392	---	---	8392	8392
	H	796.33	795.20	---	---	791.00	792.30'
0.188	Q	8392	8392	8392	8392	8392	8392
	H	791.11	789.20	790.76	789.40	788.81	787.90
0.616	Q	8392	8391	---	---	8392	8391
	H	775.45	776.90	---	---	775.11	775.80
0.777	Q	8392	8391	8392	8390	8392	8391
	H	769.25	767.50	768.57	767.90	767.30	766.70
1.017	Q	8392	8391	---	---	8392	8391
	H	763.51	763.10	---	---	759.78	760.20
1.235	Q	8392	8390	8392	8389	8392	8391
	H	755.01	755.10	755.73	755.00	751.75	750.90
1.430	Q	8392	8390	---	---	8392	8390
	H	716.91	715.90	---	---	747.44	746.90
1.708	Q	8392	8390	8391	8388	8391	8390
	H	738.68	738.40	738.30	738.10	710.65	710.20

Table 6. Continued

E. 0.50 PMF, HF=maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	827.00	789.00	828.10

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	4194	4195	4194	4195	4194	4195
	H	795.12	---	792.03	---	792.93	---
0.057	Q	4194	4195	---	---	4194	4195
	H	794.40	793.70	---	---	792.00	790.80
0.188	Q	4194	4195	4194	4195	4194	4195
	H	789.27	787.80	788.98	787.90	786.54	785.90
0.616	Q	4194	4194	---	---	4194	4194
	H	774.73	775.60	---	---	773.11	774.40
0.777	Q	4194	4194	4194	4193	4194	4193
	H	767.73	766.40	767.23	766.70	765.86	765.30
1.017	Q	4194	4193	---	---	4194	4193
	H	762.58	762.00	---	---	758.90	759.00
1.235	Q	4194	4193	4194	4193	4194	4193
	H	753.02	753.10	753.50	753.00	750.45	750.00
1.430	Q	4194	4193	---	---	4194	4193
	H	745.28	744.30	---	---	745.65	745.20
1.708	Q	4194	4193	4194	4192	4194	4193
	H	736.55	736.50	736.41	736.30	738.57	738.50

F. 0.25 PMF, HF=maxlmum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	827.00	789.00	827.57

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	2133	2093	2094	2093	2094	2093
	H	793.44	---	790.73	---	791.29	---
0.057	Q	2133	2093	---	---	2094	2093
	H	792.94	792.40	---	---	789.99	789.40
0.188	Q	2133	2093	2094	2093	2094	2093
	H	787.88	786.80	787.69	786.90	784.81	784.20
0.616	Q	2133	2091	---	---	2094	2091
	H	774.32	774.70	---	---	772.21	773.10
0.777	Q	2133	2091	2094	2090	2094	2091
	H	766.37	765.50	766.05	765.70	764.70	764.20
1.017	Q	2132	2090	---	---	2094	2090
	H	760.92	760.40	---	---	757.95	758.00
1.235	Q	2132	2090	2094	2089	2094	2090
	H	751.83	751.90	752.22	751.90	749.61	749.40
1.430	Q	2132	2090	---	---	2094	2090
	H	743.69	743.00	---	---	744.26	743.80
1.708	Q	2132	2089	2093	2088	2093	2089
	H	735.22	735.10	735.15	735.00	737.22	737.20

Table 6. Continued

G. 1.00 PMF, breach parameters: TF=0.50, BBW=80, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	789.00	80.00	0.50	827.00	789.00	827.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	45980	35607	45251	35607	45809	35607
	H	805.16	---	805.01	---	803.37	---
0.057	Q	15271	35141	---	---	15170	35267
	H	803.56	800.00	---	---	801.18	797.10
0.188	Q	11362	31051	11513	31212	13999	33792
	H	798.76	791.30	797.99	791.70	796.37	793.90
0.616	Q	12578	31012	---	---	12352	30951
	H	779.87	781.50	---	---	780.63	780.10
0.777	Q	11825	30600	11953	29137	11591	30608
	H	771.12	770.10	773.71	771.00	773.11	770.30
1.017	Q	10250	28682	---	---	10391	28721
	H	768.19	765.90	---	---	761.21	763.10
1.235	Q	39299	29283	39157	26221	38115	29368
	H	760.13	758.70	760.78	758.20	757.87	753.70
1.130	Q	38319	28673	---	---	36839	29137
	H	753.16	719.60	---	---	753.96	751.10
1.708	Q	36221	27522	36715	23768	35201	27589
	H	715.33	712.90	711.99	711.90	716.60	711.10

H. 1.00 PMF, breach parameters: TF=0.50, BBW=80, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	789.00	80.00	0.50	827.00	789.00	829.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	51977	13187	51716	13187	52122	13187
	H	806.02	---	806.21	---	801.33	---
0.057	Q	51115	39616	---	---	52056	39803
	H	801.15	800.60	---	---	802.38	797.60
0.188	Q	50557	38211	50952	38189	50321	37879
	H	799.61	791.90	798.81	795.30	797.26	791.50
0.616	Q	18893	36951	---	---	18523	36821
	H	780.11	782.10	---	---	781.25	781.30
0.777	Q	17788	36171	18072	35087	17677	36352
	H	775.08	770.90	771.43	771.60	773.91	770.90
1.017	Q	16051	31608	---	---	16220	31612
	H	768.79	766.50	---	---	761.91	763.80
1.235	Q	15102	31961	45044	32747	44031	35013
	H	760.73	759.30	761.42	759.00	758.86	754.30
1.430	Q	43932	34592	---	---	12133	34818
	H	754.31	750.10	---	---	754.96	751.80
1.708	Q	42975	32977	43132	30164	10685	32961
	H	715.78	713.70	715.71	712.90	718.09	714.90

Table 6. Continued

I. 1.00 PMF, breach parameters: TF=0.25, BBW=80, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	789.00	80.00	0.50	827.00	789.00	829.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	64742	60423	64742	60423	64482	60423 .
	H	807.32	---	807.81	---	805.61	---
0.057	Q	63004	46521	---	---	62873	46178
	H	805.61	801.30	---	---	803.53	798.40
0.188	Q	60159	48176	61488	47549	59926	48297
	H	800.80	796.20	800.06	796.60	798.34	796.10
0.616	Q	56959	42844	---	---	56272	42439
	H	781.15	783.20	---	---	781.98	782.10
0.777	Q	55073	40587	55584	38833	54809	40619
	H	775.76	771.30	775.10	772.00	774.78	771.20
1.017	Q	51981	41588	---	---	52289	41517
	H	769.32	767.10	---	---	765.54	764.50
1.235	Q	50613	39638	50340	36709	48887	40056
	H	761.32	759.80	761.94	759.40	759.48	754.80
1.430	Q	48565	38192	---	---	46341	37792
	H	754.82	750.80	---	---	755.51	752.10
1.708	Q	46919	37359	47100	33046	43672	38243
	H	746.16	744.20	746.17	743.30	748.55	745.60

J. 1.00 PMF, breach parameters: TF=1.00, BBW=80. HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	789.00	80.00	0.50	827.00	789.00	829.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	36036	29014	36060	29014	35999	29014
	H	803.83	---	803.21	---	801.87	---
0.057	Q	36019	28497	---	---	35923	28522
	H	802.35	799.20	---	---	800.13	796.20
0.188	Q	35912	28271	35936	28301	35670	28261
	H	797.49	793.40	796.77	793.80	795.13	792.90
0.616	Q	35351	26353	---	---	35389	26375
	H	779.11	780.70	---	---	779.87	779.60
0.777	Q	35265	26545	35241	25890	35169	26525
	H	773.73	769.90	773.04	770.60	772.24	769.90
1.017	Q	34809	26132	---	---	34772	26007
	H	767.65	765.60	---	---	763.63	762.80
1.235	Q	34522	25587	34385	24835	34296	25580
	H	759.55	758.20	760.27	758.00	757.34	753.30
1.430	Q	34340	25707	---	---	33748	25779
	H	752.60	749.20	---	---	753.55	750.60
1.708	Q	33955	25268	33935	24280	33105	25349
	H	745.30	742.50	744.73	742.00	746.97	743.70

Table 6. Continued

K. 1.00 PMF, breach parameters: TF=0.50, BBW=160, HF-HD=0.5 '

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	789.00	160.00	0.50	827.00	789.00	827.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	55018	41230	55134	41230	55157	41230
	H	806.60	---	806.82	---	804.78	---
0.057	Q	54917	39503	---	---	54912	39526
	H	804.99	800.60	---	---	802.85	797.60
0.188	Q	54495	38357	54528	38525	53989	38269
	H	800.22	794.90	799.33	795.40	797.78	794.60
0.616	Q	53029	33614	---	---	52746	33535
	H	780.75	781.90	---	---	781.67	780.80
0.777	Q	52155	33277	51915	30985	51853	33231
	H	775.55	770.60	774.90	771.20	774.51	770.60
1.017	Q	50116	31654	---	---	50336	31613
	H	769.18	766.20	---	---	765.35	763.40
1.235	Q	49221	32029	48978	28004	47509	32079
	H	761.16	759.00	761.80	758.40	759.34	754.00
1.430	Q	47342	30009	---	---	45487	31004
	H	754.67	749.80	---	---	755.36	751.30
1.708	Q	45726	29853	46082	25675	43218	30238
	H	745.95	743.20	745.91	742.20	747.71	744.50

L. 1.00 PMF, breach parameters: TF=0.50, BBW=160,HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	789.00	160.00	0.50	827.00	789.00	829.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	63541	49638	63550	49638	63559	49638
	H	807.71	---	808.17	---	805.89	---
0.057	Q	63366	44887	---	---	63317	45045
	H	806.03	801.10	---	---	803.91	798.20
0.188	Q	62577	43371	62876	43695	62241	43040
	H	801.24	795.60	800.33	796.10	798.83	795.30
0.616	Q	60985	40489	---	---	60959	40410
	H	781.38	782.90	---	---	782.43	781.80
0.777	Q	60182	39996	60152	38207	59869	40333
	H	776.40	771.20	775.75	771.90	775.54	771.20
1.017	Q	58089	37991	---	---	58192	38070
	H	769.93	766.80	---	---	766.23	764.10
1.235	Q	56993	38616	57299	35617	55118	38878
	H	762.02	759.70	762.66	759.30	760.52	754.70
1.430	Q	55916	38196	---	---	52831	38633
	H	755.64	750.80	---	---	756.53	752.20
1.708	Q	54503	36446	54810	32765	50357	36514
	H	746.82	744.10	746.80	743.30	749.45	745.40

Table 6. Continued

M. 1.00 PMF, breach parameters: TF=0.25, BBW=160, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	789.00	160.00	0.50	827.00	789.00	829.00

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	97494	77333	97494	77333	96381	77333
	H	811.02	---	812.11	---	809.09	---
0.057	Q	94925	72559	---	---	93707	72688
	H	808.97	803.70	---	---	806.82	800.90
0.188	Q	90586	68797	92688	68897	89228	67506
	H	'804.05	798.60	803.21	799.10	801.51	798.50
0.616	Q	84092	56127	---	---	82125	56157
	H	783.01	785.00	---	---	781.09	783.90
0.777	Q	80170	55886	81017	51578	79815	56312
	H	777.92	772.10	777.31	773.10	777.15	772.50
1.017	Q	71346	18929	---	---	71027	18367
	H	771.08	767.70	---	---	767.61	765.10
1.235	Q	71270.	19770	70917	12168	67235	49797
	H	763.33	760.80	763.79	760.00	761.76	755.70
1.430	Q	67034	19600	---	---	62361	50106
	H	756.81	752.10	---	---	757.63	753.50
1.708	Q	63763	13301	61752	38688	57151	43782
	H	747.62	744.90	747.68	744.00	750.11	746.30

N. 1.00 PMF, breach parameters: TF=1.00, BBW=160, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	789.00	160.00	0.50	827.00	789.00	829.00

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	38595	32270	38591	32270	38687	32270
	H	804.24	---	803.77	---	802.33	---
0.057	Q	38519	31104	---	---	38607	31376
	H	802.75	799.60	---	---	800.57	796.60
0.188	Q	38523	31120	38566	31126	38454	31035
	H	797.92	793.90	797.18	794.20	795.58	793.40
0.616	Q	38328	28690	---	---	38223	28673
	H.	779.41	781.10	---	---	780.21	780.00
0.777	Q	38079	28810	38108	27966	38114	28860
	H	774.09	770.20	773.42	770.80	772.67	770.20
1.017	Q	37831	28000	---	---	37872	27932
	H	767.97	765.80	---	---	761.00	763.00
1.235	Q	37718	27598	37615	26184	37316	27552
	H	759.93	758.50	760.61	758.20	757.91	753.50
1.130	Q	37318	27619	---	---	36800	27736
	H	753.23	749.50	---	---	754.13	750.90
1.708	Q	36972	26862	37153	25548	36231	27085
	H	715.51	742.80	745.12	742.20	747.19	711.00

Table 6. Continued

O. 0.50 PMF, breach parameters: TF=0.50, BBW=80, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	0.50	789.00	80.00	0.50	827.00	789.00	827.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	44949	34055	44442	34055	44442	34055
	H	805.01	---	804.74	---	803.04	---
0.057	Q	44366	32855	---	---	43727	32935
	H	803.32	799.70	---	---	801.16	796.80
0.188	Q	43081	32076	43484	32197	43198	31892
	H	798.19	794.00	797.86	794.40	796.19	793.60
0.616	Q	41348	29050	---	---	41496	28976
	H	779.73	781.20	---	---	780.41	780.00
0.777	Q	40524	28816	40874	27346	40661	28691
	H	774.32	770.20	773.60	770.80	772.94	770.10
1.017	Q	38630	26840	---	---	39364	26899
	H	768.39	765.70	---	---	764.10	762.90
1.235	Q	37800	27430	38176	24616	37525	27558
	H	759.94	758.40	760.66	758.00	757.77	753.50
1.430	Q	36696	26934	---	---	35907	27382
	H	752.93	749.40	---	---	753.80	750.90
1.708	Q	34801	25837	35666	22244	34158	25921
	H	745.26	742.60	744.87	741.70	746.64	743.80

P. 0.50 PMF, breach parameters: TF=0.50, BBW=160, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	0.50	789.00	160.00	0.50	827.00	789.00	827.50'

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	53155	39550	53653	39550	53653	39550
	H	806.29	---	806.60	---	804.53	---
0.057	Q	52888	38605	---	---	53539	38625
	H	804.67	800.40	---	---	802.57	797.50
0.188	Q	52455	37533	53287	37684	52934	37452
	H	799.66	794.80	799.19	795.20	797.60	794.50
0.616	Q	51521	32568	---	---	51366	32502
	H	780.58	781.70	---	---	781.34	780.60 .
0.777	Q	50706	32287	50799	30035	50496	32215
	H	775.38	770.50	774.76	771.10	774.32	770.50
1.017	Q	48588	30501	---	---	49135	30476
	H	769.41	766.10	---	---	765.16	763.30
1.235	Q	47446	30904	47718	26970	46501	30935
	H	761.01	758.80	761.68	758.30	759.26	753.90
1.430	Q	46349	28952	---	---	44299	29822
	H	754.18	749.60	---	---	755.17	751.20
1.708	Q	44092	28799	44817	24602	41901	29079
	H	746.20	743.10	745.78	742.10	747.80	744.30

Table 6. Concluded

Q. 0.25 PMF, breach parameters: TF=0.50, BBW=80, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	0.50	789.00	80.00	0.50	827.00	789.00	827.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	44135	32175	43814	32175	43250	32175
	H	804.89	---	804.60	---	802.92	---
0.057	Q	43543	29688	---	---	42984	29731
	H	803.23	799.30	---	---	800.98	796.30
0.188	Q	42117	29338	42029	29357	41659	29276
	H	798.05	793.60	797.67	793.90	796.02	793.10
0.616	Q	40522	26422	---	---	40131	26413
	H	779.68	780.70	---	---	780.27	779.60
0.777	Q	39619	26381	39679	24947	39415	26247
	H	774.21	769.90	773.48	770.50	772.77	769.90
1.017	Q	37807	24578	---	---	38264	24555
	H	768.30	765.40	---	---	763.97	762.60
1.235	Q	36885	25084	36854	22495	36306	25133
	H	759.84	758.10	760.53	757.70	757.58	753.30
1.430	Q	35841	24675	---	---	34799	25026
	H	752.81	749.00	---	---	753.59	750.50
1.708	Q	33926	23586	34358	20326	33011	23701
	H	745.17	742.20	744.72	741.30	746.45	743.50

R. 0.25 PMF, breach parameters: TF=0.50, BBW=160, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	0.50	789.00	160.00	0.50	827.00	789.00	827.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	51868	37450	51889	37450	51888	37450
	H	806.10	---	806.27	---	804.27	---
0.057	Q	51635	36528	---	---	51727	36528
	H	804.49	800.20	---	---	802.31	797.20
0.188	Q	51183	35693	51265	35797	50998	35642
	H	799.49	794.50	798.95	794.90	797.37	794.20
0.616	Q	50411	30618	---	---	49865	30554
	H	780.48	781.40	---	---	781.20	780.30
0.777	Q	49555	30457	49154	28271	48865	30253
	H	775.26	770.30	774.59	770.90	774.11	770.30
1.017	Q	47552	28523	---	---	47643	28548
	H	769.30	765.90	---	---	764.98	763.10
1.235	Q	46357	28927	46147	25312	44946	28933
	H	760.88	758.60	761.53	758.10	759.01	753.70
1.430	Q	45230	27129	---	---	43052	27786
	H	754.05	749.40	---	---	754.96	750.90
1.708	Q	42956	27021	43338	22947	40662	27202
	H	746.09	742.80	745.65	741.80	747.61	744.00

elevation. It should be noted that a 10-year flood hydrograph leaves a freeboard of only 1 ft. Results from 8 combinations of breach parameters with the PMF hydrograph are given in table 6-G to 6-N. Results from 2 combinations of breach parameters with the 0.50 PMF and 0.25 PMF hydrographs are given in tables 6-0 to 6-R.

The peak discharges for both methods and all combinations of breach parameters, along with the peak discharges as determined by the SCS method, are shown in table 7. The peak discharges for no-reservoir condition are essentially the same as for no-failure condition due to small storage in the reservoir. The peak outflows with the NWS and failure of the dam are about 7 to 38% higher than with the HEC. This is due to difference in the mode of breach formation. Increase in peak outflows due to higher failure elevations is about 14% with the NWS and 20% with the HEC, whereas it is 25 to 65% with a 50% reduction in failure time. Bigger breach size results in an increase of about 7 to 51% in peak outflow. The peak values are slightly lower with the 0.50 PMF and 0.25 PMF floods than with the PMF flood. The peak outflow in general varies from about 3.5 to about 11.5 times the PMF inflow peak and up to 25 times the 0.25 PMF inflow peak. The peak outflows determined with the SCS method range from about 61 to 66 thousand cfs.

The peak flows and maximum water stages in the 1.7-mi downstream channel are shown in figure 10 for TF = 0.5 hr, BBW = 160, HF-HD = 0.5 ft. The peak flows are higher for the NWS than with HEC, and the difference is approximately constant along the channel. The maximum flood stages are usually higher with the NWS, but with the PMF and no-reservoir condition, the profiles with both the NWS and HEC agree quite well. The profiles due

Table 7. Peak Outflows: Lake in the Hills Dam #1

Table 6-	Item	Inflow flood*	Breach parameters YBMIN	BBW	TF	HF	Peak outflow, cfs NWS	HEC
A	No-reservoir conditions	1.00	-	-	-	-	8,399	8,399
B	"	0.50	-	-	-	-	4,199	4,200
C	"	0.25	-	-	-	-	2,099	2,100
D	No-failure conditions	1.00	-	-	-	-	8,392	8,392
E	"	0.50	-	-	-	-	4,194	4,195
F	"	0.25	-	-	-	-	2,094	2,093
G	Failure conditions	1.00	789	80	0.50	827.5	45,980	35,607
H	"	"	"	"	0.50	829.0	51,977	43,187
I	"	"	"	"	0.25	"	64,742	60,423
J	"	"	"	"	1.00	"	36,036	29,014
K	"	"	"	160	0.50	827.5	55,018	41,230
L	"	"	"	"	0.50	829.0	63,541	49,638
M	"	"	"	"	0.25	"	97,494	77,333
N	•	"	"	"	1.00	"	38,595	32,270
O	"	0.50	"	80	0.50	827.5	44,134	34,055
P	"	"	"	160	"	"	53,692	39,550
Q	"	0.25	"	80	"	"	44,135	32,175
R	"	"	"	160	"	"	51,868	37,450
	SCS method	1.00	Q_p =	65,712	cfs	829.09		
		0.50	Q_p =	62,881	cfs	828.10		
		0.25	Q_p =	61,389	cfs	827.57		

*Inflow flood hydrograph corresponds to 0.25, 0.50, or 1.00 times the probable maximum flood, PMF, hydrograph

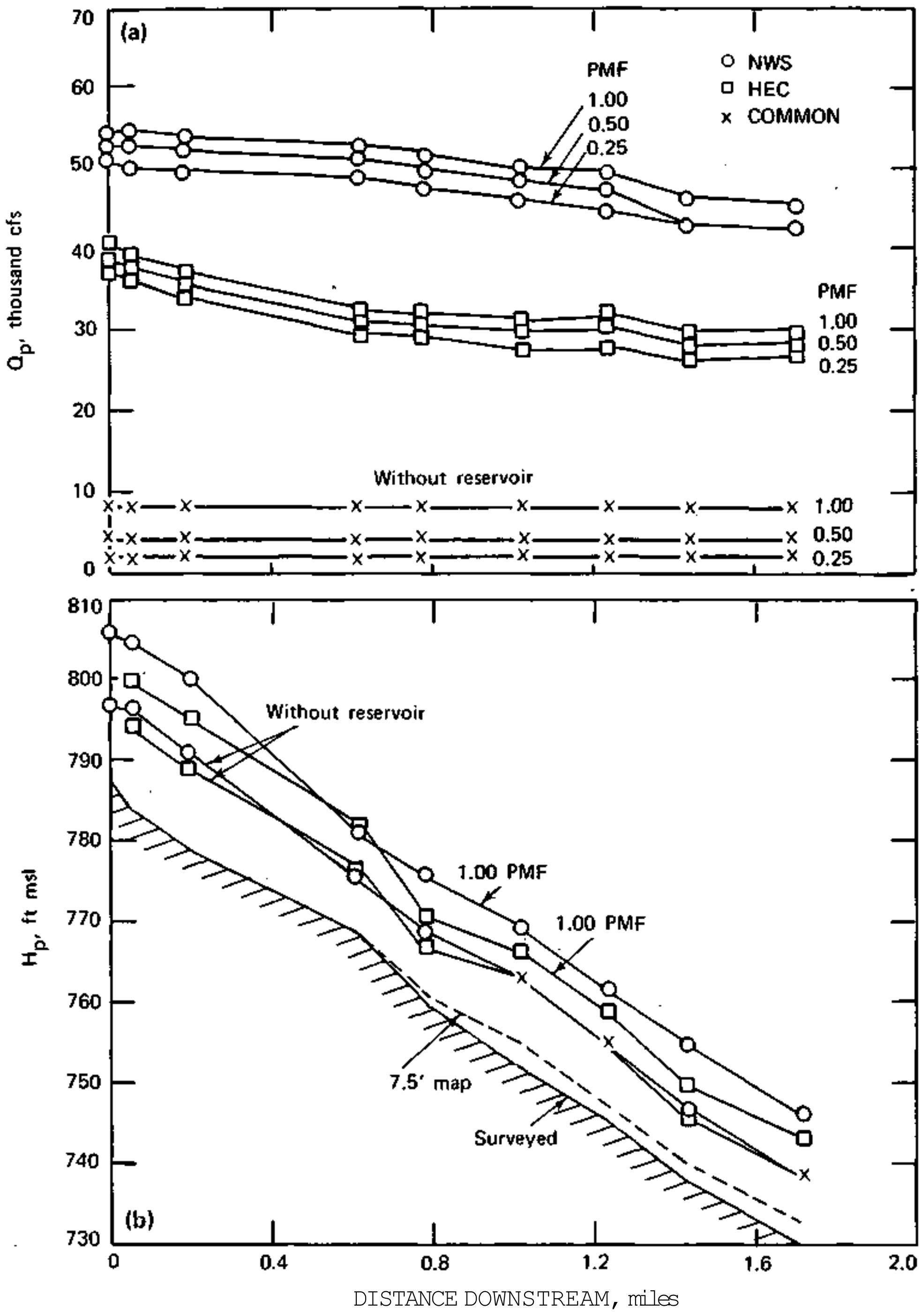


Figure 10. Peak flows and flood stages downstream of Lake in the Hills Dam #1 (BBW = 160 ft, TF = 0.50 hour; h_f = 0.5 ft)

to breach with 0.50 PMF and 0.25 PMF behave in much the same way as with 1.00 PMF, but these have been left out for clarity.

The whole range of peak flows and maximum water stages from dam breach with the PMF, in the 1.7-mi downstream channel, are shown in figure 11. The peak outflow below the dam varies from 97,494 to 29,014 cfs and at the end of the 1.7-mi reach, from 63,763 to 25,268 cfs. Thus, the flow range narrows with distance downstream. The flood stages in figure 11 follow the same pattern as in figure 10. The maximum flood stage difference is 11 ft about 0.2-mile downstream of the dam, decreasing downstream to about 5 ft at the end of the 1.7-mile reach.

The effect of the three different sets of cross sections (8 surveyed sections, 4 surveyed sections, and 8 section developed from the 7.5' quadrangle maps) on the peak discharges and maximum flood stages in the 1.7-mi downstream channel is shown in figure 12. The peak discharges with 8 and 4 surveyed cross sections are practically the same, but they are lower with the map sections in the lower one-half of the channel in the case of the NWS. The flow peaks with 8 surveyed and map sections are practically the same with the HEC, but they are lower with the 4 surveyed cross sections. The flood stages are essentially the same with 8 and 4 surveyed cross sections and criss-cross those with the 7.5' map cross sections.

The maximum and minimum flood stages with the breach and with no-reservoir condition for the 1.00 PMF are shown in figure 13 for four selected cross sections along the downstream channel, as calculated by the NWS. The elevation difference between the maximum and minimum decreases

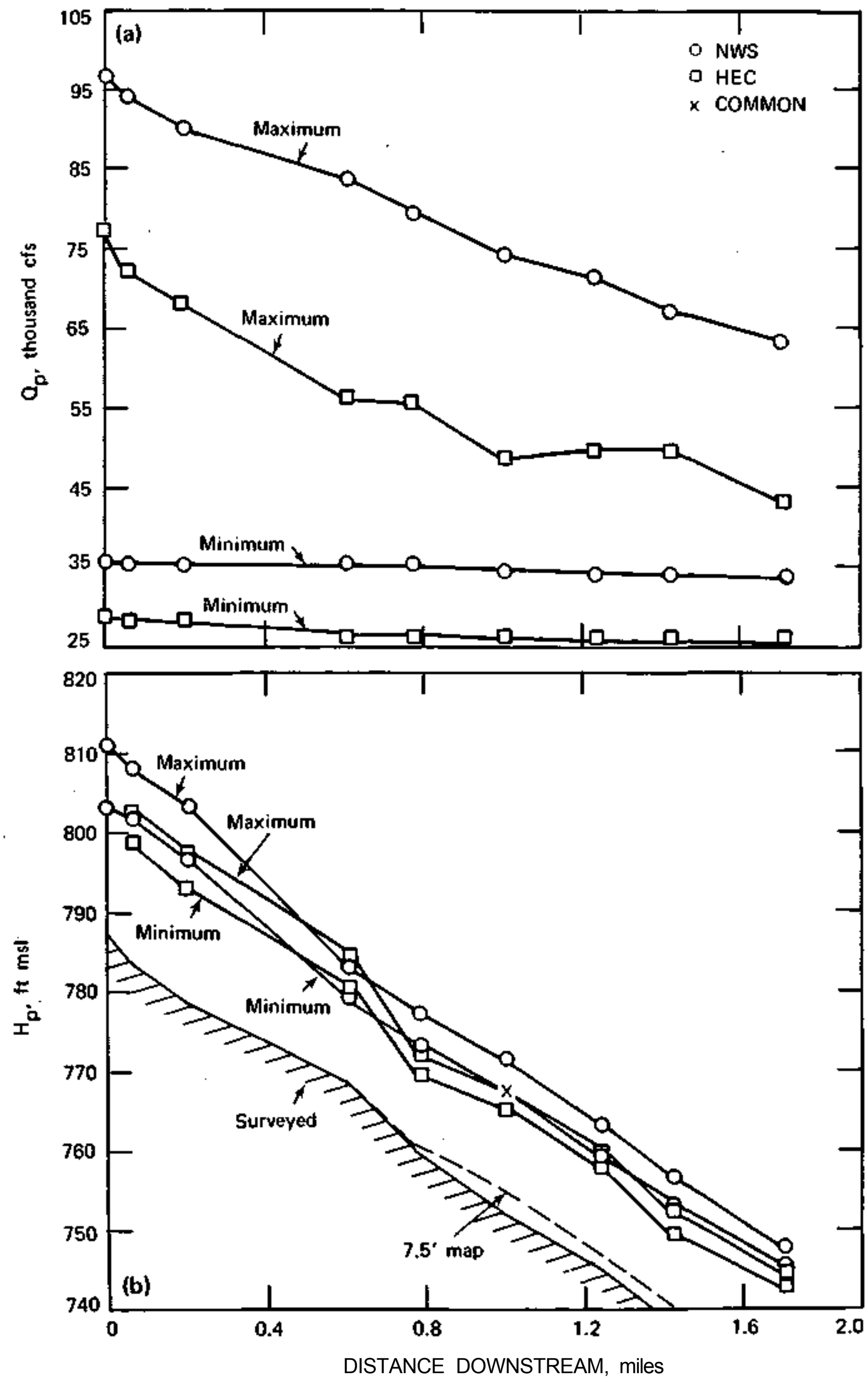


Figure 11. Maximum and minimum flood peaks and stages with the PMF: Lake in the Hills Dam #1

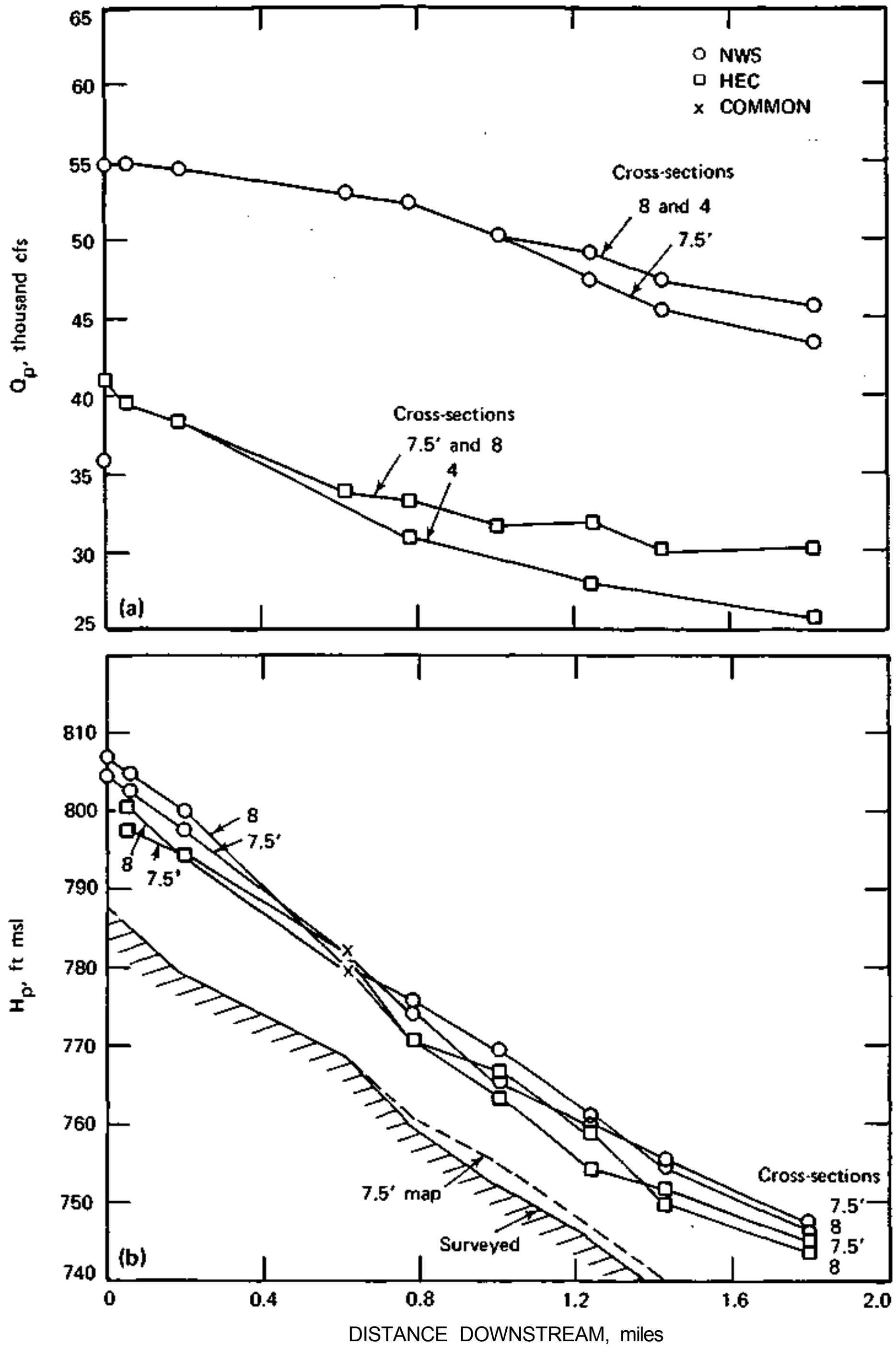


Figure 12. Peak flows and flood stages downstream of Lake in the Hills Dam #1 with surveyed and 7.5' map cross sections

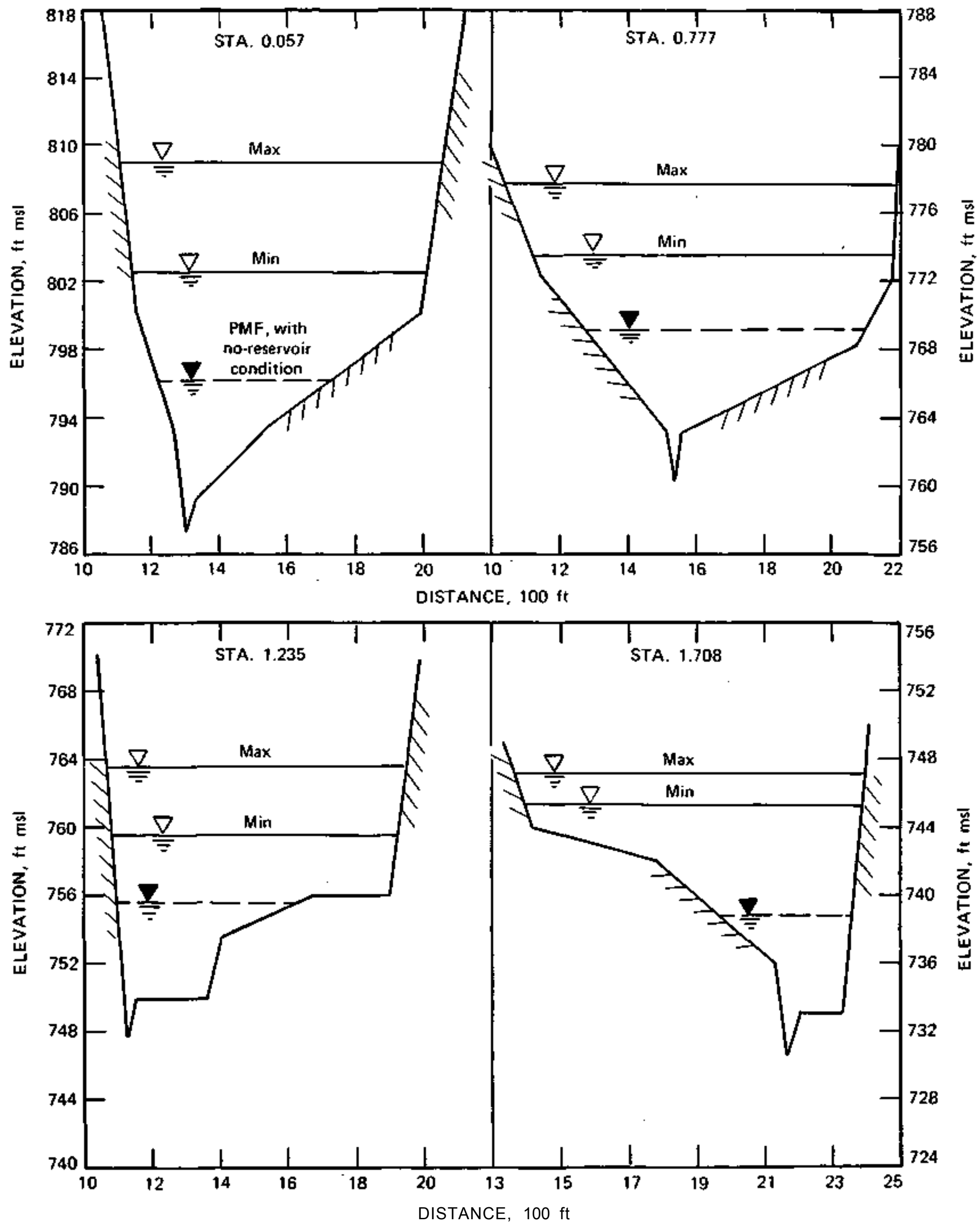


Figure 13. Range of peak flood stages downstream of Lake in the Hills Dam #1

from about 6.5 ft at station 0.057-mile to 2 ft at the end of the 1.7-mile reach.

III. Lake in the Hills Dam #2

Lake in the Hills Dam #2 (figure 9) is located on Crystal Creek in McHenry County, Illinois. It is an earth embankment, approximately 14.5 ft high and 635 ft long. The principal spillway is a rectangular drop inlet which discharges into a 6-ft diameter corrugated metal pipe (CMP). A 5-ft diameter CMP serves as an auxiliary spillway. The watershed is primarily gently roiling farmland with small areas of residential development. Basin elevations range from 890 to 960 ft msl.

The dam is classified in the small size, high hazard potential category. Failure of the dam can cause extensive property damage and endanger human lives. Pertinent data about the dam and reservoir is given below.

Pertinent Data - Lake in the Hills Dam #2

Drainage area	11.7 sq mi
Dam	
Elevation, top of dam	792.2 ft msl
Height above streambed	14.5 ft
Length	635.0 ft
Type	Earthfill embankment
Reservoir	
Elevation, normal pool*	790.0 ft msl
Area, normal pool	15.0 ac
Capacity, normal pool	79.8 ac ft
Length, normal pool	0.26 mi
Principal spillway	
Type	Uncontrolled drop inlet
Crest elevation	790.0 ft msl
Length, crest	17.4 ft up to 791.0 ft msl, 25.2 ft above 791.0 ft msl

Freeboard

Normal pool	2.2 ft

*Spillway crest elevation

The basic hydrologic and hydraulic data in table 8 consist of the PMF hydrograph, generated by the HEC-1 program, and information on reservoir area and capacity and combined discharge versus elevation. The information presented above follows the Lake in the Hills Dam #2 Inspection Report (COE, 1979b).

The surveyed cross sections were supplied by the DOWR. Cross sections were also developed from 7.5' quadrangle maps. The location of the surveyed and the map cross sections are shown in figure 9. The Manning's roughness coefficient, n, was estimated to be 0.05 for the channel and 0.07 for the overbank flow (COE, 1978b).

Analyses and Results

Below the Lake in the Hills Dam #2, Crystal Creek flows for about 1.5 miles to its confluence with the Fox River. The floodplain is wide, but well defined and has a mild slope. At about 0.4 mile downstream of the dam, Crystal Creek meets Woods Creek, which is dammed by the Lake in the Hills Dam #1 about 0.8 mile upstream. Residential and industrial areas are in the floodplain.

The breach parameters were chosen on the basis of the guidelines developed previously. The bottom elevation of the breach, YBMIN, was set at the channel bottom elevation of 777.7 ft for both breach sizes (BBW = 29 and 58 ft, respectively). The time from the inception of the breach to its

Table 8. PMF Hydrograph and Elevation-Area-Storage-Discharge Data: Lake in the Hills Dam #2

a. PMF Inflow Hydrograph

Time (hr)	0	1.0	2.0	3.0	4.0	5.0
Inflow (cfs)	1,636	2,126	2,625	3,158	3,812	4,438
Time (hr)	6.0	7.0	8.0	9.0	10.0	11.0
Inflow (cfs)	4,948	5,365	5,318	6,992	10,331	11,318
Time (hr)	12.0	13.0	14.0	15.0	16.0	17.0
Inflow (cfs)	11,306	10,759	9,863	8,791	7,676	6,569
Time (hr)	18.0	19.0	20.0			
Inflow (cfs)	5,570	4,702	3,955			

b. Elevation-Area-Storage-Discharge Data

Elevation (ft msl)	Area (ac)	Storage' (ac ft)	Discharge (cfs)
777.7	0	0	0
782.5	4	7.8	0
786.0	8	31.3	0
790.0	15	79.8	0
791.0	17	94.4	60
792.0	19	111.7	270
793.0	21	132.2	630
794.0	24	156.3	1,580
795.0	26	184.8	3,390
796.0	29	208.5	6,170
797.0	32	235.2	9,360

'Lake volume reduction due to sedimentation was not accounted for.

completion, TF, has been taken as 0.25, 0.50, or 1.00 hour. The depth of overtopping when the breach starts, or h_f = HF-HD, has been taken as 0.5 or 2.0 ft; the HF and HD denote the failure elevation and elevation of the top of the dam, respectively.

A selected set of results (flood peaks and elevations) from the flood simulations are given in tables 9-A to 9-F. The results for the PMF flood are the same for all combinations of breach parameters as well as for the no-reservoir condition. This is because of small storage in the reservoir and small size of the dam, causing the overtopping and the failure of the dam to occur a few hours before the peak inflow to the reservoir. The results for the PMF are given in table 9-A.

Two breach examples covering the range of simulation results for the 0.5 PMF hydrograph are given in tables 9-C and 9-D. Results for the 0.25 PMF hydrograph simulation are given in table 9-B for no-reservoir condition and in tables 9-E and 9-F for the two combinations of breach parameters giving minimum and maximum outflow peaks and stages, respectively.

The peak outflows with the NWS and HEC for all combinations of breach parameters, along with peak discharges as determined by the SCS method, are given in table 10. The simulation results for all inflow hydrographs are essentially the same for both the no-reservoir condition and the no-failure condition, with both NWS and HEC. In the case of the PMF inflow hydrograph, the results with different combinations of breach parameters are practically the same as with the no-reservoir or the no-failure condition. The peak outflows with the NWS for the dam breach with a. 0.5 PMF hydrograph are about 1 to 20% higher than with the HEC due to differences in the mode of breach formation. Increase in peak discharge due to higher failure

Table 9. Summary of Results for Lake in the Hills Dam #2

A. 1.00 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	0	11317	11318	11317	11313	11317	11318
	H	789.80	---	788.10	---	788.30	---
0.119	Q	11316	11325	---	---	11316	11326
	H	787.40	787.60	---	---	781.20	784.70
0.184	0	11317	11325	11316	11323	11316	11327
	H	782.40	784.20	782.70	783.20	781.20	781.10
0.305	Q	11316	11322	---	---	11316	11321
	H	776.60	775.90	---	---	775.60	775.10
0.504	Q	11315	11322	11315	11315	11315	11323
	H	769.70	768.20	769.10	768.10	768.00	767.80
0.741	Q	11311	11320	---	---	.1315	11320
	H	764.40	763.80	---	---	760.30	760.70
0.962	0	11314	11317	11314	11312	11315	11318
	H	756.40	755.70	756.70	755.70	752.50	751.40
1.157	Q	11314	11316	---	---	11314	11319
	H	748.00	746.70	---	---	748.40	747.80
1.436	Q	11313	11316	11313	11312	11312	11317
	H	739.80	738.50	739.50	738.20	741.90	741.00

B. 0.25 PMF, maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	792.20	777.70	794.69

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	2826	2827	0	2827	2826	2827
	H	785.90	---	0.00	---	784.00	---
0.119	Q	2826	2827	---	---	2826	2827
	H	783.90	784.00	---	---	778.90	780.40
0.181	Q	2826	2827	0	2827	2826	2827
	H	779.30	779.70	0.00	779.10	776.10	776.60
0.305	Q	2826	2827	---	---	2826	2827
	H	771.50	773.90	---	---	772.40	772.10
0.504	Q	2826	2827	0	2827	2826	2827
	H	767.00	765.90	0.00	765.80	765.20	765.00
0.744	Q	2826	2827	---	---	2826	2827
	H	761.00	761.20	---	---	758.30	758.30
0.962	Q	2826	2827	0	2827	2826	2827
	H	752.20	751.90	0.00	751.90	750.00	749.60
1.157	Q	2826	2827	---	---	2826	2827
	H	744.30	743.30	---	---	744.80	744.40
1.436	Q	2826	2827	0	2826	2828	2827
	H	735.90	735.40	0.00	735.20	737.80	737.70

Table 9. Continued

C. 0.50 PMF, breach parameters: TF=0.50, BBW=29, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	0.50	777.70	29.00	0.50	792.20	777.70	792.70

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	5720	5646	0	5646	5668	5646
	H	787.90	---	0.00	---	786.00	---
0.119	Q	5717	5645	---	---	5665	5645
	H	786.30	785.60	---	---	781.10	782.30
0.184	0	5716	5645	0	5645	5665	5645
	H	778.80	781.60	0.00	780.90	777.80	778.50
0.305	Q	5714	5645	---	---	5664	5645
	H	777.00	774.80	---	---	773.80	773.40
0.504	Q	5712	5644	0	5644	5663	5645
	H	768.20	766.90	0.00	766.80	766.50	766.20
0.744	Q	5711	5644	---	---	5661	5644
	H	763.30	762.70	---	---	759.40	759.40
0.962	Q	5710	5643	0	5642	5661	5643
	H	753.40	753.40	0.00	753.30	750.90	750.40
1.157	Q	5709	5643	---	---	5659	5643
	H	746.00	744.80	---	---	746.40	745.90
1.436	Q	5708	5642	0	5641	5658	5642
	H	736.70	736.60	0.00	736.50	739.30	739.20

D. 0.50 PMF, breach parameters: TF=0.25, BBW=58, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	0.25	777.70	58.00	0.50	792.20	777.70	794.20

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	10393	9078	0	9078	10394	9078
	H	789.20	---	0.00	---	787.60	---
0.119	0	9285	7392	---	---	9346	7366
	H	786.70	786.40	---	---	783.20	783.10
0.184	Q	9189	7505	0	7354	9234	7489
	H	781.90	782.60	0.00	781.70	779.30	779.50
0.305	Q	8834	7254	---	---	8804	7451
	H	776.20	775.10	---	---	774.80	774.00
0.504	Q	8269	6920	0	6459	8408	6916
	H	768.80	767.20	0.00	767.00	767.30	766.60
0.744	Q	7272	6215	---	---	8005	6448
	H	763.60	762.80	---	---	759.90	759.60
0.962	Q	6823	6007	0	5775	7792	6205
	H	754.10	753.60	0.00	753.40	751.40	750.50
1.157	Q	6626	5818	---	---	7417	5922
	H	746.30	744.90	---	---	747.10	746.00
1.436	Q	6279	5655	0	5654	7102	5762
	H	737.80	736.60	0.00	736.50	739.80	739.20

Table 9. Concluded

E. 0.25 PMF, breach parameters: TF=0.50, BBW=29, HF-HD=0.5

FLOOD	TF	YBMIN	BBH	Z	HD	LD	HF
0.25 PMF	0.50	777.70	29.00	0.50	792.20	777.70	792.70

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	0	4130	3877	0	3877	4309	3877
	H	786.70	---	0.00	---	785.00	---
0.119	Q	3865	3720	---	---	4042	3773
	H	781.50	781.60	---	---	779.80	781.20
0.184	Q	3844	3608	0	3611	4023	3735
	H	780.00	780.30	0.00	779.70	777.00	777.30
0.305	Q	3759	3595	---	---	3930	3571
	H	771.80	771.20	---	---	773.00	772.60
0.501	Q	3571	3392	0	3321	3831	3528
	H	767.30	766.10	0.00	766.00	765.60	765.30
0.711	Q	3197	3210	---	---	3696	3256
	H	761.90	761.50	---	---	758.60	758.50
0.962	Q	3019	3147	0	2987	3649	3101
	H	752.20	752.10	0.00	752.00	750.20	719.70
1.157	Q	2983	3103	---	---	3528	3068
	H	744.40	743.50	---	---	745.30	744.60
1.436	Q	2913	2994	0	2822	3407	2919
	H	735.90	735.50	0.00	735.20	738.10	737.70

F. 0.25 PMF, breach parameters: TF=0.25, BBW=58, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	0.25	777.70	58.00	0.50	792.20	777.70	794.20

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS , NWS	7.5' MAP SECTIONS HEC
0.000	Q	10169	9313	0	9313	10506	9313
	H	789.20	---	0.00	---	787.70	---
0.119	Q	9310	7603	---	---	9450	7583
	H	786.70	786.40	---	---	783.20	783.20
0.184	Q	9225	7695	0	7557	9338	7688
	H	781.90	782.70	0.00	781.80	779.30	779.60
0.305	Q	8907	7429	---	---	8907	7627
	H	776.20	775.20	---	---	774.80	774.10
0.504	Q	8377	7128	0	6678	8510	7132
	H	768.80	767.30	0.00	767.10	767.30	766.70
0.744	Q	7379	6447	---	---	8108	6628
	H	763.70	762.80	---	---	759.90	759.70
0.962	Q	6946	6214	0	5984	7887	6412
	H	754.20	753.70	0.00	753.50	751.50	750.60
1.157	Q	6741	6054	---	---	7510	6106
	H	746.40	745.00	---	---	747.10	746.10
1.436	Q	6391	5845	0	5587	7199	5970
	H	737.90	736.70	0.00	736.40	739.90	739.30

Table 10. Peak Outflows: Lake in the Hills Dam #2

Table 9-	Item	Inflow flood*	Breach parameters YBMIN	BBW	TF	HF	Peak outflow, cfs NWS	HEC
A	No-reservoir conditions	1.00	-	-	-	-	11,317	11,318
		0.50	-	-	-	-	5,659	5,659
B	"	0.25	-	-	-	-	2,830	2,830
	No-failure conditions	1.00	-	-	-	-	11,312	11,313
	"	0.50	-	-	-	-	5,656	5,656
		0.25	-	-	-	-	2,826	2,827
A	Failure conditions	1.00	All combinations				11,312	11,312
C	"	0.50	777.7	29	0.50	792.7	5,720	5,646
					0.50	794.2	5,793	5,646
					0.25	"	6,925	6,148
	"	"	"	"	1.00	"	5,696	5,646
				58	0.50	792.7	5,920	5,655
					0.50	794.2	7,594	6,335
D	"	"	"	"	0.25	"	10,393	9,078
					1.00	"	5,791	5,655
E	"	0.25	"	29	0.50	792.7	4,130	3,877
			"	"	0.50	794.2	6,137	5,561
					0.25	"	6,984	6,305
		"	"	"	1.00	"	5,118	4,734
				58	0.50	792.7	5,550	4,620
					0.50	794.2	7,865	6,720
F	"	"	"	"	0.25	"	10,169	9,313
					1.00	"	5,743	4,958
	SCS method	0.25	Q_p = 12,268 cfs			794.69		
		0.50	Q_p = 13,820 cfs			795.82		
		1.00	Q_p = 16,451 cfs			797.61		

*Inflow flood hydrograph corresponds to 0.25, 0.50, or 1.00 times the probable maximum flood, PMF, hydrograph

elevation is negligible for the smaller breach size, but about 12 to 18% for the larger one. Increase in peak discharge due to 50% reduction in failure time is about 1 to 20% for the smaller breach and 12 to 43% for the larger breach. The larger breach size causes negligible increase in peak discharges for lower failure elevations and longer failure time, but up to 50% increase for the higher failure elevation and shorter failure time. The peak discharges with a 0.25 PMF hydrograph follow the same general pattern as for the 0.50 PMF except failure elevations have effects for both breach sizes. The outflow peak with 0.25 PMF is, for some cases, slightly higher than with 0.50 PMF. This is largely caused by the breach formation starting closer to the 0.25 PMF inflow hydrograph peak resulting in higher inflows and water elevations in the reservoir at the time of peak outflow. The peak outflow determined with the SCS method is 12,268 cfs with 0.25 PMF, 13,820 cfs with 0.50 PMF, and 16,451 cfs with the 1.00 PMF.

The peak discharges in the 1.4-mile downstream channel for the selected cases given in table 9 are shown in figure 14(a). If the dam breaches at a much lower inflow than the PMF, the reservoir practically empties before the PMF impinges on the reservoir. Under this condition, the outflow peak and stages with the PMF are essentially the same as with no-reservoir condition. The peak flow and stages along the downstream channel thus are nearly the same with both the NWS and HEC. With 0.25 and 0.50 PMF inflow flood hydrographs, the interaction with any remaining storage at the time of the failure as well as relatively higher inflow can cause the flow peak to be higher than the peak inflow. The maximum water stage profiles for the cases in tables 9-A and 9-B, giving the maximum and minimum flood levels, respectively, are shown in figure 14(b). There is

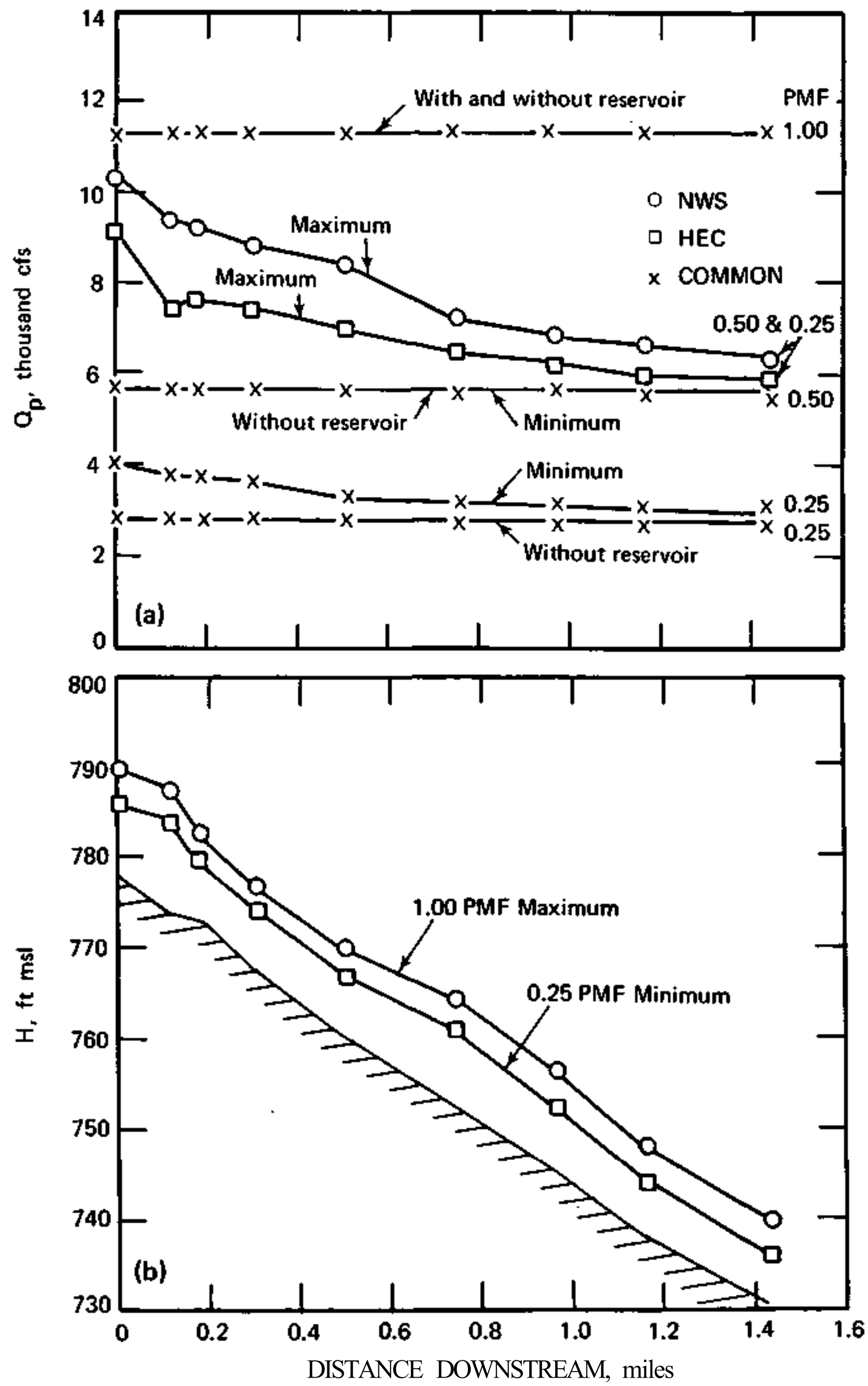


Figure 14. Peak flows and flood stages downstream of Lake in the Hills Dam #2

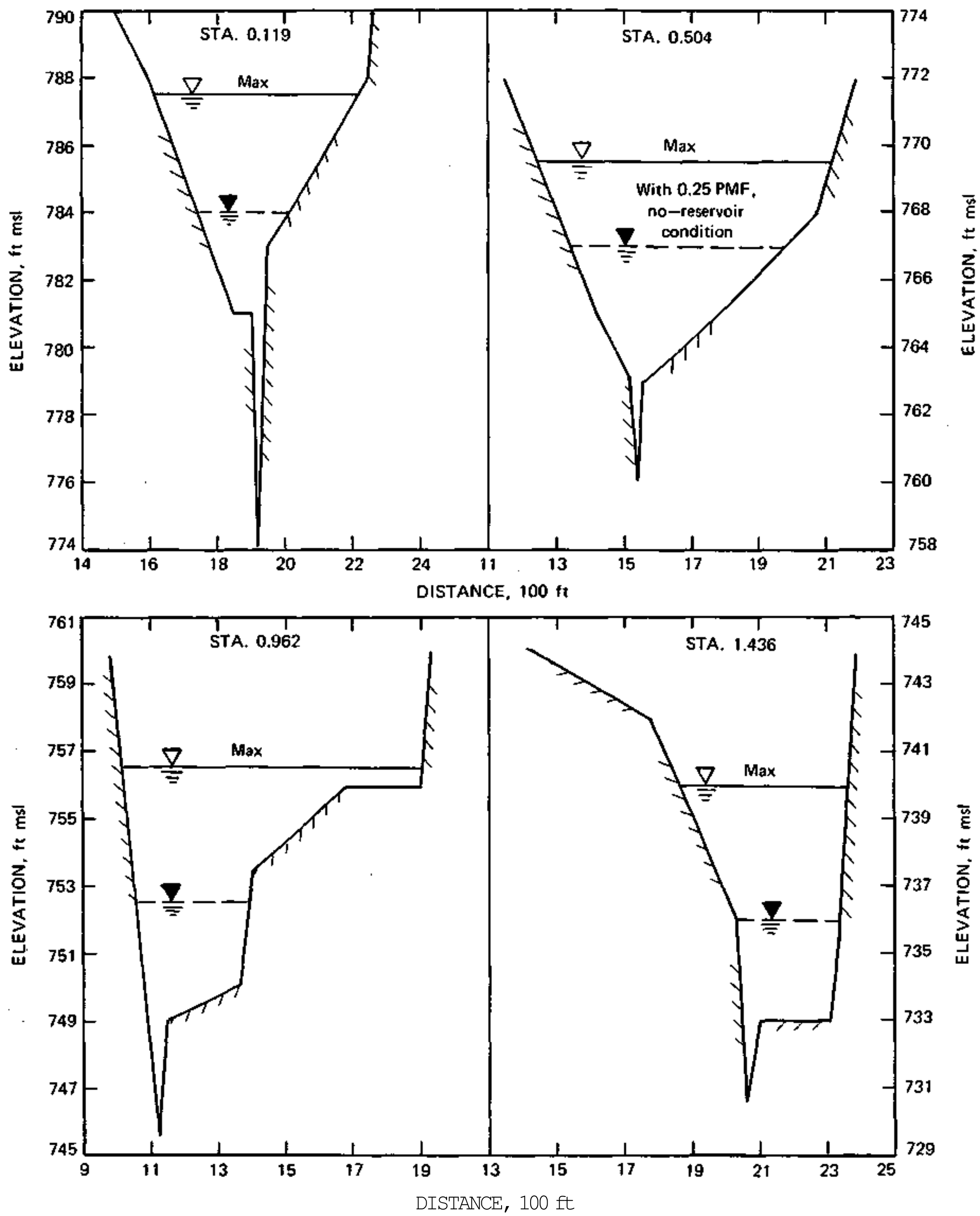


Figure 15. Range of peak flood stages downstream of Lake in the Hills Dam #2

almost a constant difference of about 4 feet in flood levels along the downstream channel. This is also shown in figure 15 for four selected surveyed cross sections.

IV. Lake Marian Dam

Lake Marian Dam (figure 16) is located on Delta Creek, a small, intermittent stream, a direct tributary to the Fox River in Kane County, Illinois. It is an earth embankment about 50 ft high and 745 ft long. The appurtenant works consist of a drop inlet service spillway and rectangular broad-crested weir emergency spillway. The watershed is predominantly residential and moderately wooded. The terrain is steeply sloping adjacent to the lake, becoming rolling as the ridge lines are reached. Basin elevations range from about 780 to 940 ft msl.

The dam is classified in the intermediate and high hazard potential category because a road, a residence, and a municipal sewage treatment plant are located downstream of it. Pertinent data about the dam and the reservoir are given below.

Pertinent Data - Lake Marian Dam

Drainage area	1.13 sq mi
Dam	
Elevation, top of dam	785.34 ft msl
Height above streambed	50.0 ft
Length	745.0 ft
Type	Earth embankment
Reservoir	
Elevation, normal pool*	779.84 ft msl
Area, normal pool	11.5 ac
Capacity, normal pool	151.0 ac ft
Length, normal pool	0.4 mi

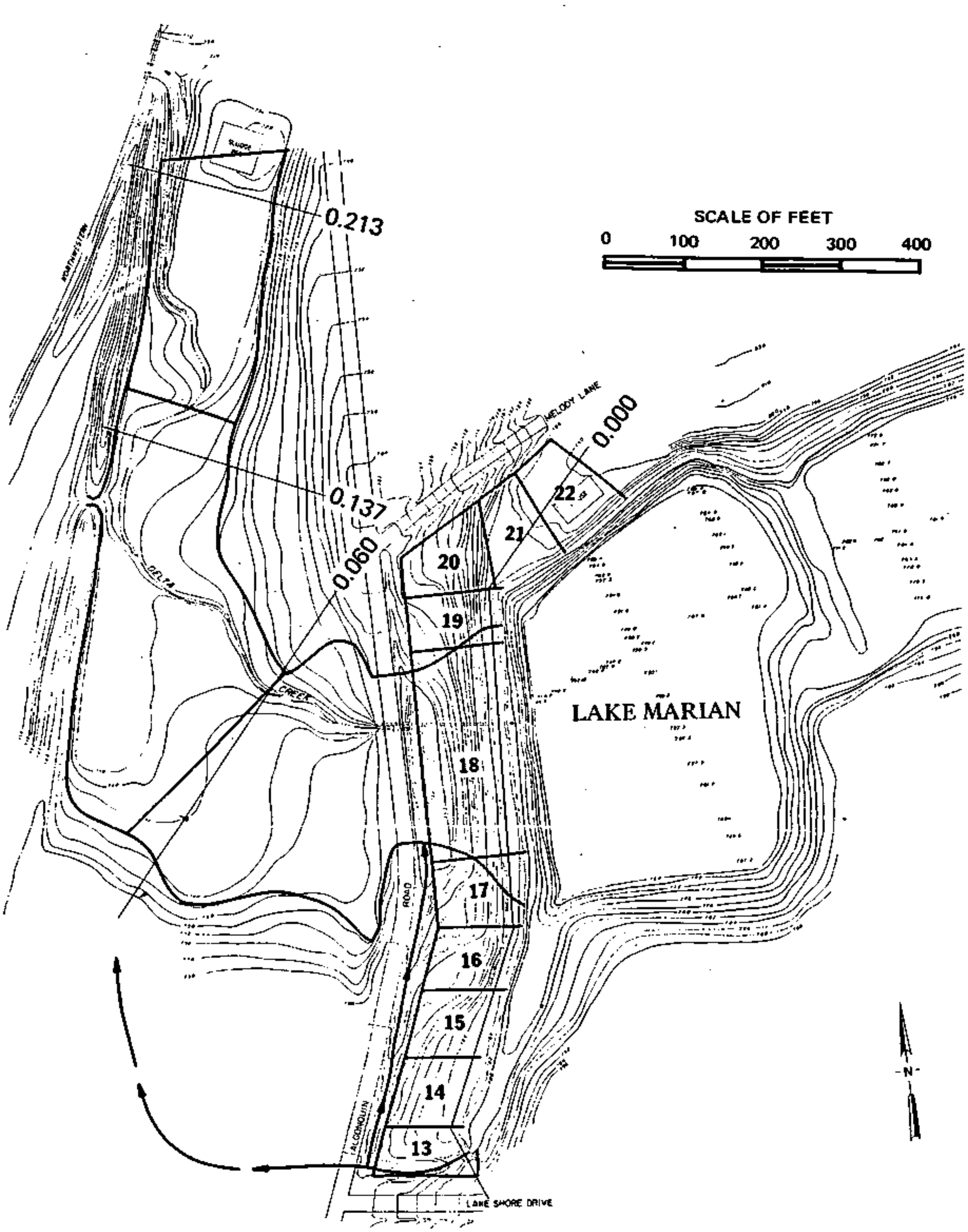


Figure 16. Location of Lake Marian Dam and downstream channel cross sections

Service spillway

Type	Circular drop inlet
Elevation, crest.	779.84 ft msl
Inside diameter	3.0 ft

Emergency spillway

Type	Rectangular weir
Elevation, crest	783.34 ft msl
Length, crest	16.0 ft
Height of walls	2.0 ft

Freeboard

Normal pool	5.5 ft
Emergency spillway crest	2.0 ft

*Service spillway crest elevation

The basic hydrologic and hydraulic data in table 11 consist of the PMF hydrograph, generated by the HEC-1 program, and information on reservoir area and capacity and combined discharge versus elevation. The information presented above follows the Lake Marian Dam Inspection Report (COE, 1978c).

The surveyed cross sections were supplied by the DOWR as well as a 2-ft contour map. The 7.5' quadrangle map was not detailed enough to be usable for development of cross sections. The Manning's roughness coefficient, n, was varied from 0.04 for the channel to 0.065 for the overbank flow.

Analyses and Results

Immediately downstream from the Lake Marian Dam is Algonquin Road with about a 10-ft high embankment. It has been assumed that the road embankment would wash away immediately when it is overtopped. The Delta Creek takes a 90° turn to the north just below the dam, and flows in a northerly direction for about 0.3 mile when it takes a westerly direction to its

Table 11. PMF Hydrograph and Elevation-Area-Storage-Discharge Data: Lake Marian Dam

a. PMF Inflow Hydrograph

Time (hr)	0	0.5	1.0	1.5	2.0	2.5
Inflow (cfs)	1,220	1,700	2,060	2,520	2,760	3,020
Time (hr)	3.0	3.5	4.0	4.5	5.0	5.5
Inflow (cfs)	3,164	3,080	2,800	2,400	1,800	1,200
Time (hr)	6.0	6.5	7.0	7.5		
Inflow (cfs)	1,000	920	860	800		

b. Elevation-Area-Storage-Discharge Data

Elevation (ft msl)	Area (ac)	Storage (ac ft)	Discharge (cfs)
740.50	0	0	0
779.84	11.5	151	0
783.34	12.9	194	66
784.34	13.4	207	127
785.34	13.8	221	231
786.34	14.3	235	1,300
787.34	14.7	249	3,954

confluence with the Fox River. On the left side, the floodplain is confined for about 0.3 mile by an old railroad embankment with a height of about 14 feet. After the creek turns westward, it is crossed by a railroad track. A sludge bed and a sewer treatment plant are located in the floodplain about 0.25 mi downstream of the dam.

The breach parameters were chosen on the basis of the guidelines established previously. The bottom elevation of the breach, YBMIN, was set at 745 fr msl for the smaller breach (BBW = 100 ft) and at 753 ft for the larger breach (BBW = 200 ft). The time from the inception of the breach to its completion, TF, has been taken as 0.25, 0.50, or 1.00 hour. The depth of overtopping (h_f = HF-HD) when breach starts has been taken as 0.5 or 2.0 ft; the HF and HD denote the failure elevation and elevation of the top of the dam, respectively.

Results from the simulation of floods are given in tables 12-A to 12-C for no-reservoir condition and in tables 12-D to 12-F with the reservoir and dam intact. It is apparent that all floods (1.00 PMF, 0.50 PMF, and 0.25 PMF) will overtop the dam and breach it for the lower failure elevation. Results from two combinations of breach parameters for the three floods are given in tables 12-G to 12-L. The peak discharges with both methods and all combinations of breach parameters along with the peak discharge as determined by the SCS method are given in table 13.

The peak discharges with the reservoir intact are only slightly lower than with no-reservoir condition. The peak outflows due to the failure of the dam are about 21 to 37% higher with the NWS than with the HEC. This is due to differences in the mode of breach formation. Bigger breach size results in about 12% increase with the NWS and 6 to 8% increase with the

Table 12. Summary of Results for Lake Marian

A. 1.00 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	3163	3164	---	---	---	---
	H	750.44	---	---	---	---	---
0.060	Q	3160	3161	---	---	---	---
	H	744.74	745.80	---	---	---	---
0.137	Q	3154	3161	---	---	---	---
	H	738.66	738.00	---	---	---	---
0.213	Q	3152	3162	---	---	---	---
	H	733.45	731.80	---	---	---	---

B. 0.50 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	1581	1521	---	---	---	---
	H	748.90	---	---	---	---	---
0.060	Q	1580	1580	---	---	---	---
	H	743.66	744.20	---	---	---	---
0.137	Q	1576	1581	---	---	---	---
	H	737.31	736.60	---	---	---	---
0.213	Q	1576	1581	---	---	---	---
	H	732.12	730.70	---	---	---	---

Table 12. Continued

C. 0.25 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	789	791	---	---	---	---
	H	747.61	---	---	---	---	---
0.060	Q	789	790	---	---	---	---
	H	742.83	743.00	---	---	---	---
0.137	Q	788	790	---	---	---	---
	H	736.38	735.60	---	---	---	---
0.213	Q	788	790	---	---	---	---
	H	731.21	729.90	---	---	---	---

D. 1.00 PMF, HF=max. water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	785.34	740.20	787.04

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	3152	3154	---	---	---	---
	H	750.37	---	---	---	---	---
0.060	Q	2986	3153	---	---	---	---
	H	744.62	745.80	---	---	---	---
0.137	Q	2862	3154	---	---	---	---
	H	738.41	738.00	---	---	---	---
0.213	Q	2754	3154	---	---	---	---
	H	733.16	731.80	---	---	---	---

Table 12. Continued

E. 0.50 PMF, HF=max. water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	785.34	---		740.20	786.44

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	1576	1577	---	---	---	---
	H	748.84	---	---	---	---	---
0.060	Q	1476	1577	---	---	---	---
	H	743.56	744.20	---	---	---	---
0.137	Q	1418	1577	---	---	---	---
	H	737.13	736.60	---	---	---	---
0.213	Q	1368	1577	---	---	---	---
	H	731.90	730.70	---	---	---	---

F. 0.25 PMF, HF=max. water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	785.34	740.20	785.86

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	784	784	---	---	---	---
	H	747.55	---	---	---	---	---
0.060	Q	732	784	---	---	---	---
	H	742.75	742.90	---	---	---	---
0.137	Q	707	784	---	---	---	---
	H	736.25	735.60	---	---	---	---
0.213	Q	686	784	---	---	---	---
	H	7.31.06	729.90	---	---	---	---

Table 12. Continued

G. 1.00 PMF, breach parameters: TF=0.50, BBW=1.00. HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	745.00	100.00	0.50	785.34	740.20	785.84

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	13873	10086	---	---	---	---
	H	754.89	---	---	---	---	---
0.060	Q	13510	9096	---	---	---	---
	H	748.32	749.90	---	---	---	---
0.137	Q	12872	9057	---	---	---	---
	H	743.20	741.30	---	---	---	---
0.213	Q	12358	9003	---	---	---	---
	H	738.07	734.40	---	---	---	---

H. 1.00 PMF, breach parameters: TF=0.50, BBW=200. HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	753.00	200.00	0.50	785.34	740.20	785.84

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	12389	9520	---	---	---	---
	H	754.48	---	---	---	---	---
0.060	Q	12041	8662	---	---	---	---
	H	747.93	749.70	---	---	---	---
0.137	Q	11461	8529	---	---	---	---
	H	742.69	741.00	---	---	---	---
0.213	Q	11013	8376	---	---	---	---
	H	737.48	734.20	---	---	---	---

Table 12. Continued

I. 0.50 PMF, breach parameters: TF=0.50, BBW=100, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	0.50	745.00	100.00	0.50	785.34	740.20	785.84

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	12976	10073	---	---	---	---
	H	754.65	---	---	---	---	---
0.060	Q	12599	9066	---	---	---	---
	H	748.09	749.90	---	---	---	---
0.137	Q	12023	9031	---	---	---	---
	H	742.89	741.30	---	---	---	---
0.213	Q	11515	8980	---	---	---	---
	H	737.74	734.40	---	---	---	---

J. 0.50 PMF, breach parameters: TF=0.50, BBW=200, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	0.50	753.00	200.00	0.50	785.34	740.20	785.84

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	11551	9506	---	---	---	---
	H	754.23	---	---	---	---	---
0.060	Q	11162	8650	---	---	---	---
	H	747.68	749.60	---	---	---	---
0.137	Q	10674	8517	---	---	---	---
	H	742.38	741.00	---	---	---	---
0.213	Q	10208	8364	---	---	---	---
	H	737.15	734.20	---	---	---	---

Table 12. Concluded

K. 0.25 PMF, breach parameters: TF=0.50, BBW=100, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	0.50	745.00	100.00	0.50	785.34	740.20	785.84

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	12783	9975	---	---	---	---
	H	754.59	---	---	---	---	---
0.060	Q	12367	8843	---	---	---	---
	H	748.03	749.80	---	---	---	---
0.137	Q	11836	8843	---	---	---	---
	H	742.82	741.20	---	---	---	---
0.213	Q	11312	8816	---	---	---	---
	H	737.65	734.40	---	---	---	---

L. 0.25 PMF, breach paramters: TF=0.50, BBW=200, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	0.50	753.00	200.00	0.50	785.34	740.20	785.84

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	11361	9240	---	---	---	---
	H	754.17	---	---	---	---	---
0.060	Q	10980	8561	---	---	---	---
	H	747.62	749.60	---	---	---	---
0.137	Q	10491	8429	---	---	---	---
	H	742.32	741.00	---	---	---	---
0.213	Q	10040	8278	---	---	---	---
	H	737.07	734.20	---	---	---	---

Table 13. Peak Outflows: Lake Marian Dam

Table 12-	Item	Inflow flood*	Breach parameters YBMIN	BBW	TF	HF	Peak outflow, cfs NWS	HEC
A	No-reservoir conditions	1.00	-	-	-	-	163	3,164
B	"	0.50	-	-	-	-	1,581	1,582
C	"	0.25	-	-	-	-	789	791
D	No-failure conditions	1.00	-	-	-	-	3,152	3,154
E	"	0.50	-	-	-	-	1,576	1,577
F	"	0.25	-	-	-	-	784	784
G	Failure conditions	1.00	745 .	100	0.50	785.84	13,873	10,086
H	"	1.00	"	200	"	"	12,389	9,520
I	"	0.50	"	100	"	"	12,976	10,073
J	"	0.50	"	200	"	"	11,551	9,506
K	"	0.25	"	100	"	"	12,783	9,975
L	"	0.25	"	200	"	"	11,361	9,240
	SCS method	0.25	Q_p = 92,113 cfs			785.86		
		0.50	Q_p = 94,079 cfs			786.44		
		1.00	Q_p = 96,133 cfs			787.04		

*Inflow flood hydrograph corresponds to 0.25, 0.50, or 1.00 times the probable maximum flood, PMF, hydrograph

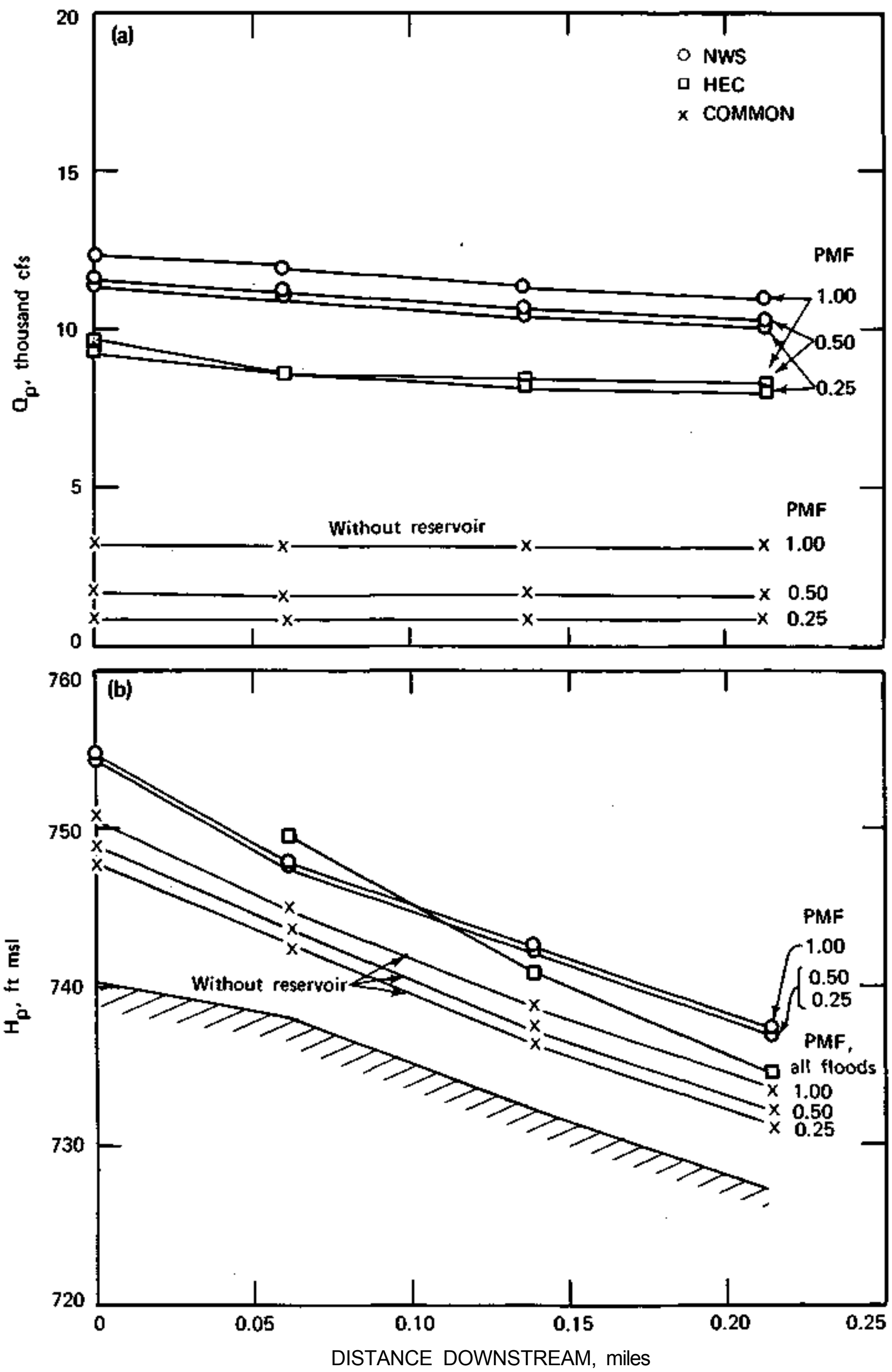


Figure 17. Peak flows and flood stages downstream of Lake Marian Dam (BBW = 200 ft, TF = 0.50 hour, h_f = 0.5 ft)

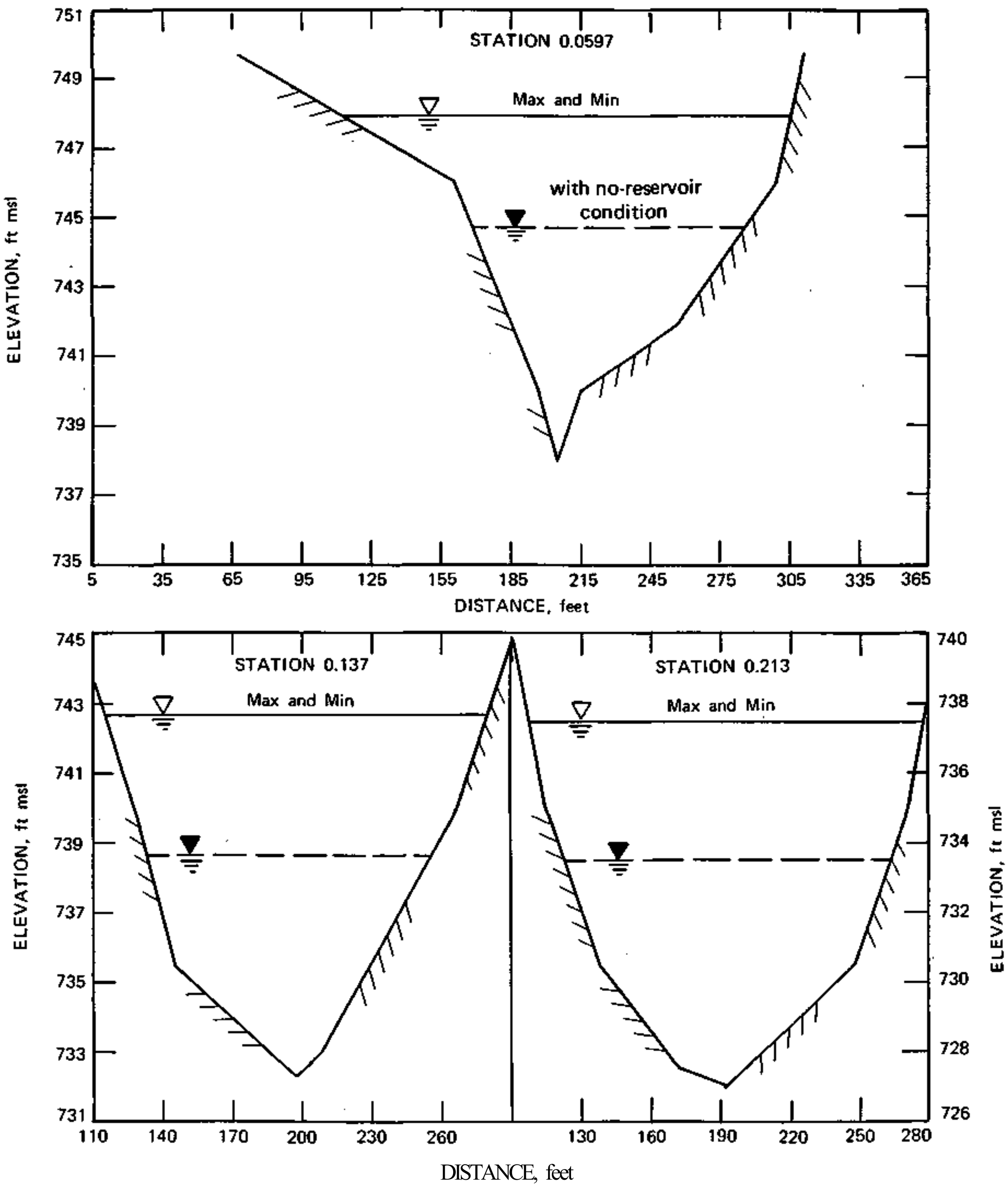


Figure 18. Range of peak flood stages downstream of Lake Marian Dam

HEC. The peak discharges due to 0.50 PMF and 0.25 PMF inflow hydrographs are only slightly lower than due to the PMF inflow hydrograph. The peak outflow determined with the SCS method varies from about 92 to 96 thousand cfs. This is about 6.9 times larger than the maximum simulated outflow.

The peak flows and maximum water stages in the 0.21-mile downstream channel are shown in figure 17 for TF = 0.50, BBW = 200 ft, HF-HD =0.5 ft. The peak outflows with the NWS are higher than with the HEC, the difference staying constant in the short downstream channel. The maximum flood stages with the HEC are about 2 ft higher than with the NWS in the first cross section, but decay more along the channel and are about 3.5 ft lower in the cross section furthest downstream. The maximum flood stages with the PMF for the three cross sections along the channel are shown in figure 18 as calculated with the NWS.

V. Clinton Lake Dam

Clinton Lake Dam (figure 19) is located on Salt Creek about 4 miles east of Clinton, DeWitt County, Illinois. It is an earth embankment, approximately 65 ft high and 2980 ft long. The appurtenant works consist of a concrete chute principal spillway with an ogee crest weir and a stilling basin, and a 1 200 ft wide earthcut emergency spillway located at the left abutment. The watershed is gently to moderately rolling and is about 50% cropland, 40% pasture and forest, and 10% farmsteads and roads. Basin elevations range from about 650 to 920 ft msl.

The dam is classified in the large size and high hazard potential category. Failure of the dam will cause Illinois Power Company's Clinton Nuclear Power Plant to stop production. Failure of the dam can also

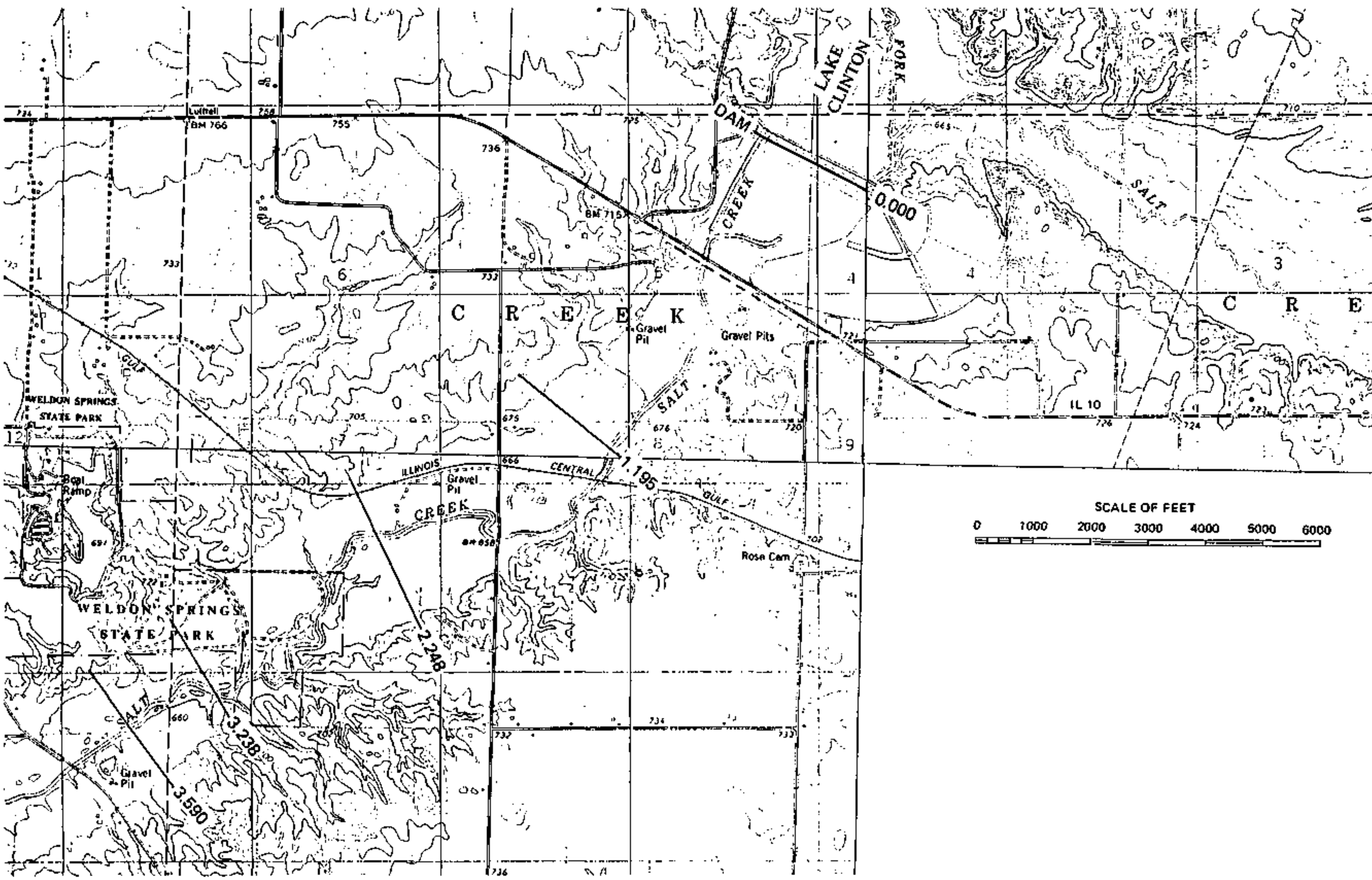


Figure 19. Location of Clinton Lake Dam and downstream channel cross sections

endanger human lives and cause damage to roads and railroads downstream of the dam. Pertinent data about the dam, spillways, and reservoir are given below.

Pertinent Data - Clinton Lake Dam

Drainage area	291.5 sq mi
Dam	
Elevation, top of dam	712 ft msl
Height above streambed	65 ft
Length	2,980 ft
<u>Reservoir</u>	
Elevation, normal pool*	690 ft msl
Area, normal pool	4,895 ac
Capacity, normal pool	74,200 ac ft
Length, normal pool	13.8 mi
<u>Principal spillway</u>	
Type	Chute spillway with ogee-weir
Elevation, crest	690 ft msl
Crest length	175 ft
Chute width	80 ft
<u>Emergency spillway</u>	
Type	Earthcut with bituminous concrete crest
Elevation, crest	700 ft msl
Crest length	1,200 ft
<u>Freeboard</u>	
Normal pool	22 ft

*Based on top of principal spillway crest

The basic hydrologic and hydraulic data in table 14 consist of the PMF hydrograph, generated by the HEC-1 program, and information on reservoir area and capacity and combined spillway discharge versus elevation. The information presented above follows the Clinton Lake Dam Inspection Report (COE, 1980b).

Table 14. PMF Hydrograph and Elevation-Area-Storage-Discharge Data: Clinton Lake Dam

a. PMF Inflow Hydrograph

Time (hr)	0	2.0	4.0	6.0	8.0	10.0
Inflow (cfs)	21,000	29,000	44,300	78,800	125,000	119,000
Time (hr)	12.0	14.0	16.0	18.0	20.0	22.0
Inflow (cfs)	102,500	120,500	133,300	144,300	150,200	146,800
Time (hr)	24.0	26.0	28.0	30.0	32.0	34.0
Inflow (cfs)	13,500	120,000	103,000	82,500	63,500	51,300
Time (hr)	36.0	38.0	40.0	42.0	44.0	46.0
Inflow (cfs)	41,300	33,300	26,900	21,800	17,500	13,500

b. Elevation-Area-Storage-Discharge Data

Elevation (ft msl)	Area (ac)	Storage (ac ft)	Discharge (cfs)
647.0	0	0	0
690.0	4,895	74,200	0
694.0	5,700	95,000	4,619
698.0	6,800	120,000	13,759
700.0	7,380	133,300	19,247
702.0	7,800	149,000	32,954
704.0	8,180	164,300	55,873
706.0	8,600	182,000	85,648
708.0	9,260	199,200	120,336
710.0	11,158	221,400	161,103
712.0	17,700	250,000	200,000

The surveyed cross sections were supplied by the DOWR. Cross sections were also developed from 7.5' quadrangle maps. The location of the surveyed and the map cross sections are shown in figure 19. The Manning's roughness coefficient, n, was taken as 0.03 for the channel and 0.05 for the overbank flow. The 0.000-mile cross section is taken as the dashed section (which is the control section) for considering backwater effects.

Analyses and Results

Below the Clinton Lake Dam, Salt Creek flows in a westerly direction for about 78 miles to its confluence with the Sangamon River. Illinois Route 10 crosses the channel about 2100 ft downstream of the dam, and the Illinois Central Gulf railroad crosses it at about 7000 ft below the dam. The floodplain is well defined and fairly uniform with mild slope.

The breach parameters were chosen on the basis of the guidelines established previously. The bottom elevation of the breach, YBMIN, was set at 670 ft, which is about 23 ft above the channel bottom elevation. The bottom breach width, BBW, was taken to be 130 and 260 ft. Values of 520 and 1040 ft were tried for comparison. The time from the inception of the breach to its completion, TF, has been taken as 0.25, 0.50 and 1.00 hour. Since none of the floods (1.00 PMF, 0.50 PMF, 0.25 PMF) overtopped the dam, arbitrary failure elevations, HF, of 707 ft (5 ft below the top of the dam; h_f = HF-HD = -5ft) and 705.5 ft (hf = -6.5) were chosen to simulate piping failure with the PMF inflow hydrograph.

Results from the flood simulations are given in table 15-A for no-reservoir condition and in table 15-B with the reservoir and dam intact.

Table 15. Summary of Results for Clinton Lake

A. 1.00 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	150200	150200	150200	150200	150200	150200
	H	680.12	---	679.15	---	684.11	---
1.195	Q	149324	149977	---	---	149283	149894
	H	676.73	670.30	---	---	681.86	675.60
2.248	Q	149323	149579	148656	149314	148592	149748
	H	674.96	674.10	674.91	668.70	680.69	668.80
3.238	Q	148534	14949	---	---	147989	149667
	H	673.75	665.00	---	---	679.91	668.00
3.590	Q	148514	149494	148049	149196	147828	149646
	H	673.25	667.00	671.61	667.00	678.40	667.50

B. 1.00 PMF, HF = Max V7ater level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	.50	670.00	130.00	0.00	712.00	650.00	708.70

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	134682	130236	134682	130236	134682	130236
	H	678.17	---	676.98	---	680.64	---
1.195	Q	134604	130218	---	---	134584	130213
	H	673.96	669.20	---	---	677.13	674.30
2.248	Q	134650	130157	134637	130085	134602	130190
	H	671.27	672.50	671.26	667.50	674.86	667.50
3.238	Q	134736	130132	---	---	134732	130177
	H	669.38	663.60	---	---	673.46	666.60
3.590	Q	134820	130130	134818	130043	134807	130173
	H	668.52	665.50	668.53	665.50	672.98	666.20

Table 15. Continued

C. 1.00 PMF, breach parameters: TF=0.50, BBW=130, HF-HD=-6.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	.50	670.00	130.00	0.00	712.00	650.00	705.50

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	162768	163766	177982	163766	162719	163766
	H	679.15	---	679.93	---	681.15	---
1.195	Q	154948	160242	---	---	154506	159201
	H	674.17	670.80	---	---	676.53	676.30
2.248	Q	152849	156412	182628	154188	153219	158161
	H	670.50	674.70	673.70	669.00	672.87	669.30
3.238	Q	152390	155936	---	---	152943	157787
	H	667.41	665.40	---	---	670.15	668.50
3.590	Q	152361	155943	193069	153730	152941	157809
	H	665.64	667.50	670.50	667.30	669.15	668.10

D. 1.00 PMF, breach parameters: TF=0.50, BBW=130, HF-HD=-5.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	.50	670.00	130.00	0.00	712.00	650.00	707.00

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	194476	195087	194476	195087	194412	195087
	H	681.13	---	679.76	---	683.51	---
1.195	Q	186443	190761	---	---	184913	189330
	H	675.99	672.40	---	---	678.97	678.10
2.248	Q	182926	186156	182232	183288	182620	188126
	H	672.26	676.90	672.21	670.60	675.52	671.00
3.238	Q	182286	185483	---	---	182148	187582
	H	668.94	667.20	---	---	672.96	670.30
3.590	Q	182241	185533	181595	182625	182114	187393
	H	666.98	669.60	666.95	669.40	671.25	669.90

Table 15. Continued

E. 1.00 PMF, breach parameters: TF=0.25, BBW=130, HF-HD=-5.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	.25	670.00	130.00	0.00	712.00	650.00	707.00

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	194270	194757	194270	194757	194205	194757
	H	681.09	---	679.72	---	683.48	---
1.195	Q	185462	189840	---	---	184029	188431
	H	675.96	672.30	---	---	678.96	678.00
2.248	Q	182439	185083	181703	182287	182337	187130
	H	672.24	676.80	672.18	670.60	675.51	670.90
3.238	Q	181815	184505	---	---	181967	186580
	H	668.91	667.20	---	---	672.95	670.20
3.590	Q	181769	184499	181101	181580	181964	186497
	H	666.96	669.50	666.93	669.30	671.24	669.80

F. 1.00 PMF, breach parameters: TF=1.00, BBW=130, HF-HD=-5.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	670.00	130.00	0.00	712.00	650.00	707.00

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	194870	195717	194870	195717	194807	195717
	H	681.21	---	679.84	---	683.59	---
1.195	Q	187766	192469	---	---	186348	191073
	H	676.07	672.50	---	---	679.04	678.20
2.248	Q	184297	188187	183598	185382	183839	190054
	H	672.34	677.00	672.28	670.80	675.59	671.10
3.238	Q	183662	187512	---	---	183330	189480
	H	669.00	667.30	---	---	673.01	670.40
3.590	Q	183617	187456	182960	184650	183294	189405
	H	667.04	669.70	667.01	669.50	671.30	670.00

G. 1.00 PMF, breach parameters: TF=0.50, BBW=260, HF-HD=-6.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	.50	670.00	260.00	0.00	712.00	650.00	705.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	246144	245734	246144	245734	245917	245734
	H	683.32	---	681.94	---	685.57	---
1.195	Q	228650	235559	---	---	225826	232812
	H	677.93	674.40	---	---	680.54	680.40
2.248	Q	219518	225280	217349	218938	217142	229911
	H	674.17	679.50	674.02	672.50	676.63	673.00
3.238	Q	217432	223808	---	---	214961	228543
	H	670.61	669.30	---	---	673.45	672.60
3.590	Q	217311	223620	215581	217166	215333	228793
	H	668.50	672.00	668.42	671.60	672.08	672.10

H. 1.00 PMF, breach parameters: TF=0.50, BBW=260, HF-HD=-5.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	.50	670.00	260.00	0.00	712.00	650.00	707.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	283900	281861	283900	281861	283623	281861
	H	685.27	---	683.95	---	687.82	---
1.195	Q	265114	269524	---	---	261886	267466
	H	679.76	675.80	---	---	682.90	682.20
2.248	Q	256469	258566	255366	251897	253493	264202
	H	675.99	681.70	675.84	674.10	679.27	674.50
3.238	Q	254091	256732	---	---	252003	262791
	H	672.23	671.00	---	---	676.17	674.40
3.590	Q	253915	256803	254780	249719	251872	262066
	H	669.98	673.90	669.97	673.50	674.11	673.80

Table 15. Concluded

I. 1.00 PMF, breach parameters: TF=0.25, BBW=260, HF-HD=-5.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	.25	670.00	260.00	0.00	712.00	650.00	707.00

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	285056	283293	285056	283293	284774	283293
	H	685.24	---	683.92	---	687.81	---
1.195	Q	264655	269200	---	---	261012	266823
	H	679.75	675.80	---	---	682.92	682.10
2.248	Q	255590	257460	254908	250915	253245	263317
	H	675.99	681.60	675.84	674.10	679.28	674.50
3.238	Q	254066	255825	---	---	252344	261965
	H	672.23	671.00	---	---	676.18	674.40
3.590	Q	253918	256010	254624	248853	252194	261357
	H	669.98	673.80	669.97	673.40	674.12	673.80

J. 1.00 PMF, breach parameters: TF=1.00, BBW=260, HF-HD=-5.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	670.00	260.00	0.00	712.00	650.00	707.00

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	281641	279091	281641	279091	281373	279091
	H	685.32	---	684.00	---	687.86	---
1.195	Q	265686	270619	---	---	262705	268523
	H	679.79	675.80	---	---	682.92	682.20
2.248	Q	257035	260391	256266	253740	253941	265653
	H	676.02	681.80	675.89	674.20	679.28	674.60
3.238	Q	254790	258713	---	---	252219	264164
	H	672.26	671.10	---	---	676.18	674.50
3.590	Q	254612	258313	256338	251663	252090	263901
	H	670.01	674.00	670.02	673.60	674.12	673.90

Results from 8 combinations of breach parameters with the PMF hydrograph are given in tables 15-C to 15-J.

The peak discharges for both methods and all combinations of breach parameters along with peak discharge as determined by the SCS method are shown in table 16. The peak outflows for no-failure conditions are lower than those for no-reservoir condition due to storage in the reservoir. The peak outflows, with no-failure condition, are higher with the NWS than with the HEC because NWS was given higher initial water elevation in the reservoir (704 ft versus 700 ft for HEC) when the routing started.

The peak outflows due to the failure of the dam are about the same with both methods (NWS and HEC). The increase in peak discharges due to higher failure elevation is about 15 to 19%, whereas there is less than 1% difference with a 50% reduction in failure time. Bigger breach sizes result in an increase of about 46 to 51%.

The peak flows and maximum water stages in the 3.6-mile downstream channel are shown in figure 20 for TF = 0.5 hour, BBW = 260 ft, HF-HD = -6.5 ft. The peak outflows with the HEC are slightly higher than with the NWS. The maximum flood stages show moderately sloping profiles with the NWS and undulating profiles with the HEC, caused primarily by the inability of the HEC model to simulate satisfactorily the flow in non-prismatic channels. The maximum stage profile with the NWS is higher without reservoir than with reservoir and breach in the lower one-half of the downstream channel. It is attributed to different stage discharge loops for the two conditions because the hydrograph with dam break has very rapidly varying flow near the peak.

Table 16. Peak Outflows: Clinton Lake Dam

Table		Inflow	Breach parameters				Peak outflow, cfs	
15-	Item	flood*	YBMIN	BBW	TF	HF	NWS	HEC
A	No-reservoir conditions	1.00	-	-	-	-	150,200	150,200
B	No-failure conditions	1.00	-	-	-	-	134,682	130,236
C	Failure conditions	1.00	670	130	0.50	705.5	162,768	163,766
D	"	"	"	"	0.50	707.0	194,476	195,087
E	"	"	"	"	0.25	"	194,270	194,757
F	"	"	"	"	1.00	"	194,870	195,717
G	"	"		260	0.50	705.5	246,144	245,734
H	"	"	"	"	0.50	707.0	283,900	281,861
I	"	"	"	"	0.25	"	285,056	283,293
J	"	"	"	"	1.00	"	281,641	279,091
	SCS method	1.00	Q_p = 133,334 cfs			708.70		

*Inflow flood hydrograph corresponds to 1.00 times the probable maximum flood, PMF, hydrograph

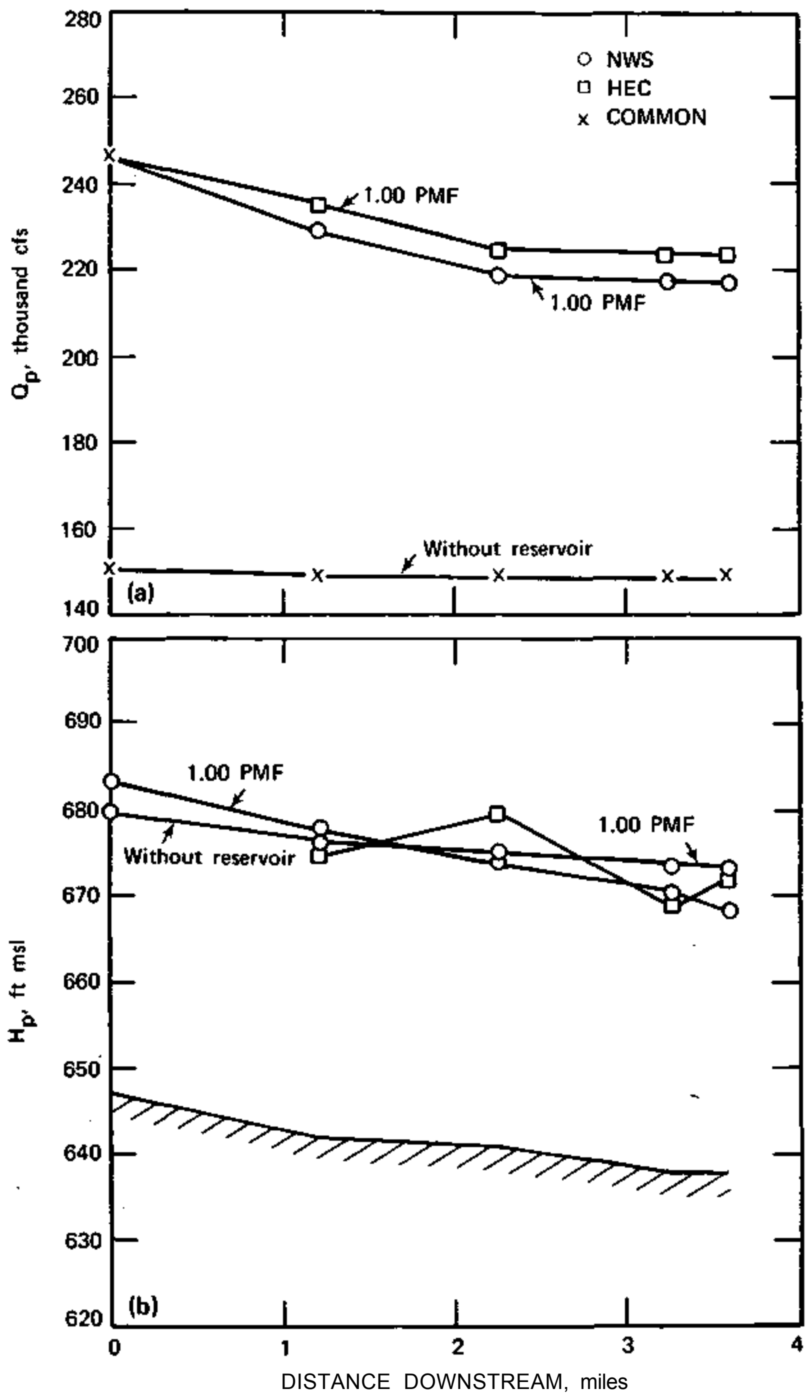


Figure 20. Peak flows and flood stages downstream of Clinton Lake Dam (PMF, BBW = 260 ft, TF = 0.50 hour, h_f = -6.5 ft)

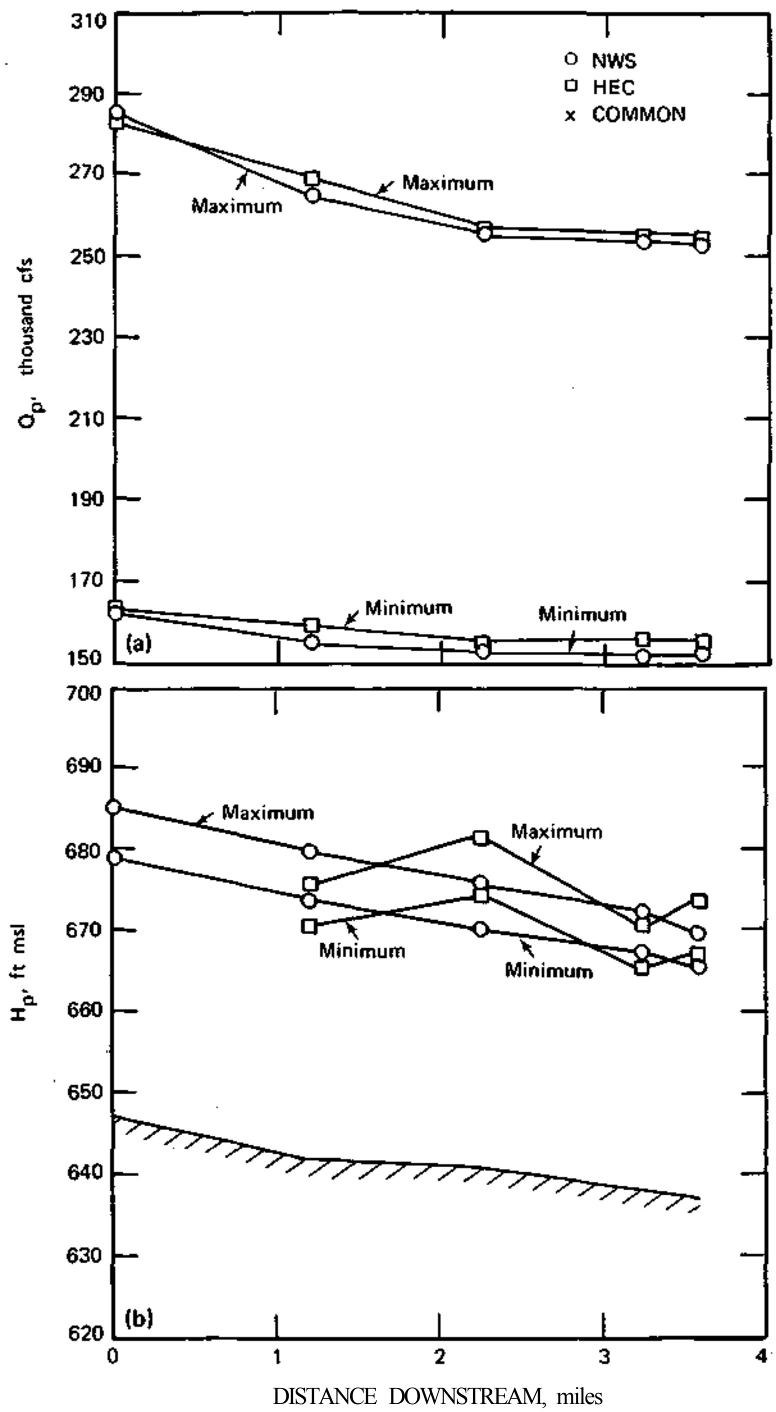


Figure 21. Maximum and minimum flood peaks and stages: Clinton Lake Dam

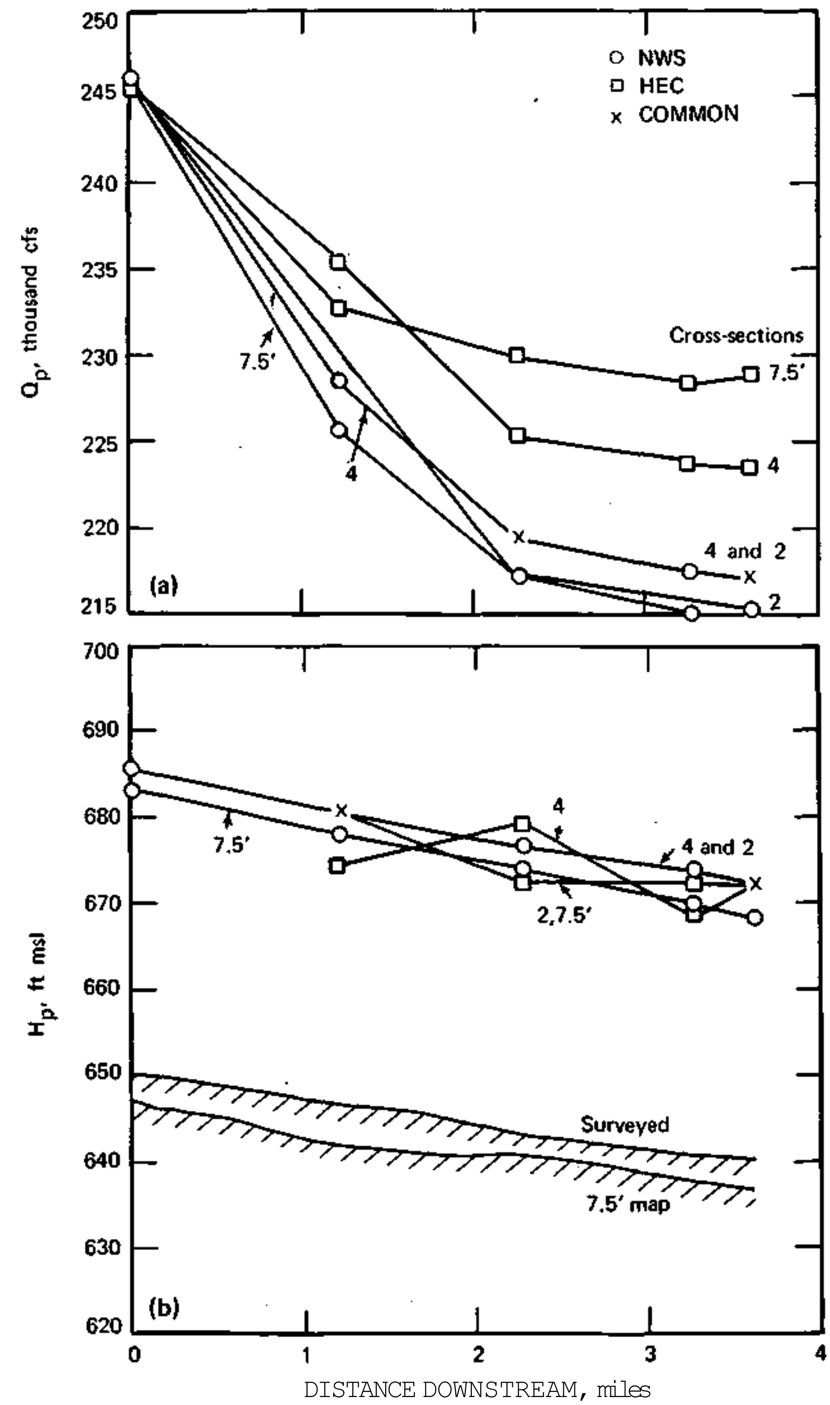


Figure 22. Peak flows and flood stages downstream of Clinton Lake Dam with surveyed and 7.5' map cross sections

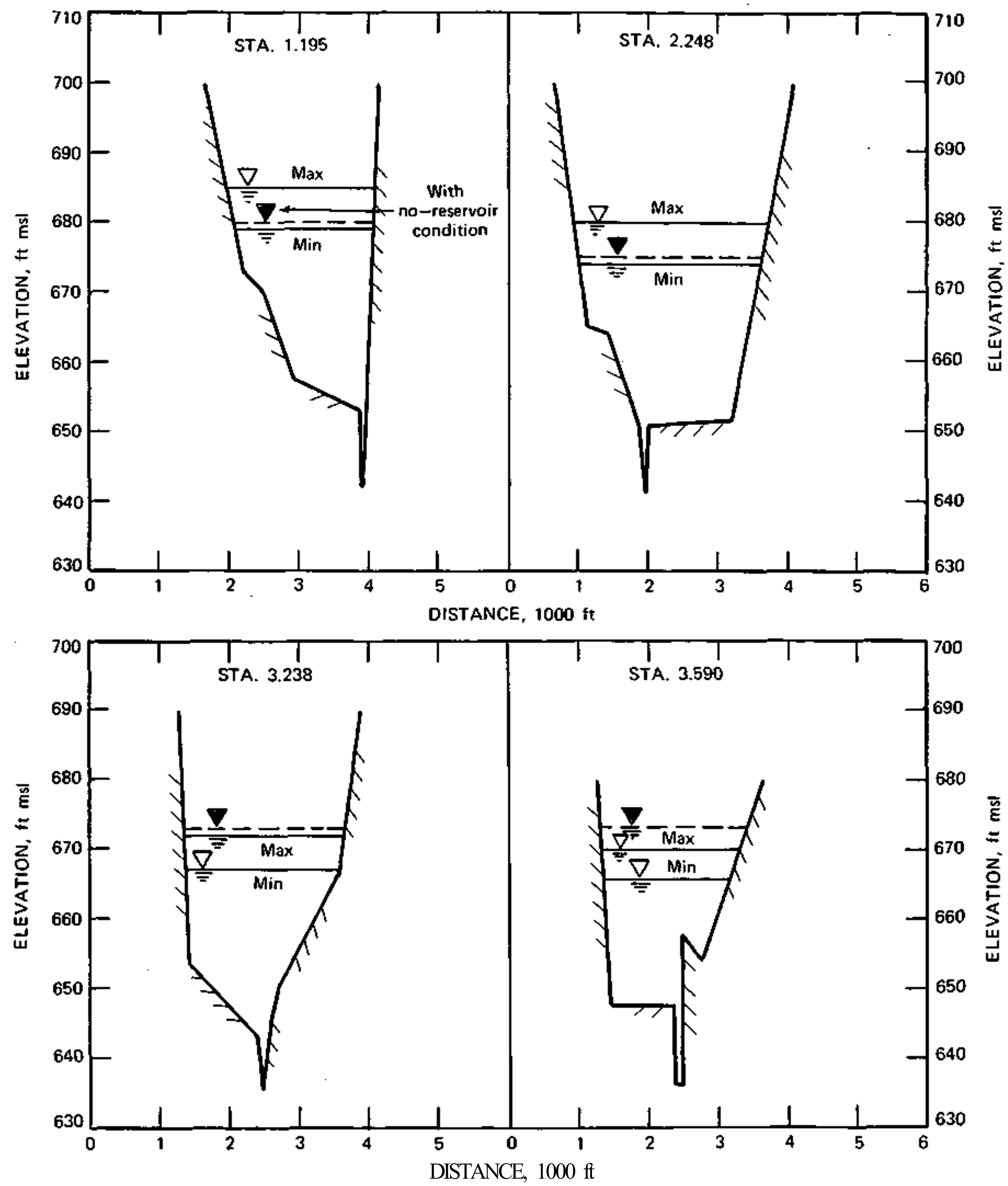


Figure 23. Range of peak flood stages downstream of Clinton Lake Dam

The whole range of peak flows and maximum water stages are shown in figure 21. The peak outflow below the dam varies from 285,056 to 162,768 cfs, and at the end of the 3.6-mile reach varies from 258,313 to 152,361 cfs. Thus, the flow range narrows with distance downstream. The flood stages follow the same pattern as in figure 20 with a difference of 4.5 to 6 feet between the maximum and minimum stages, as calculated by the NWS.

The effects of three different sets of cross sections (4 surveyed sections, 2 surveyed sections, and 4 sections developed from the 7.5' quadrangle maps) on the peak discharges and maximum flood stages in the downstream channel are shown in figure 22. The peak discharges with the NWS are similar with all sets of cross sections, whereas they differ slightly with the HEC (5,000 to 12,000 cfs at the end of the 3.6-mile reach). The flood stages with the NWS are similar with 4 and 2 surveyed cross sections and are consistently 2 to 3 feet lower than with the 7.5' map cross sections. The flood stages with the HEC are similar with 2 surveyed sections and 4 sections from the 7.5' map, and are declining along the downstream channel. The flood stages with 4 surveyed sections, however, undulate as in figure 20.

The maximum and minimum flood stages, along with those for the PMF and no-reservoir condition, are shown in figure 23 for four surveyed cross sections of the downstream channel, as calculated by the NWS.

VI. Lake Springfield Dam (Spaulding Dam)

Lake Springfield Dam (figure 24) is located on Sugar Creek in Sangamon County, Illinois. It is an earthfill structure approximately 48 ft high and 1580 ft long. The appurtenant works consist of a controlled spillway,

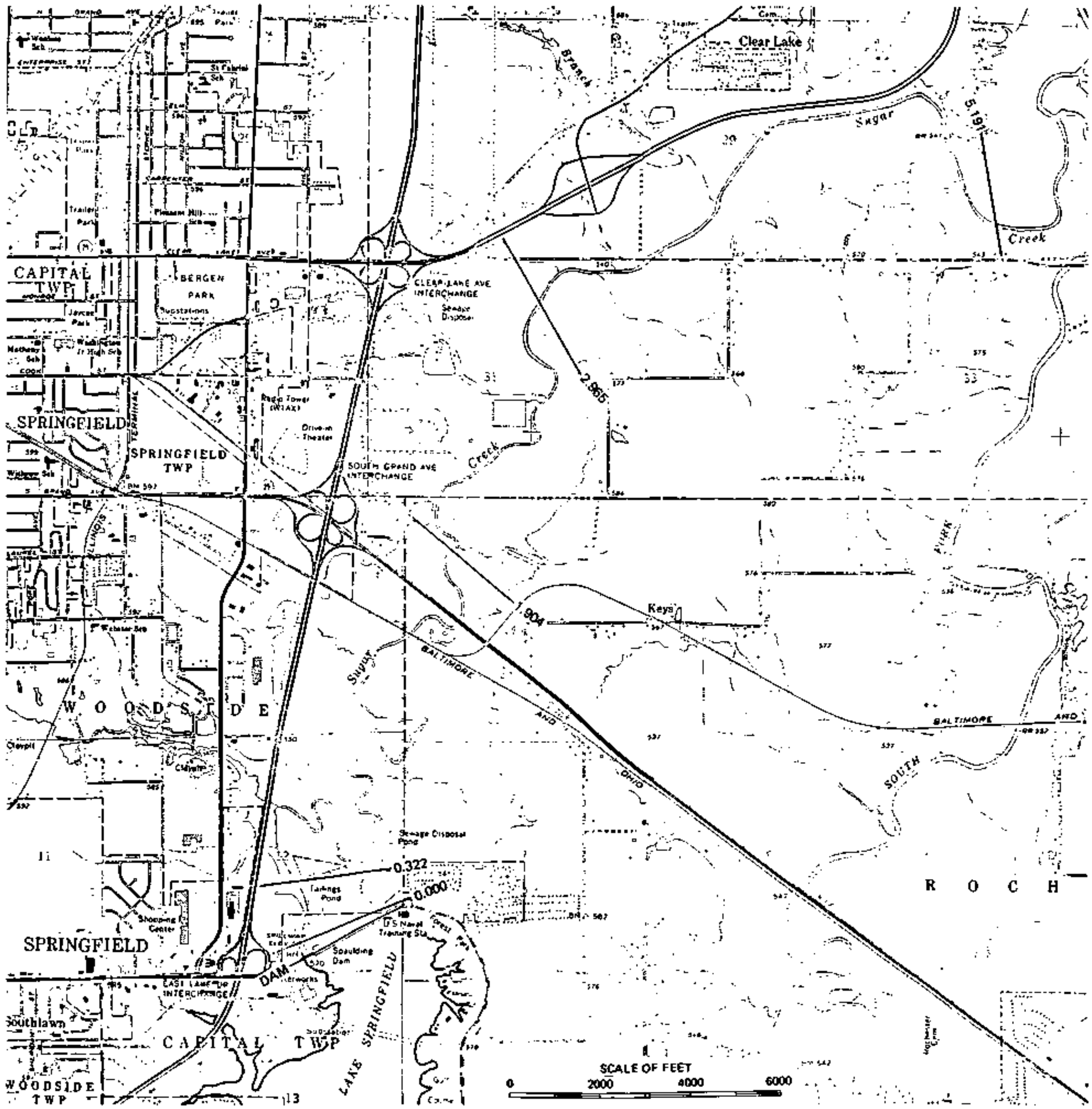


Figure 24. Location of Lake Springfield Dam and downstream channel cross sections

an outlet works, and a saddle dam. The spillway includes five steel "floating" drum gates, each 45 feet long and 8 feet high with separate controls. The outlet works include five sluice gates to permit water supply withdrawals from the lake at various levels. The saddle dam is an earthfill embankment, 29 ft high and 1720 ft long, built to prevent loss of lake water to an adjoining watershed. The watershed has fairly uniform slopes with elevation ranging from about 560 to 710 ft msl.

The dam is classified in the large size and high hazard potential category. Failure of the dam can result in extensive property damage and endanger human lives. A breach will result in loss of water supply and power generating capacity for the City of Springfield. Pertinent data about the reservoir and the dam are given below.

Pertinent data - Lake Springfield Dam

Drainage area	265 sq mi
<u>Main dam</u>	
Type	Earthfill
Elevation, top of dam	570 ft msl
Height	48 ft
Length	1,580 ft
<u>Saddle dam</u>	
Type	Earthfill
Elevation, top of dam	570 ft msl
Height	29 ft
Length	1,720 ft
<u>Reservoir</u>	
Elevation, normal pool	560 ft msl
Area, normal pool	4,224 ac
Capacity, normal pool	53,504 ac ft
Length, normal pool	9 mi

Spillway

Type	Controlled, five steel drum gates
Elevation, spillway crest	
raised portion	560 ft msl
lowered portion	552 ft msl
Crest length	225 ft

Freeboard

Normal pool	10 ft

The basic hydrologic and hydraulic data in table 17 consist of the PMF hydrograph generated by the HEC-1 program, and information on reservoir area and capacity and combined discharge versus elevation. The information presented above follows the Spaulding Dam, Lake Springfield Inspection Report (COE, 1980c).

Cross sections were developed from 7.5' quadrangle maps. Their location is shown in figure 24. The Manning's roughness coefficient, n, was taken to be 0.03 for the channel and 0.05 for the overbank flow.

Analyses and Results

Below the Lake Springfield Dam, Sugar Creek flows in a northeasterly direction for about 8 miles to its confluence with the Sangamon River. The floodplain is narrow just below the dam, but widens considerably about 0.5 mile downstream, and is relatively flat and uniform until it joins the Sangamon River floodplain.

The breach parameters were chosen on the basis of the guidelines established previously. The bottom elevation of the breach, YBMIN, was set at 535 ft, which is about 13 ft above the channel bottom elevation. The bottom breach width, BBW, was set at 96 and 192 ft for the small and the large breach, respectively. The time from inception of the breach to its completion, TF, has been taken as 0.25, 0.50, and 1.00 hour. The depth of

Table 17. PMF Hydrograph and Elevation-Area-Storage-Discharge Data: Lake Springfield Dam

a. PMF Inflow Hydrograph

Time (hr)	0	1	2	3	4	5
Inflow (cfs)	23,453	32,282	42,332	53,078	66,179	75,127
Time (hr)	6	7	8	9	10	11
Inflow (cfs)	85,705	95,448	103,917	110,837	116,099	119,636
Time (hr)	12	13	14	15	16	17
Inflow (cfs)	121,364	121,234	119,208	115,470	110,754	105,772
Time (hr)	18	19	20	21	22	23
Inflow (cfs)	100,859	96,135	91,570	87,137	82,802	78,442
Time (hr)	24	25	26	27	28	29
Inflow (cfs)	74,260	70,010	65,730	61,511	57,480	53,680
Time (hr)	30	31	32	33	34	35
Inflow (cfs)	50,159	46,871	43,808	40,954	38,295	35,818
Time (hr)	36	37	38	39	40	
Inflow (cfs)	33,511	31,363	29,360	27,443	25,752	

b. Elevation-Area-Storage-Discharge Data

Elevation (ft msl)	Area (ac)	Storage (ac ft)	Discharge (cfs)
535.0	0	0	0
550.0	2,293	21,405	0
555.0	3,186	35,041	0
560.0	4,224	53,504	0
561.0	4,330	57,781	5,199
562.0	4,436	62,164	25,808
564.0	4,654	71,253	33,671
566.0	4,877	80,783	42,866
567.0	4,990	85,716	45,607
568.0	5,105	96,763	48,348
570.0	5,338	101,205	53,268
571.0	5,493	106,620	64,980
572.0	5,649	112,191	84,606
572.7	5,760	116,409	102,489

overtopping when the breach starts, or h_f = HF-HD, has been taken as 0.5 and 2.0 ft. The HF and HD denote the failure elevation and the elevation of the top of the dam, respectively.

Results from the simulation of floods are given in tables 18-A to 18-C for no-reservoir condition, and in tables 18-D to 18-F with the reservoir and the dam intact. It is apparent that only the PMF will overtop the dam and will breach it for both failure elevations. Results from 8 combinations of breach parameters with the PMF flood hydrograph are given in tables 18-G to 18-N.

The peak discharges for both methods and all combinations of breach parameters along with peak discharges as determined with the SCS method are shown in table 19. The peak discharges with the reservoir intact are lower than with no-reservoir condition due to storage in the reservoir. The peak outflows due to failure of the dam are similar with both methods (NWS and HEC). Increase in peak discharge due to higher failure elevation is about 15 to 21%, whereas there is less than 3% difference with a 50% reduction in failure time. Bigger breach size results in an increase of about 35 to 46%.

The peak flow and maximum water stages in the 5.2-mile downstream channel are shown in figure 25 for TF = 0.5 hr, BBW = 192, HF-HD = 0.5 ft. The peak outflows with the HEC are higher than with the NWS with the difference increasing downstream. The maximum flood stages, however, are considerably higher with the NWS. The water stage profiles with the HEC seem less reasonable (because of significant undulations in levels) than with the NWS.

Table 18. Summary of Results for Lake Springfield

A. 1.00 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	121363	121351
	H	---	---	---	---	557.96	---
0.322	Q	---	---	---	---	121084	121341
	H	---	---	---	---	557.19	548.00
1.904	Q	---	---	---	---	119232	121277
	H	---	---	---	---	554.93	543.50
2.965	Q	---	---	---	---	117264	121258
	H	---	---	---	---	554.05	545.70
5.191	Q	---	---	---	---	113202	121253
	H	---	---	---	---	552.52	542.50

B. 0.50 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	60681	60676
	H	---	---	---	---	551.65	---
0.322	Q	---	---	---	---	60578	60670
	H	---	---	---	---	550.69	545.10
1.904	Q	---	---	---	---	59668	60617
	H	---	---	---	---	547.61	539.70
2.965	Q	---	---	---	---	58569	60592
	H	---	---	---	---	546.58	541.40
5.191	Q	---	---	---	---	55757	60587
	H	---	---	---	---	545.24	537.20

Table 18. Continued

C. 0.25 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	30340	30338
	H	---	---	---	---	547.62	---
0.322	Q	---	---	---	---	30309	30336
	H	---	---	---	---	546.58	543.00
1.904	Q	---	---	---	---	30005	30299
	H	---	---	---	---	542.62	536.70
2.965	Q	---	---	---	---	29572	30269
	H	---	---	---	---	541.17	538.10
5.191	Q	---	---	---	---	27823	30265
	H	---	---	---	---	539.17	532.60

D. 1.00 PMF, HF=Maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	570.00	527.00	572.72

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	102482	103267
	H	---	---	---	---	556.10	---
0.322	Q	---	---	---	---	102186	103263
	H	---	---	---	---	555.30	547.30
1.904	Q	---	---	---	---	100637	103196
	H	---	---	---	---	552.93	542.50
2.965	Q	---	---	---	---	98906	103152
	H	---	---	---	---	552.05	544.50
5.191	Q	---	---	---	---	94974	103150
	H	---	---	---	---	550.60	541.20

Table 18. Continued

E. 0.50 PMF, HF=maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	570.00	527.00	566.49

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	44059	44222
	H	---	---	---	---	549.72	---
0.322	Q	---	---	---	---	44035	44222
	H	---	---	---	---	548.76	544.00
1.904	Q	---	---	---	---	43699	44215
	H	---	---	---	---	545.94	538.10
2.965	Q	---	---	---	---	43223	44212
	H	---	---	---	---	545.16	540.00
5.191	Q	---	---	---	---	41718	44211
	H	---	---	---	---	544.23	535.00

F. 0.25 PMF, HF=maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	570.00	527.00	562.30

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	27052	27003
	H	---	---	---	---	547.12	---
0.322	Q	---	---	---	---	27043	27002
	H	---	---	---	---	546.09	542.70
1.904	Q	---	---	---	---	26891	26995
	H	---	---	---	---	542.21	536.30
2.965	Q	---	---	---	---	26618	26988
	H	---	---	---	---	540.90	537.60
5.191	Q	---	---	---	---	25256	26988
	H	---	---	---	---	538.96	532.00

Table 18. Continued

G. 1.00 PMF, breach parameters: TF=0.50, BBW=96, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	535.00	96.00	0.50	570.00	527.00	570.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	134698	134601
	H	---	---	---	---	557.99	---
0.322	Q	---	---	---	---	134437	134789
	H	---	---	---	---	557.22	548.60
1.904	Q	---	---	---	---	125343	131791
	H	---	---	---	---	555.08	544.10
2.965	Q	---	---	---	---	121752	131417
	H	---	---	---	---	554.29	546.30
5.191	Q	---	---	---	---	116557	131424
	H	---	---	---	---	552.99	543.20

H. 1.00 PMF, breach parameters: TF=0.50, BBW=96, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	535.00	96.00	0.50	570.00	527.00	572.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	162974	163004
	H	---	---	---	---	558.69	---
0.322	Q	---	---	---	---	160734	159788
	H	---	---	---	---	557.79	549.60
1.904	Q	---	---	---	---	144176	153899
	H	---	---	---	---	555.23	545.20
2.965	Q	---	---	---	---	133970	152202
	H	---	---	---	---	554.40	547.40
5.191	Q	---	---	---	---	125584	152092
	H	---	---	---	---	553.04	544.50

Table 18. Continued

I. 1.00 PMF, breach parameters: TF=0.25, BBW=96, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	535.00	96.00	0.50	570.00	527.00	572.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	161434	163216
	H	---	---	---	---	558.60	---
0.322	Q	---	---	---	---	160385	163321
	H	---	---	---	---	557.72	549.70
1.904	Q	---	---	---	---	142679	153235
	H	---	---	---	---	555.20	545.20
2.965	Q	---	---	---	---	132592	151248
	H	---	---	---	---	554.37	547.40
5.191	Q	---	---	---	---	124797	151397
	H	---	---	---	---	553.02	544.50

J. 1.00 PMF, breach parameters: TF=1.00, BBW=96, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	535.00	96.00	0.50	570.00	527.00	572.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	162124	162020
	H	---	---	---	---	558.86	---
0.322	Q	---	---	---	---	158242	161212
	H	---	---	---	---	557.91	549.70
1.904	Q	---	---	---	---	146396	155121
	H	---	---	---	---	555.28	545.30
2.965	Q	---	---	---	---	135899	153502
	H	---	---	---	---	554.44	547.50
5.191	Q	---	---	---	---	126648	153408
	H	---	---	---	---	553.07	544.60

Table 18. Continued

K. 1.00 PMF, breach parameters: TF=0.50, BBW=192, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	535.00	192.00	0.50	570.00	527.00	570.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	96501	194588
	H	---	---	---	---	561.01	---
0.322	Q	---	---	---	---	194667	191225
	H	---	---	---	---	560.15	550.70
1.904	Q	---	---	---	---	172433	182966
	H	---	---	---	---	557.56	546.60
2.965	Q	---	---	---	---	163528	181935
	H	---	---	---	---	556.47	549.00
5.191	Q	---	---	---	---	155393	181784
	H	---	---	---	---	554.43	546.30

L. 1.00 MPF, breach parameters: TF=0.50, BBW=192, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	535.00	192.00	0.50	570.00	527.00	572.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	226280	224351
	H	---	---	---	---	561.76	---
0.322	Q	---	---	---	---	220784	218051
	H	---	---	---	---	560.92	551.70
1.904	Q	---	---	---	---	194150	206058
	H	---	---	---	---	558.40	547.60
2.965	Q	---	---	---	---	174076	202190
	H	---	---	---	---	557.33	550.00
5.191	Q	---	---	---	---	163070	202303
	H	---	---	---	---	555.28	547.40

Table 18. Concluded

M. 1.00 PMF, breach parameters: TF=0.25, BBW=192, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	535.00	192.00	0.50	570.00	527.00	572.00

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	---	---	---	---	225125	226969
	H	---	---	---	---	561.69	---
0.322	Q	---	---	---	---	221865	227926
	H	---	---	---	---	560.85	552.00
1.904	Q	---	---	---	---	192294	204726
	H	---	---	---	---	558.32	547.60
2.965	Q	---	---	---	---	172768	201899
	H	---	---	---	---	557.25	550.00
5.191	Q	---	---	---	---	162387	201799
	H	---	---	---	---	555.19	547.40

N. 1.00 PMF, breach parameters: TF=1.00, BBW=192, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	535.00	192.00	0.50	570.00	527.00	572.00

STATION MILE		SURVEY SECTIONS NWS	HEC	SURVEY SECTIONS NWS	HEC	7.5' MAP SECTIONS NWS	HEC
0.000	Q	---	---	---	---	219533	219009
	H	---	---	---	---	561.85	---
0.322	Q	---	---	---	---	213533	216017
	H	---	---	---	---	561.02	551.60
1.904	Q	---	---	---	---	192713	206496
	H	---	---	---	---	558.53	547.70
2.965	Q	---	---	---	---	174853	202487
	H	---	---	---	---	557.48	550.00
5.191	Q	---	---	---	---	63619	202366
	H	---	---	---	---	555.44	547.40

Table 19. Peak Outflows: Lake Springfield Dam

Table 18-	Item	Inflow flood*	Breach parameters YBMIN	BBW	TF	HF	Peak outflow, cfs NWS	HEC
A	No-reservoir conditions	1.00	-	-	-	-	121,363	121,351
B	"	0.50	-	-	-	-	60,681	60,676
C	"	0.25	-	-	-	-	30,340	30,338
D	No-failure conditions	1.00	-	-	-	-	102,482	103,267
E	"	0.50	-	-	-	-	[illegible]4,059	44,222
F	"	0.25	-	-	-	-	27,052	27,003
G	Failure conditions	1.00	535.0	96	0.50	570.5	134,698	134,601
H	"	"	"	"	0.50	572.0	162,974	163,004
I	"	"	"	"	0.25	"	161,434	163,216
J	"	"	"	"	1.00	"	162,124	162,020
K	"	"	"	192	0.50	570.5	196,501	194,588
L	"	"	"	"	0.50	572.0	226,280	224,351
M	"	"	"	"	0.25	"	225,125	226,969
N	"	"	"	"	1.00	"	219,533	219,009
	SCS method	1.00	Q_p = 92,789 cfs			572.72		

*Inflow flood hydrograph corresponds to 0.25, 0.50, or 1.00 times the probable maximum flood, PMF, hydrograph

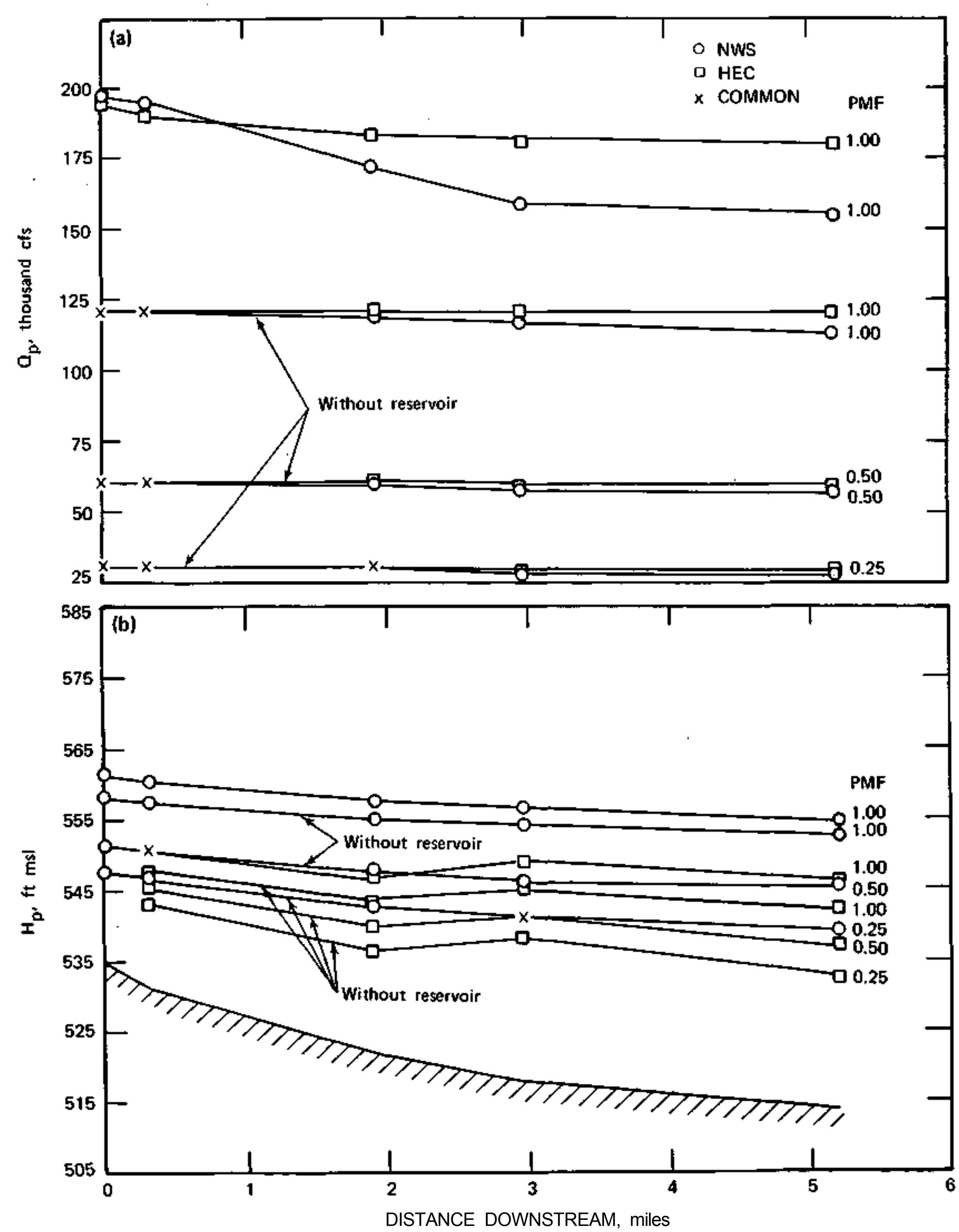


Figure 25. Peak flows and flood stages downstream of Lake Springfield Dam (BBW = 192 ft, TF = 0.50 hour, h_f = 0.5 ft)

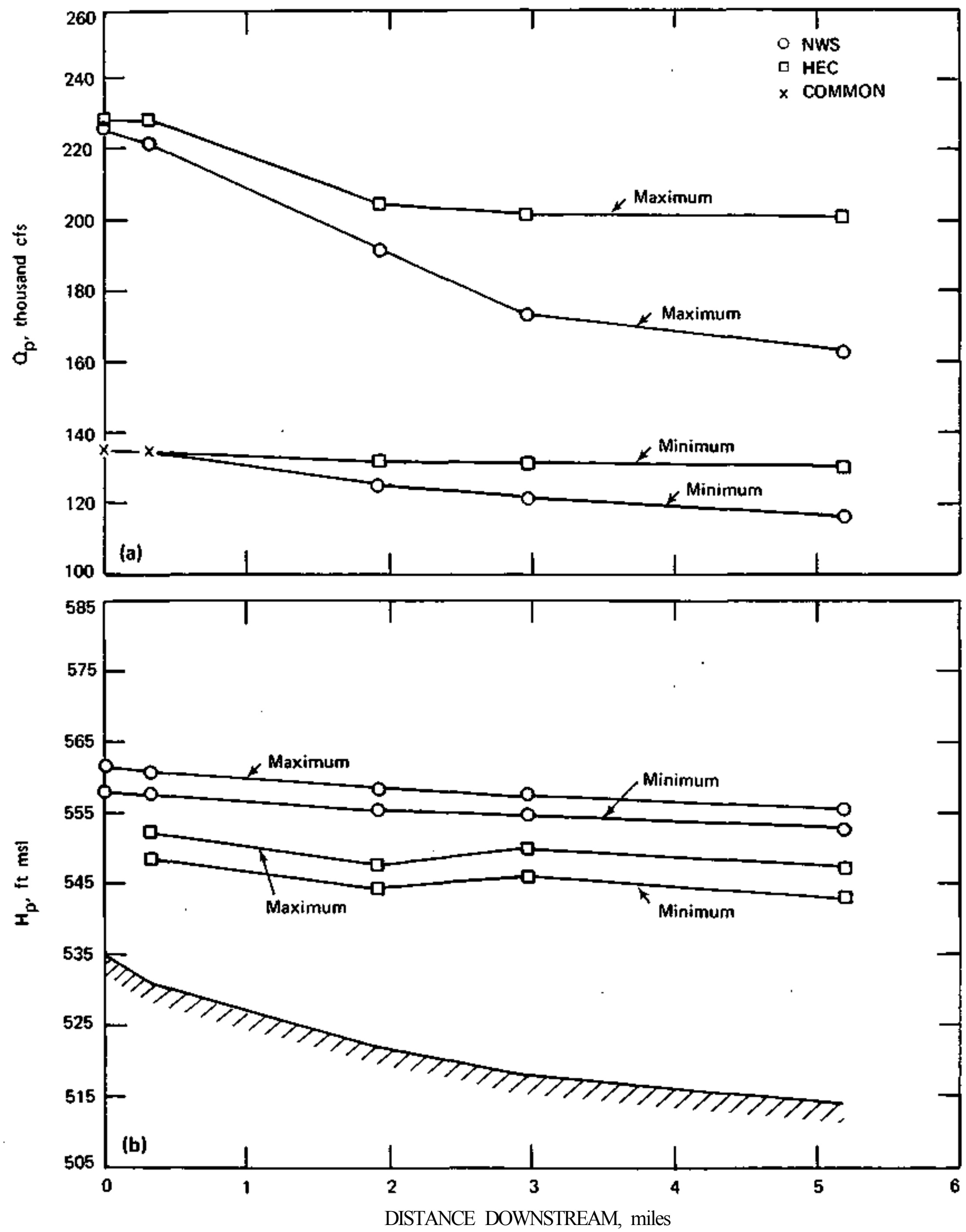


Figure 26. Maximum and minimum flood peaks and stages: Lake Springfield Dam

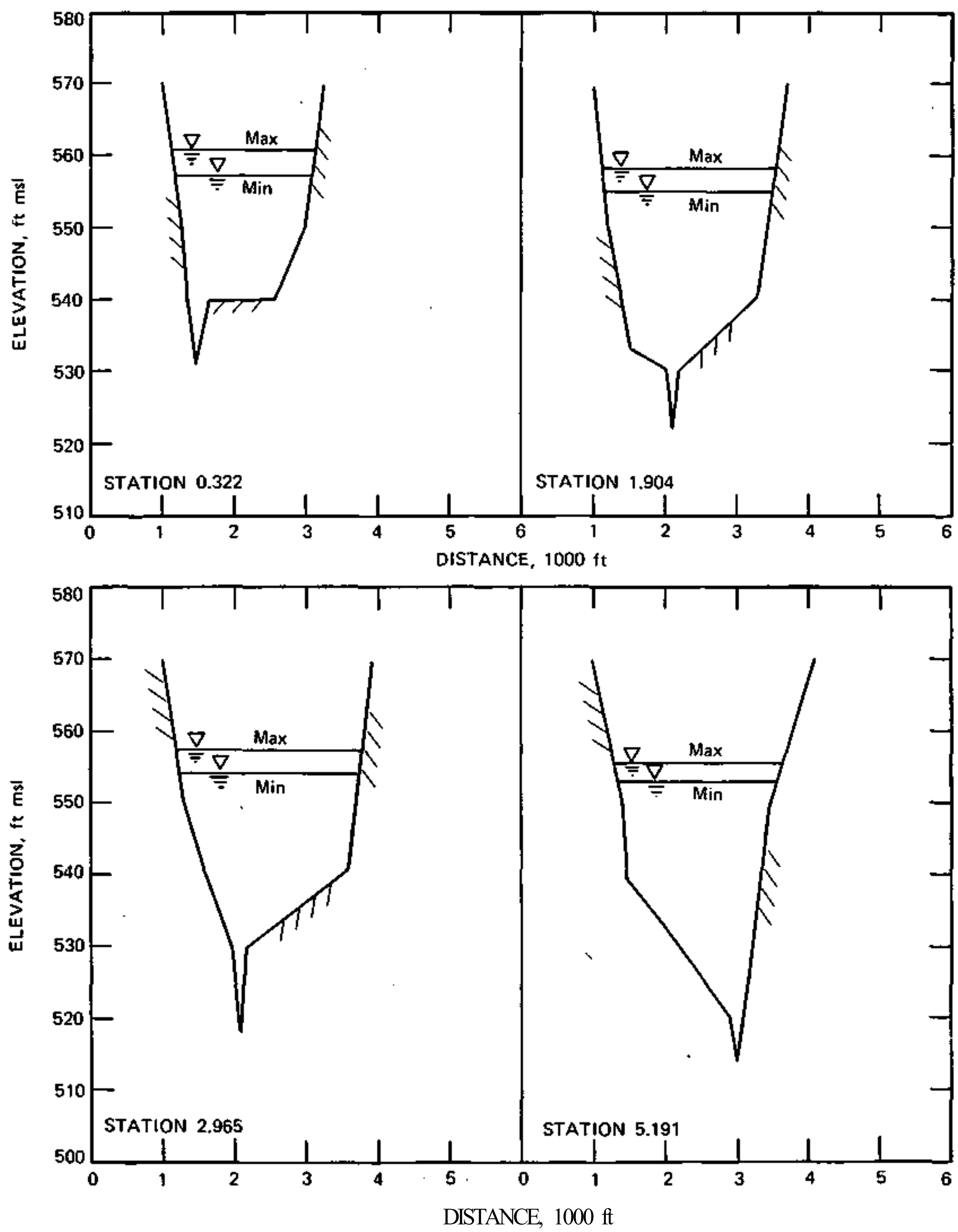


Figure 27. Range of peak flood stages downstream of Lake Springfield Dam

The whole range of peak flows and maximum water stages in the 5.2-mile downstream channel is shown in figure 26. The peak outflow below the dam varies from 226,969 to 134,601 cfs, and at the end of the 5.2-mile reach varies from 202,366 to 116,557 cfs. Thus, the flow range narrows slightly with distance downstream. The flood stages in figure 26 follows the same pattern as in figure 25. The maximum and minimum flood stages with the PMF and dam breach are shown in figure 27 for four cross sections along the downstream channel as calculated by the NWS. The peak flood stages with the PMF and no reservoir condition are less than 0.5 ft lower than shown as Min in figure 27.

VII. Weslake Dam

Weslake Dam (figure 28) is located on a small tributary to Schoenberger Creek, about 1/2 mile west of Fairview Heights, St. Clair County, Illinois. It is an earthfill structure, approximately 48 ft high and 330 ft long. The appurtenant works consist of an uncontrolled corrugated metal pipe spillway without head walls or energy dissipating devices. A road with curbs and gutters has been constructed over the crest of the dam. The watershed is about 30 to 40% in residential development, with the rest pasture and forested areas. The maximum elevation difference is about 60 ft.

The dam is classified in the intermediate and high hazard potential category. Failure of the dam can interrupt transportation and utilities and endanger human lives. Pertinent data about the dam and reservoir are given on page 134.

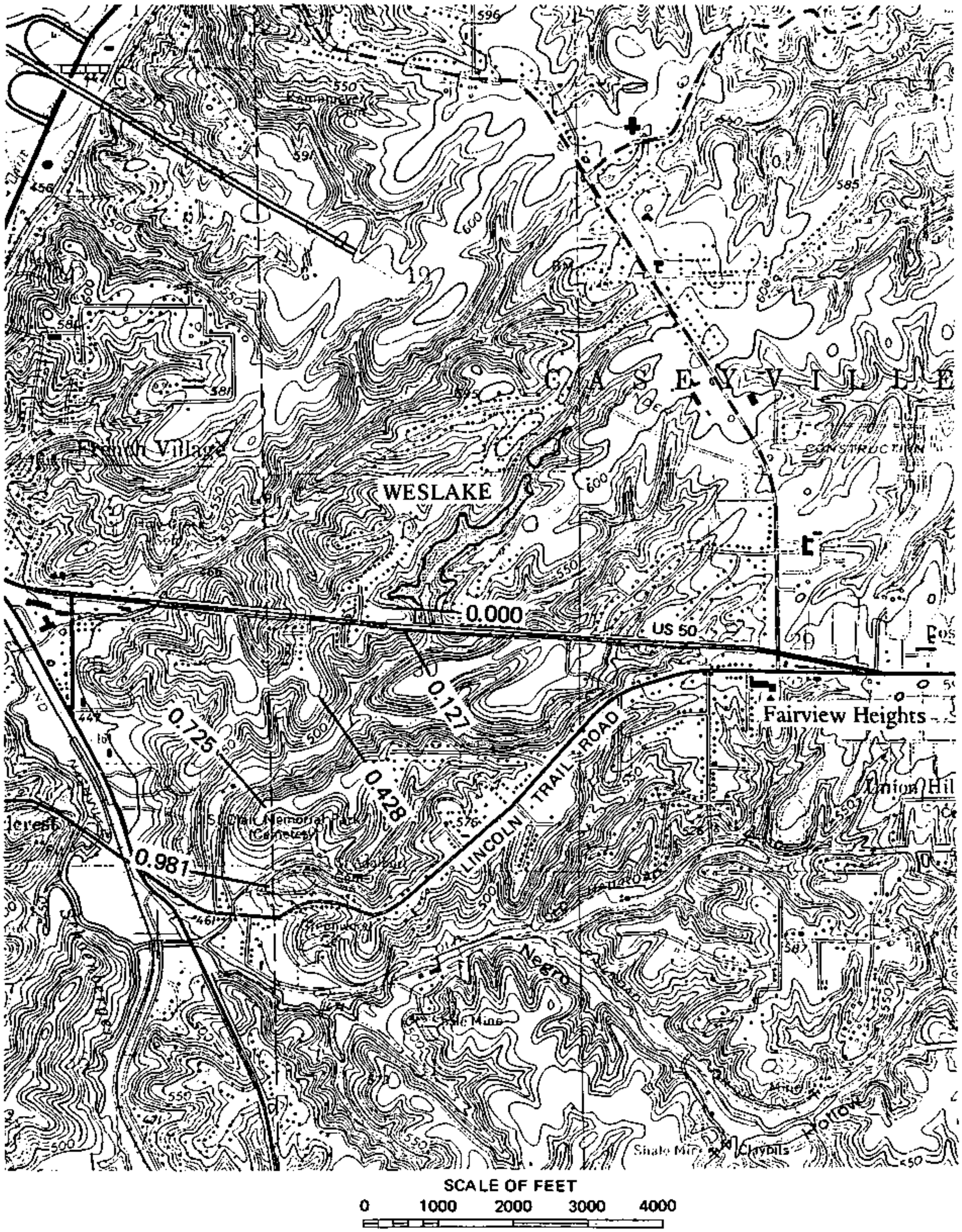


Figure 28. Location of Wesla
ke Dam and downstream channel cross sections

Pertinent data - Weslake Dam

Drainage area	0.225 sq mi
Dam	
Elevation, top of dam	546.7 ft msl
Height above streambed	48.0 ft
Length	330.0 ft
Type	Earth embankment
Reservoir	
Elevation, normal pool*	540.0 ft msl
Area, normal pool	15.3 ac
Capacity, normal pool	224.0 ac ft
Length, normal pool	0.44 mi
Spillway	
Elevation, invert	540.0 ft msl
Type	Corrugated metal pipe, 30" dia
Exit channel	Earth channel on downstream face of dam
Freeboard	
Normal pool	6.7 ft

*Based on invert elevation of spillway

The basic hydrologic and hydraulic data in table 20 consist of the PMF hydrograph, generated by the HEC-1 program, and information on reservoir area and capacity and combined discharge versus elevation. The information presented above follows the Weslake Dam Inspection Report (COE, 1979a).

No surveyed cross sections were available. Cross sections were developed from 7.5' quadrangle maps. The Manning's roughness coefficient, n, was not available, but was assumed to be 0.05 for the channel and 0.07 for the overbank flow.

Analyses and Results

Immediately downstream from the Weslake Dam is U.S. Route 50. Its embankment is about 4 ft lower than the dam and has a 7'x7' box culvert.

Table 20. PMF Hydrograph and Elevation-Area-Storage-Discharge Data: Weslake Dam

a. PMF Inflow Hydrograph

Time (hr)	0	0.5	1.0	1.5	2.0	2.5
Inflow (cfs)	95	100	105	110	115	130
Time (hr)	3.0	3.5	4.0	4.5	5.0	5.5
Inflow (cfs)	160	240	420	900	1243	1050
Time (hr)	6.0	6.5	7.0	7.5	8.0	8.5
Inflow (cfs)	770	580	440	330	240	180
Time (hr)	9.0	9.5	10.0			
Inflow (cfs)	132	90	70			

b. Elevation-Area-Storage-Discharge Data

Elevation (ft msl)	Area (ac)	Storage (ac ft)	Discharge (cfs)[1]
495.0	0.0	0	0
540.0	15.3	224	0
542.0	16.5	256	14
544.0	17.7	290	32
545.0	18.2	308	39
546.0	18.8	326	44
547.0	19.4	345	78
548.0	20.0	365	472
549.0	20.6	385	1356
550.0	21.1	406	2820

[1]Combined discharge through the spillway and over the top of the dam.

Following COE, 1979a, it was assumed that during a dam breach this culvert would plug quickly and the embankment would fail instantaneously when overtopped. The floodplain downstream of Weslake Dam is quite narrow until it reaches the Schoenberger Creek, about 1 mile downstream. About 30 homes are located where the Lincoln Trail Road crosses the floodplain just upstream of the confluence.

The breach parameters were chosen on the basis of the guidelines established previously. The bottom of the breach, YBMIN, was set at an elevation of 495.0 ft, which is the approximate channel bottom as determined from the 7.5' map. The bottom breach width, BBW, for the smaller breach was set at 96 ft and at 192 ft for the larger breach. The time from the inception of the breach to its completion, TF, was taken as 0.25, 0.50, or 1.00 hour. The depth of overtopping when the breach starts, or h_f equal to HF-HD, has been taken as 0.5 or 2.0 ft; the HD and HF denote the failure elevation and elevation of the top of the dam, respectively.

Results from the simulation of floods are given in tables 21-A to 21-C for no-reservoir condition and in tables 21-D to 21-F with the reservoir and dam intact. It is apparent that only the PMF flood will breach the dam for both failure elevations, and the 0.5 PMF and 0.25 PMF floods will breach it for the lower failure elevation. Results from 8 combinations of breach parameters with the PMF hydrograph are given in tables 21-G to 21-N. Results from 2 combinations of breach parameters with the 0.50 PMF and 0.25 PMF hydrograph are given in tables 21-0 to 21-R.

The peak discharges for both methods and all flood simulations along with peak discharge as determined by the SCS method are shown in table 22. The peak discharges with the reservoir intact are slightly lower than with

Table 21. Summary of Results for Weslake Dam

A. 1.00 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	---	---	---

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	---	---	---	---	1242	1243
	H	---	---	---	---	498.55	---
0.127	Q	---	---	---	---	1237	1234
	H	---	---	---	---	490.03	490.60
0.428	Q	---	---	---	---	1222	1220
	H	---	---	---	---	476.45	477.30
0.725	Q	---	---	---	---	1210	1204
	H	---	---	---	---	467.50	468.70
0.981	Q	---	---	---	---	1207	1197
	H	---	---	---	---	458.46	458.80

B. 0.50 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	---	---	---

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	---	---	---	---	621	622
	H	---	---	---	---	497.71	---
0.127	Q	---	---	---	---	619	617
	H	---	---	---	---	489.13	489.70
0.428	Q	---	---	---	---	609	599
	H	---	---	---	---	475.65	475.60
0.725	Q	---	---	---	---	604	593
	H	---	---	---	---	466.47	467.70
0.981	Q	---	---	---	---	603	589
	H	---	---	---	---	457.44	458.00

Table 21. Continued

C. 0.25 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	310	311
	H	---	---	---	---	497.08	---
0.127	Q	---	---	---	---	309	307
	H	---	---	---	---	488.42	488.60
0.428	Q	---	---	---	---	304	299
	H	---	---	---	---	475.04	474.30
0.725	Q	---	---	---	---	301	293
	H	---	---	---	---	465.68	465.50
0.981	Q	---	---	---	---	300	290
	H	---	---	---	---	456.65	456.10

D. 1.00 PMF, HF=max. water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	546.70	495.00	548.74

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	1124	1124
	H	---	---	---	---	498.64	---
0.127	Q	---	---	---	---	1123	1124
	H	---	---	---	---	489.96	490.40
0.428	Q	---	---	---	---	1122	1121
	H	---	---	---	---	476.39	477.20
0.725	Q	---	---	---	---	1119	1116
	H	---	---	---	---	467.37	468.60
0.981	Q	---	---	---	---	1118	1114
	H	---	---	---	---	458.34	458.70

Table 21. Continued

E. 0.50 PMF, HF=max. water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	546.70	495.00	548.05

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	517	518
	H	---	---	---	---	497.75	---
0.127	Q	---	---	---	---	517	518
	H	---	---	---	---	488.98	489.50
0.428	Q	---	---	---	---	516	512
	H	---	---	---	---	475.53	475.20
0.725	Q	---	---	---	---	514	506
	H	---	---	---	---	466.27	467.40
0.981	Q	---	---	---	---	513	502
	H	---	---	---	---	457.24	457.60

F. 0.25 PMF, HF=max. water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	546.70	495.00	547.37

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	225	225
	H	---	---	---	---	497.03	---
0.127	Q	---	---	---	---	225	225
	H	---	---	---	---	488.20	487.90
0.428	Q	---	---	---	---	225	223
	H	---	---	---	---	474.85	474.00
0.725	Q	---	---	---	---	224	222
	H	---	---	---	---	465.40	464.90
0.981	Q	---	---	---	---	224	220
	H	---	---	---	---	456.38	455.60

Table 21. Continued

G. 1.00 PMF, breach parameters: TF=0.50, BBW=96, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	495.00	96.00	0.50	546.70	495.00	547.20

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	19895	15053
	H	---	---	---	---	507.07	---
0.127	Q	---	---	---	---	19682	13829
	H	---	---	---	---	498.83	499.40
0.428	Q	---	---	---	---	18984	12060
	H	---	---	---	---	483.57	483.00
0.725	Q	---	---	---	---	17545	10509
	H	---	---	---	---	475.80	476.70
0.981	Q	---	---	---	---	16953	9605
	H	---	---	---	---	465.52	464.70

H. 1.00 PMF, breach parameters: TF=0.50, BBW=96, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	495.00	96.00	0.50	546.70	495.00	548.70

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	21901	17173
	H	---	---	---	---	507.71	---
0.127	Q	---	---	---	---	21718	16852
	H	---	---	---	---	499.41	500.40
0.428	Q	---	---	---	---	20956	14596
	H	---	---	---	---	484.14	483.90
0.725	Q	---	---	---	---	19501	13128
	H	---	---	---	---	476.31	477.50
0.981	Q	---	---	---	---	18931	11872
	H	---	---	---	---	465.94	465.70

Table 21. Continued

I. 1.00 PMF, breach parameters: TF=0.25, BBW=96, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	495.00	96.00	0.50	546.70	495.00	548.70

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	39638	29031
	H	---	---	---	---	511.82	---
0.127	Q	---	---	---	---	39325	22896
	H	---	---	---	---	503.06	502.30
0.428	Q	---	---	---	---	37180	20700
	H	---	---	---	---	487.23	485.70
0.725	Q	---	---	---	---	30313	18492
	H	---	---	---	---	478.53	479.20
0.981	Q	---	---	---	---	27606	16789
	H	---	---	---	---	467.25	467.00

J. 1.00 PMF, breach parameters: TF=1.00, BBW=96, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	495.00	96.00	0.50	546.70	495.00	548.70

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	12204	10206
	H	---	---	---	---	504.38	---
0.127	Q	---	---	---	---	12153	9906
	H	---	---	---	---	496.29	497.50
0.428	Q	---	---	---	---	11946	9288
	H	---	---	---	---	481.60	482.10
0.725	Q	---	---	---	---	11590	8720
	H	---	---	---	---	473.99	475.50
0.981	Q	---	---	---	---	11430	8263
	H	---	---	---	---	464.33	464.10

Table 21. Continued

K. 1.00 PMF, breach parameters: TF=0.50, BBW=192, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	495.00	192.00	0.50	546.70	495.00	547.20

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	21261	17090
	H	---	---	---	---	507.49	
0.127	Q	---	---	---	---	21121	16529
	H	---	---	---	---	499.22	500.30
0.428	Q	---	---	---	---	20140	13597
	H	---	---	---	---	483.82	483.50
0.725	Q	---	---	---	---	18177	11285
	H	---	---	---	---	475.96	476.90
0.981	Q	---	---	---	---	17477	9936
	H	---	---	---	---	465.57	464.80

L. 1.00 PMF, breach parameters: TF=0.50, BBW=192, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	495.00	192.00	0.50	546.70	495.00	548.70

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	23486	19299
	H	---	---	---	---	508.15	
0.127	Q	---	---	---	---	23298	18552
	H	---	---	---	---	499.85	500.90
0.428	Q	---	---	---	---	22201	15561
	H	---	---	---	---	484.41	484.20
0.725	Q	---	---	---	---	20194	13451
	H	---	---	---	---	476.50	477.60
0.981	Q	---	---	---	---	19692	11912
	H	---	---	---	---	468.14	465.80

Table 21. Continued

M. 1.00 PMF, breach parameters: TF=0.25, BBW=192, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	495.00	192.00	0.50	546.70	495.00	548.70

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	42886	33060
	H	---	---	---	---	512.39	---
0.127	Q	---	---	---	---	42499	32480
	H	---	---	---	---	503.55	504.80
0.428	Q	---	---	---	---	39373	25947
	H	---	---	---	---	487.61	486.90
0.725	Q	---	---	---	---	31669	20979
	H	---	---	---	---	478.76	480.00
0.981	Q	---	---	---	---	28823	18459
	H	---	---	---	---	467.42	467.40

N. 1.00 PMF, breach parameters: TF=1.00, BBW=192, HF-HD=2.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	495.00	192.00	0.50	546.70	495.00	548.70

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	13019	10980
	H	---	---	---	---	504.70	---
0.127	Q	---	---	---	---	12983	10951
	H	---	---	---	---	496.60	498.00
0.428	Q	---	---	---	---	12690	10506
	H	---	---	---	---	481.81	482.50
0.725	Q	---	---	---	---	12161	9584
	H	---	---	---	---	474.19	476.10
0.981	Q	---	---	---	---	11949	8857
	H	---	---	---	---	464.45	464.30

Table 21. Continued

O. 0.50 PMF, breach paramters: TF=0.50, BBW=96, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	0.50	495.00	96.00	0.50	546.70	495.00	547.20

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	20190	15232
	H	---	---	---	---	507.16	---
0.127	Q	---	---	---	---	19979	14239
	H	---	---	---	---	498.91	499.50
0.428	Q	---	---	---	---	19261	12417
	H	---	---	---	---	483.66	483.10
0.725	Q	---	---	---	---	17822	10835
	H	---	---	---	---	475.87	476.80
0.981	Q	---	---	---	---	17225	9873
	H	---	---	---	---	465.57	464.80

P. 0.50 PMF, breach parameters: TF=0.50, BBW=192, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	0.50	495.00	192.00	0.50	546.70	495.00	547.20

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	21526	17279
	H	---	---	---	---	507.57	---
0.127	Q	---	---	---	---	21392	16721
	H	---	---	---	---	499.30	500.30
0.428	Q	---	---	---	---	20404	13788
	H	---	---	---	---	483.89	483.60
0.725	Q	---	---	---	---	18434	11498
	H	---	---	---	---	476.03	477.00
0.981	Q	---	---	---	---	17728	10111
	H	---	---	---	---	465.62	464.90

Table 21. Concluded

Q. 0.25 PMF, breach parameters: TF=0.50, BBW=96, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	0.50	495.00	96.00	0.50	546.70	495.00	547.20

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	19994	15111
	H	---	---	---	---	507.10	---
0.127	Q	---	---	---	---	19781	13953
	H	---	---	---	---	498.86	499.40
0.428	Q	---	---	---	---	19079	12163
	H	---	---	---	---	483.60	483.10
0.725	Q	---	---	---	---	17634	10587
	H	---	---	---	---	475.82	476.70
0.981	Q	---	---	---	---	17038	9668
	H	---	---	---	---	465.53	464.70

R. 0.25 PMF, breach parameters: TF=0.50, BBW=192, HF-HD=0.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	0.50	495.00	192.00	0.50	546.70	495.00	547.20

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	---	---	---	---	21356	17160
	H	---	---	---	---	507.52	---
0.127	Q	---	---	---	---	21224	16605
	H	---	---	---	---	499.25	500.30
0.428	Q	---	---	---	---	20237	13662
	H	---	---	---	---	483.85	483.60
0.725	Q	---	---	---	---	18265	11349
	H	---	---	---	---	475.99	477.00
0.981	Q	---	---	---	---	17559	9982
	H	---	---	---	---	465.58	464.90

Table 22. Peak Outflows: Weslake Dam

Table 21-	Item	Inflow flood*	Breach parameters				Peak outflow, cfs	
			YBMIN	BBW	TF	HF	NWS	HEC
A	No-reservoir conditions	1.00	-	-	-	-	1,242	1,243
B	"	0.50	-	-	-	-	621	622
C	"	0.25	-	-	-	-	310	311
D	No-failure conditions	1.00	-	-	-	-	1,124	1,124
E	"	0.50	-	-	-	-	517	518
F	"	0.25	-	-	-	-	225	225
G	Failure conditions	1.00	495	96	0.50	547.2	19,895	15,053
H	"	"	"	"	0.50	548.7	21,901	17,173
I	"	"	"	"	0.25	"	39,638	29,031
J	"	"	"	"	1.00	"	12,204	10,206
K	"	"	"	192	0.50	547.2	21,261	17,090
L	"	"	"	"	0.50	548.2	23,486	19,299
M	"	"	"	"	0.25	"	42,886	33,060
N	"	"	"	"	1.00	"	13,019	10,980
O	"	0.50	"	96	0.50	547.2	20,190	15,232
P	"	"	"	192	"	"	21,526	17,279
Q	"	0.25	"	96	"	"	19,994	15,111
R	"	"	"	192	"	"	21,356	17,160
	SCS method	0.25	Q_p = 85,972 cfs		547.37			
		0.50	Q_p = 88,208 cfs			548.05		
		1.00	Q_p = 90,500 cfs			548.74		

*Inflow flood hydrograph corresponds to 0.25, 0.50, or 1.00 times the probable maximum flood, PMF, hydrograph

no-reservoir condition because of small storage in the reservoir. The peak outflows due to the failure of the dam are about 19 to 37% higher with the NWS. This is due to the difference in the mode of breach formation as discussed previously. Increases in peak discharge due to higher failure elevation are about 10% and 14% for the NWS and HEC, respectively. For a 50% reduction in failure time, the increase in peak outflow is 70% to 83%. Bigger breach size results in an increase of about 7 to 13%. The peak outflows with the 0.50 PMF and 0.25 PMF are slightly higher than those due to the PMF. This is largely due to the fact that the breach formation starts closer to the peak of the 0.50 PMF and 0.25 PMF inflow hydrographs resulting in higher inflows and water levels in the reservoir at the time of maximum outflow. The peak discharge in general varies from 12 to more than 34 times the PMF peak. The peak discharge determined with the SCS method is about two times greater than the maximum outflow from various combinations of breach parameters in table 22.

The peak flows and maximum water stages in the 1-mile downstream channel are shown in figure 29 for TF = 0.5 hr, BBW = 192 ft, HF-HD = 0.5 ft. The peak outflows are higher with NWS than with HEC and the difference increases downstream. The results for all floods are the same for each respective method. The maximum flood stages are essentially the same for both methods and all floods. The flood stages with the PMF and no-reservoir condition are about 7 to 9 feet lower than for the breach condition under consideration.

The whole range of peak flows and maximum water stages caused by the PMF in the 1-mile downstream channel are shown in figure 30. The peak outflow below the dam varies from 42,886 to 10,206 cfs, and at river mile

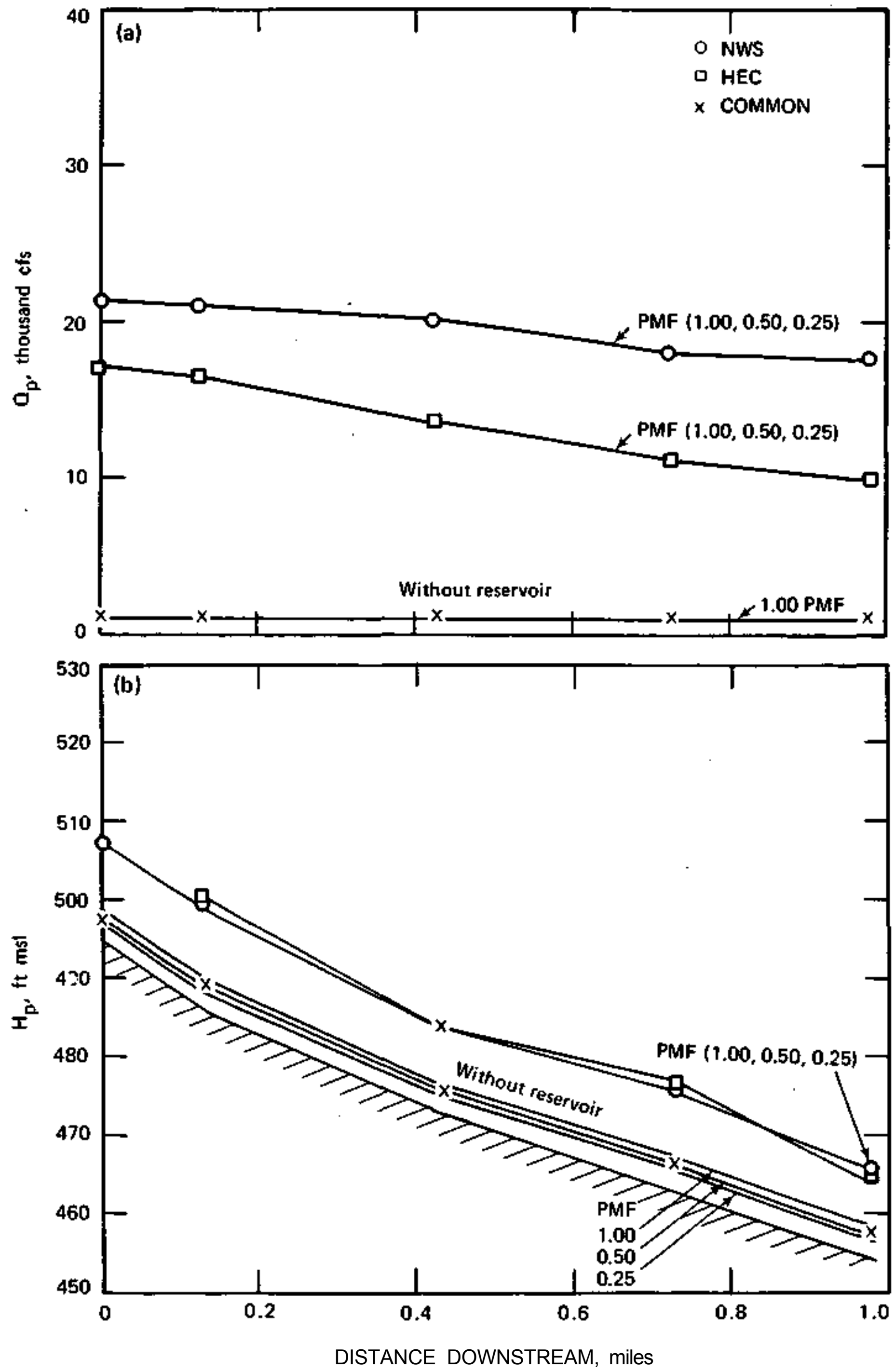


Figure 29. Peak flows and flood stages downstream of Weslake Dam (BBW = 192 ft, TF = 0.50 hour, h_f = 0.5 ft)

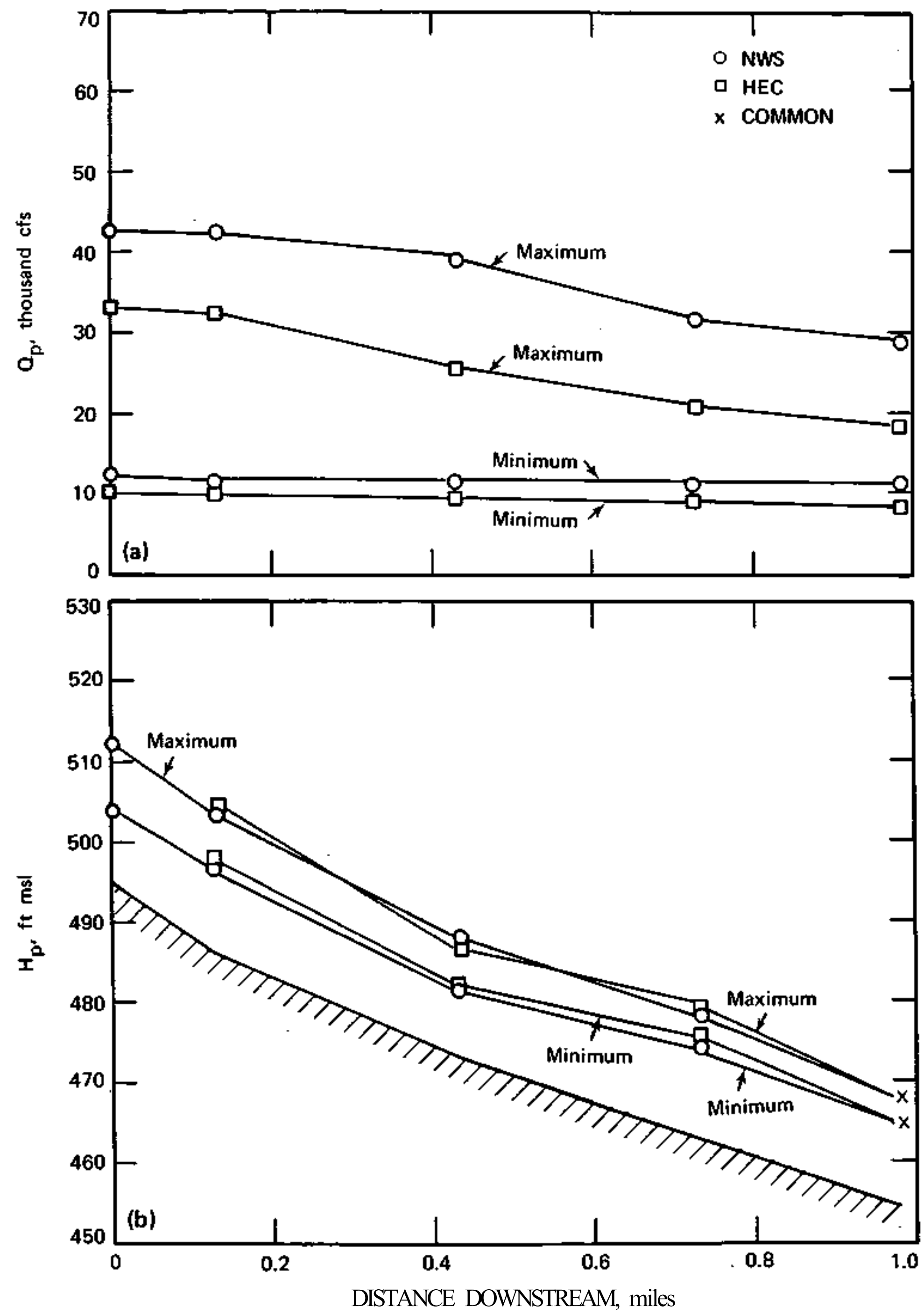


Figure 30. Maximum and minimum flood peaks and stages: Weslake Dam

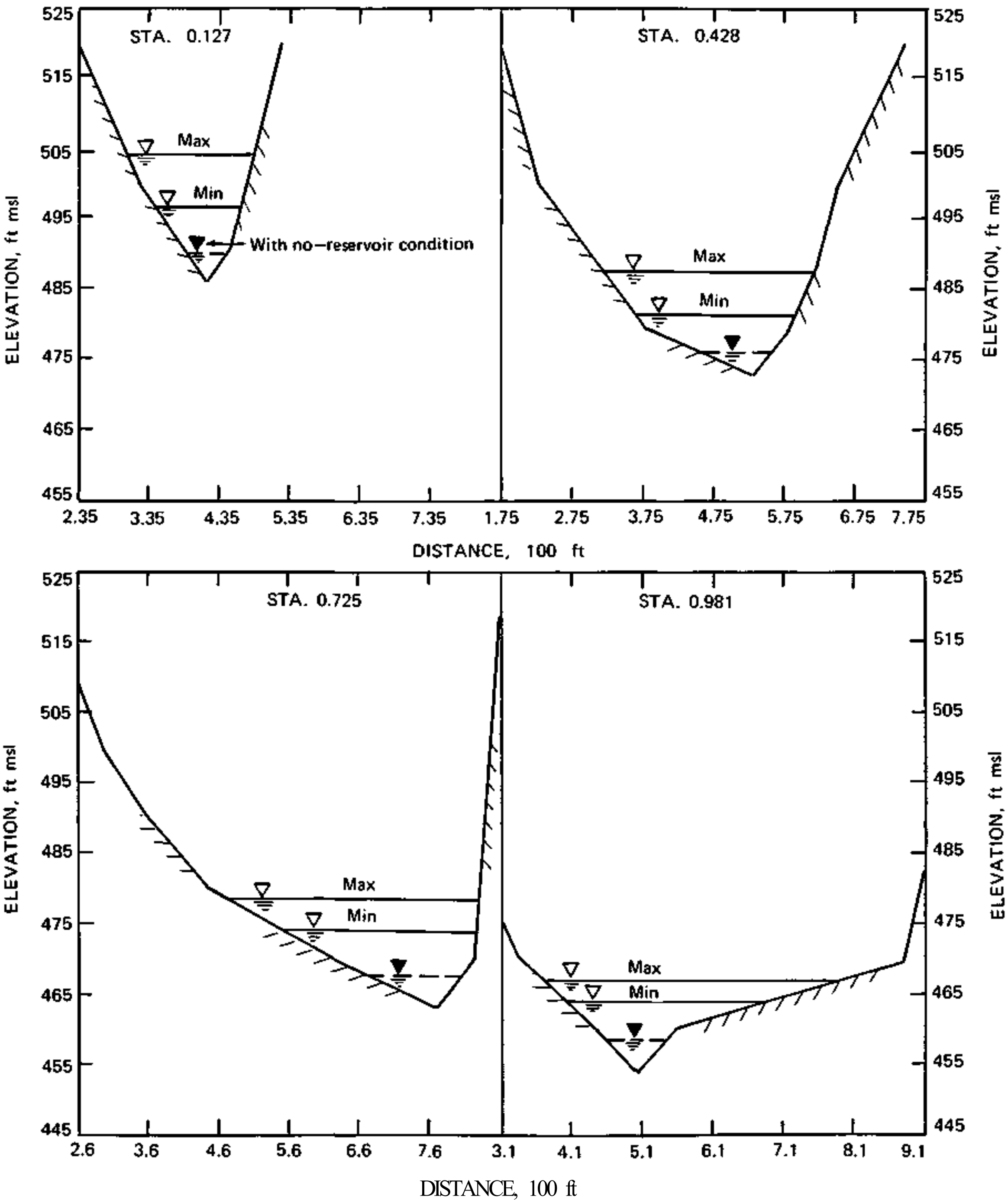


Figure 31. Range of peak flood stages downstream of Weslake Dam

0.981 it varies from 28,823 to 8,263 cfs. Thus, the flow range decreases with distance downstream. The flood stages due to these extremes differ about 8 ft at the dam, decreasing to about 3 ft in the cross section at the end of the reach. The NWS and HEC give similar results with maximum water stage differences of about 1 foot. The maximum and minimum flood stages along with those for the PMF and no-reservoir condition are shown in figure 31 for four selected cross sections along the channel, as calculated by the NWS.

VIII. Kinkaid Lake Dam (Crisenberry Dam)

Kinkaid Lake Dam (figure 32) is located on Kinkaid Creek, about 7 miles west of Murphysboro, Jackson County, Illinois. It is an earthfill structure, approximately 92 ft high and 980 ft long. A rock cut chute spillway is located about 700 ft east of the left abutment. The watershed is fairly steep with uniform slopes. It is lightly to heavily forested. The elevation in the watershed ranges from about 420 to 730 ft.

The dam is classified in the large size and high hazard potential category. Failure of the dam can affect 50-60 homes, 6 of which are immediately below the dam. Pertinent data about the dam, spillway, and reservoir are given below.

Pertinent Data - Kinkaid Lake Dam

Drainage area	62.3 sq mi
<u>Dam</u>	
Elevation, top of dam	435.0 ft msl
Height above streambed	92.0 ft
Length	980.0 ft
Type	Zoned earthfill

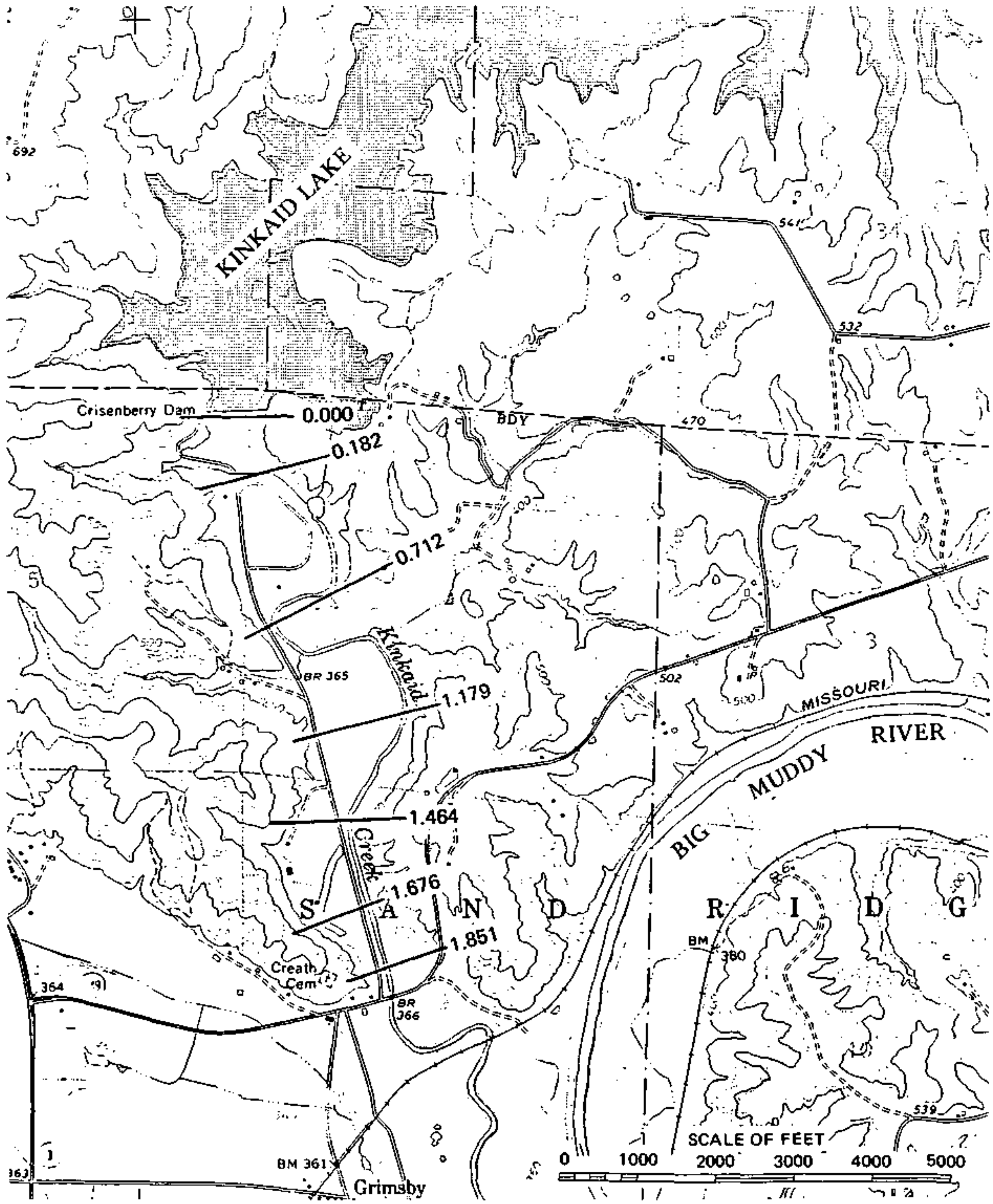


Figure 32. Location of Kinkaid Lake Dam and downstream channel cross sections

<u>Reservoir</u>	
Elevation, normal pool*	420.0 ft msl
Area, normal pool	2,654 ac
Capacity, normal pool	78,500 ac ft
Length, normal pool	10.5 mi
<u>Spillway</u>	
Elevation, weir crest	420.0 ft msl
Length, crest	250.0 ft
Type	Rock cut chute
<u>Freeboard</u>	
Normal pool	15.0 ft

*Based on top of spillway crest

The basic hydrologic and hydraulic data in table 23 consist of the PMF hydrograph, generated by the HEC-1 program, and information on reservoir area and capacity and spillway discharge versus elevation. The information presented above follows the Crisenberry Dam, Kinkaid Lake Inspection Report (COE, 1978d).

The surveyed data were supplied by the DOWR. They consisted of detailed surveyed cross sections of the downstream channel and valley along with a 10-ft contour map. Cross sections were also developed from 7.5' quadrangle maps. The location of the surveyed and the map cross sections are shown in figure 32. The Manning's roughness coefficient, n, was taken to be 0.03 for the channel and 0.05 for the overbank flow.

Analyses and Results

Below the Kinkaid Lake Dam, Kinkaid Creek flows in a southerly direction for about 3.6 miles to its confluence with the Big Muddy River. The floodplain of the Kinkaid Creek is quite narrow until it joins the Big

Table 23. PMF Hydrograph and Elevation-Area-Storage-Discharge Data: Kinkaid Lake Dam

a. PMF Inflow Hydrograph

Time (hr)	0	1.0	2.0	3.0	4.0	5.0
Inflow (cfs)	14,000	20,000	26,500	35,000	42,500	50,000
Time (hr)	6.0	7.0	8.0	9.0	10.0	11.0
Inflow (cfs)	57,000	63,000	69,000	71,000	70,000	66,000
Time (hr)	12.0	13.0	14.0	15.0	16.0	17.0
Inflow (cfs)	61,000	55,500	49,000	42,500	35,000	27,000
Time (hr)	18.0	19.0	20.0	21.0		
Inflow (cfs)	21,000	16,000	11,500	9,000		

b. Elevation-Area-Storage-Discharge Data

Elevation (ft msl)	Area (ac)	Storage (ac ft)	Discharge (cfs)
348.0	0	0	0
420.0	2,654	78,500	0
422.0	2,809	85,000	2,250
424.0	2,980	91,000	6,250
426.0	3,121	98,000	11,500
428.0	3,311	104,000	17,700
430.0	3,444	112,700	24,600
432.0	3,638	120,122	32,524
434.0	3,825	127,942	41,182
436.0	4,051	139,000	67,336

Muddy River floodplain about 2 miles downstream of the dam. A major constriction of the floodplain occurs at about 0.7 mile downstream; otherwise it is relatively uniform in width. The downstream channel has a slope of only about 4.3 ft/mi.

The breach parameters were chosen on the basis of the guidelines established previously. The bottom elevation of the breach, YBMIN, was varied from 360 to 400 ft msl, which is about 15 to 55 ft above the channel bottom elevation at the dam. For YBMIN equal to 360 ft, severe backwater effects occurred, and for the general flood simulation a value of 380 was used. The breach bottom width, BBW, was taken to be 180 ft and 360 ft. The side slope of the breach, z, was taken as 0.0, but the value of z equal to 1.00 was also used for comparative purposes. The time from the inception of the breach to its completion, TF, has been taken as 0.25, 0.50, or 1.00 hour for the flood simulations. A value of 3.00 hours was used for comparison. Since none of the floods (1.00 PMF, 0.50 PMF, and 0.25 PMF) overtoppd the dam, arbitrary failure elevations, HF, of 434 ft (1 ft below the top of the dam; h_f = HF-HD = -1 ft) and 432.5 ft (h_f = -2.5 ft) were chosen to simulate piping failure with the PMF inflow hydrograph.

Results from the simulations of floods are given in tables 24-A to 24-C for no-reservoir condition and in tables 24-D to 24-F with the reservoir and dam intact. Results from 8 combinations of breach parameters with the PMF inflow hydrograph are given in tables 24-G to 24-N.

The peak discharges for both methods and all combinations of breach parameters along with peak discharge as determined by the SCS method are shown in table 25. The peak outflows with the reservoir intact area

Table 24. Summary of Results for Kinkaid Lake

A. 1.00 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	70999	71000	70999	71000	70999	71000
	H	331.80	---	382.19	---	380.96	---
0.182	Q	70942	70960	---	---	7092 9	70953
	H	381.18	375.10	---	---	380.31	375.40
0.712	Q	70850	70901	70859	70868	70836	70896
	H	377.41	381.80	378.81	381.80	374.41	380.80
1.179	Q	70743	70873	---	---	70741	70869
	H	375.75	362.20	---	---	370.63	365.90
1.464	Q	70698	70862	70743	70817	70694	70865
	H	375.19	368.30	375.69	368.30	369.31	363.80
1.676	Q	70685	70864	---	---	70678	70867
	H	374.98	361.80	---	---	368.75	360.80
1.851	Q	70679	70858	70722	70805	70671	70863
	H	374.20	374.30	374.20	374.30	367.53	365.00

B. 0.50 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	35499	35500	35499	35500	35499	35500
	H	375.06	---	375.68	---	373.35	---
0.182	Q	35457	35477	---	---	35454	35477
	H	374.45	370.50	---	---	372.71	369.10
0.712	Q	35372	35438	35347	35417	35407	35445
	H	371.50	373.00	374.08	373.00	367.80	373.30
1.179	Q	35275	35410	---	---	35361	35420
	H	370.24	359.30	---	---	363.81	363.10
1.464	Q	35236	35403	35159	35377	35328	35415
	H	369.37	363.10	372.63	363.10	362.35	358.90
1.676	Q	35224	35402	---	---	35314	35413
	H	369.73	357.80	---	---	361.70	355.80
1.851	Q	35218	35397	35082	35367	35312	35413
	H	369.14	368.60	372.02	368.60	360.65	358.60

Table 24. Continued

C. 0.25 PMF, no-reservoir condition

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	---	---	---

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	17749	17750	17749	17750	17749	17750
	H	369.62	---	368.87	---	367.31	---
0.182	Q	17695	17738	---	---	17727	17738
	H	369.12	366.50	---	---	366.69	364.10
0.712	Q	17581	17714	17599	17702	17699	17718
	H	367.24	365.90	367.87	365.90	362.64	367.20
1.179	Q	17413	17693	---	---	17682	17705
	H	366.54	356.90	---	---	358.26	361.20
1.464	Q	17318	17688	17414	17669	17664	17702
	H	366.34	359.30	366.71	359.30	356.64	354.60
1.676	Q	17264	17687	---	---	17657	17701
	H	366.26	354.90	---	---	355.95	351.50
1.851	Q	17228	17685	17340	17660	17655	17699
	H	365.97	362.90	366.05	362.90	355.09	353.20

D. 1.00 PMF, HF=maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	2	HD	LD	HF
1.00 PMF	---	---	---	---	435.00	344.00	434.68

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	44480	44585	44480	44585	44480	44585
	H	380.75	---	380.72	---	376.74	---
0.182	Q	44391	44585	---	---	44456	44585
	H	380.54	371.90	---	---	376.23	371.00
0.712	Q	44064	44578	44328	44572	44367	44579
	H	379.63	375.70	379.67	375.70	373.07	375.70
1.179	Q	43587	44568	---	---	44193	44575
	H	379.45	360.20	---	---	372.09	363.90
1.464	Q	43309	44567	44060	44560	44058	44574
	H	379.37	364.60	379.15	364.60	371.75	360.40
1.676	Q	43172	44566	---	---	43973	44572
	H	379.35	359.00	---	---	371.64	357.30
1.851	Q	43052	44565	43912	44559	43903	44573
	H	379.26	370.50	378.97	370.50	371.41	360.50

Table 24. Continued

E. 0.50 PMF, HF=maximum water level in reservoir no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.50 PMF	---	---	---	---	435.00	344.00	428.84

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	20603	19685	20603	19685	20592	19685
	H	371.43	---	370.80	---	368.54	---
0.182	Q	20582	19685	---	---	20593	19685
	H	371.01	367.20	---	---	367.92	364.80
0.712	Q	20507	19683	20520	19681	20593	19683
	H	369.31	366.90	369.82	366.90	363.68	368.10
1.179	Q	20387	19680	---	---	20589	19681
	H	368.74	357.30	---	---	359.31	361.40
1.464	Q	20283	19679	20364	19675	20583	19681
	H	368.59	359.90	368.81	359.90	357.72	355.20
1.676	Q	20214	19678	---	---	20578	19681
	H	368.53	355.30	---	---	356.98	352.20
1.851	Q	20162	19678	20256	19673	20574	19680
	H	368.31	363.70	368.32	363.70	356.04	353.90

F. 0.25 PMF, HF-maximum water level in reservoir for no breach

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
0.25 PMF	---	---	---	---	435.00	344.00	425.23

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	9472	8745	9472	8745	9472	8745
	H	364.03	---	363.16	---	362.67	---
0.182	Q	9463	8744	---	---	9463	8745
	H	363.42	362.20	---	---	362.02	360.20
0.712	Q	9440	8743	9434	8742	9462	8743
	H	361.85	360.20	362.35	360.20	358.75	362.20
1.179	Q	9403	8742	---	---	9162	8743
	H	360.91	355.30	---	---	354.59	355.10
1.464	Q	9373	8741	9394	8738	9459	8743
	H	360.47	356.00	361.05	356.00	352.59	351.30
1.676	Q	9359	8741	---	---	9457	8743
	H	360.29	353.00	---	---	351.89	348.30
1.851	Q	9355	8741	9384	8737	9455	8742
	H	359.77	357.10	359.80	357.10	351.19	349.10

Table 24. Continued

G. 1.00 PMF, breach parameters: TF=0.50, BBW=180, HF-HD=-2.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	380.00	180.00	0.00	435.00	344.00	432.50

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	243197	241059	243197	241059	243043	241059
	H	396.40	---	398.35	---	395.69	---
0.182	Q	238235	243130	---	---	236189	243760
	H	395.72	389.10	---	---	395.51	390.50
0.712	Q	227302	229005	227585	226175	232263	232732
	H	390.62	401.30	392.94	401.10	388.67	397.10
1.179	Q	225751	228940	---	---	221548	232500
	H	388.88	369.00	---	---	386.76	374.20
1.464	Q	225564	228686	226704	225473	220301	233011
	H	387.57	383.20	388.36	383.00	385.22	377.50
1.676	Q	225489	228598	---	---	219934	233169
	H	387.16	373.10	---	---	384.51	373.60
1.851	Q	225483	228688	226691	225240	219737	232900
	H	385.58	389.30	385.66	389.10	382.84	381.80

H. 1.00 PMF, breach paramters: TF=0.50, BBW=180, HF-HD=-1.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	380.00	180.00	0.00	435.00	344.00	434.00

STATION		SURVEY SECTIONS		SURVEY SECTIONS		7.5' MAP SECTIONS	
MILE		NWS	HEC	NWS	HEC	NWS	HEC
0.000	Q	258010	254014	258010	254014	257850	254014
	H	397.25	---	399.27	---	396.58	---
0.182	Q	253246	25574	---	---	2250623	256309
	H	396.58	389.90	---	---	396.44	391.30
0.712	Q	241081	239868	241358	236542	246117	244119
	H	391.45	402.20	393.79	401.90	389.58	398.30
1.179	Q	239226	23965	---	---	2234423	244007
	H	389.73	.369.40	---	---	387.77	374.70
1.464	Q	238888	239409	240007	235831	233080	244140
	H	388.37	384.00	389.16	383.80	386.20	378.30
1.676	Q	238769	239426	---	---	232675	243952
	H	387.94	373.70	---	---	385.47	374.30
1.851	Q	238661	239582	239833	235576	232441	243689
	H	386.32	390.20	386.38	389.90	383.78	382.60

Table 24. Continued

I. 1.00 PMF, breach parameters: TF=0.25, BBW=180, HF-HD=-1.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	380.00	180.00	0.00	435.00	344.00	434.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	260323	257848	260323	257848	260159	257848
	H	397.09	---	399.12	---	396.57	---
0.182	Q	252109	254596	---	---	251055	254816
	H	396.41	389.80	---	---	396.43	391.20
0.712	Q	243089	241241	241537	237457	247255	245194
	H	391.25	402.30	393.60	402.00	389.58	398.40
1.179	Q	236686	240979	---	---	234251	245080
	H	389.54	369.40	---	---	387.77	374.70
1.464	Q	235968	240680	237280	236733	233018	245195
	H	388.19	384.10	388.98	383.80	386.20	378.30
1.676	Q	235711	240853	---	---	232628	245422
	H	387.76	373.80	---	---	385.48	374.40
1.851	Q	235590	241030	236887	236677	232428	245726
	H	386.15	390.30	386.22	390.00	383.79	382.80

J. 1.00 PMF, breach parameters: TF=1.00, BBW=180, HF-HD=-1.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	380.00	180.00	0.00	435.00	344.00	434.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	253216	246250	253216	246250	253062	246250
	H	397.12	---	399.12	---	396.53	---
0.182	Q	250342	245401	---	---	249212	245656
	H	396.43	389.20	---	---	396.38	390.60
0.712	Q	240630	234932	240730	231903	242711	238891
	H	391.28	401.80	393.61	401.50	389.47	397.80
1.179	Q	237103	234369	---	---	234086	238094
	H	389.57	369.20	---	---	387.64	374.40
1.464	Q	236475	234557	237528	231178	232386	238241
	H	388.21	383.70	388.99	383.40	386.07	377.90
1.676	Q	236223	234579	---	---	231784	238234
	H	387.79	373.40	---	---	385.34	373.90
1.851	Q	236102	234544	237141	231213	231396	238163
	H	386.17	389.80	386.23	389.50	383.65	382.20

Table 24. Continued

K. 1.00 PMF, breach parameters: TF=0.50, BBW=360, HF-HD=-2.5

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	380.00	360.00	0.00	435.00	344.00	432.50

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	452788	435729	452788	435729	451752	435729
	H	405.71	---	408.20	---	405.86	---
0.182	Q	445044	434490	---	---	440045	435790
	H	405.15	399.80	---	---	406.21	401.20
0.712	Q	417700	413789	414857	403675	426623	421498
	H	400.31	409.10	402.78	408.70	399.47	407.40
1.179	Q	401628	411717	---	---	391750	424184
	H	398.90	374.70	---	---	398.35	381.20
1.464	Q	398990	413406	401911	400913	388581	420752
	H	397.02	395.30	397.93	394.60	396.43	387.90
1.576	Q	397274	413734	---	---	387550	421147
	H	396.49	382.50	---	---	395.55	384.00
1.851	Q	395852	412410	398850	400383	386931	424028
	H	394.45	401.40	394.59	400.70	393.72	394.50

L. 1.00 PMF, breach parameters: TF=0.50, BBW=360, HF-HD=-1.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.50	380.00	360.00	0.00	435.00	344.00	434.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	476219	455446	476219	455446	475347	455446
	H	406.58	---	409.09	---	406.89	---
0.182	Q	467612	453487	---	---	462975	454731
	H	406.05	400.70	---	---	407.30	402.10
0.712	Q	438313	432833	435067	420466	447226	439575
	H	401.31	409.70	403.76	409.30	400.60	408.20
1.179	Q	421167	429020	---	---	411061	443092
	H	399.93	375.20	---	---	399.52	381.80
1.464	Q	418087	431783	421100	417073	407710	441064
	H	398.00	396.40	398.90	395.60	397.56	388.90
1.676	Q	415918	432915	---	---	406576	438089
	H	397.46	383.30	---	---	396.67	384.80
1.851	Q	414392	432885	417523	417484	405944	441009
	H	395.39	402.70	395.53	401.70	394.84	395.50

Table 24. Concluded

M. 1.00 .PMF, breach parameters: TF=0.25, BBW=360, HF-HD=-1.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	0.25	380.00	360.00	0.00	435.00	344.00	434.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	485649	468645	485649	468645	484888	468645
	H	406.49	---	408.99	---	406.94	---
0.182	Q	471249	455601	---	---	451697	455012
	H	405.97	400.80	---	---	407-35	402.20
0.712	Q	447036	435801	441446	424157	453665	444667
	H	401.31	409.80	403.76	409.40	400.66	408.40
1.179	Q	416351	433609	---	---	411431	449934
	H	399.92	375.30	---	---	399.59	382.00
1.464	Q	414064	435952	417301	420716	408399	449166
	H	398.00	396.70	398.91	395.80	397.63	389.30
1.676	Q	413240	436042	---	---	407331	446275
	H	397.46	383.50	---	---	396.73	385.20
1.851	Q	412774	435434	415880	420338	406774	447529
	H	395.38	402.80	395.53	401.90	394.90	395.80

N. 1.00 PMF. breach parameters: TF=1.00, BBW=360, HF-HD=-1.0

FLOOD	TF	YBMIN	BBW	Z	HD	LD	HF
1.00 PMF	1.00	380.00	360.00	0.00	435.00	344.00	434.00

STATION MILE		SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	SURVEY SECTIONS NWS	SURVEY SECTIONS HEC	7.5' MAP SECTIONS NWS	7.5' MAP SECTIONS HEC
0.000	Q	457492	430260	457492	430260	456494	430260
	H	406.26	---	408.74	---	406.58	---
0.182	Q	452003	423836	---	---	447090	424636
	H	405.73	399.30	---	---	406.98	400.70
0.712	Q	432563	413654	431936	407492	432117	420705
	H	401.02	409.10	403.45	408.90	400.15	407.40
1.179	Q	412273	414072	---	---	408758	418980
	H	399.63	374.80	---	---	399.07	381.00
1.464	Q	409425	411471	412275	404713	403738	419427
	H	397.72	395.20	398.60	394.80	397.11	387.90
1.676	Q	408381	412520	---	---	401614	418977
	H	397.18	382.40	---	---	396.22	383.90
1.851	Q	407788	413488	410400	403889	400274	417867
	H	395.11	401.50	395.24	400.90	394.38	394.20

Table 25. Peak Outflows: Kinkaid Lake Dam

Table 24-	Item	Inflow flood*	Breach parameters YBMIN	BBW	TF	HF	Peak outflow, cfs NWS	HEC
A	No-reservoir conditions	1.00	-	-	-	-	70,999	71,000
B	"	0.50	-	-	-	-	35,499	35,500
C	"	0.25	-	-	-	-	17,749	17,750
D	No-failure conditions	1	-	-	-	-	8 0	44,585
E	"	0.50	-	-	-	-	20,603	19,685
F	"	0.25	-	-	-	-	9,472	8,745
G	Failure conditions	1.00	380	180	0.50	432.5	243,197	241,059
H	"	"	"	"	0.50	434.0	258,010	254,014
I	"	"	"	"	0.25	"	260,323	257,848
J	"	"	"	"	1.00	"	253,216	246,250
K	"	"	"	360	0.50	432.5	452,788	435,729
L	"	"	"	"	0.50	434.0	476,219	455,446
M	"	"	"	"	0.25	"	485,649	468,645
N	"	"	"	"	1.00	"	457,492	430,260
	SCS method	0.25	Q_p= 226,840 cfs			425.23		
		0.50	Q_p= 245,606 cfs			428.84		
		1.00	Q_p= 277,410 cfs			434.68		

*Inflow flood hydrograph corresponds to 0.25, 0.50, or 1.00 times the probable maximum flood, PMF, hydrograph

considerably lower than with no-reservoir condition due to storage in the reservoir. The peak outflows with the NWS due to the failure of the dam are about 1 to 6% higher than with the HEC. This is due to differences in the mode of breach formation. The increase in peak discharge due to higher failure elevation is about 5% and about 1 to 6% with a 50% reduction in failure time. Bigger breach size results in an increase of about 75 to 87%. The increase in peak discharges due to increase of the side slope of the breach, z, from 0.0 to 1.00 was about 20%. With the YBMIN set at elevation 360.0 ft, the peak outflows increased about 50% but decreased about 40 to 47% with YBMIN equal to 400.0 ft. The increase in the failure time, TF, from 1.00 to 3.00 hours caused 8 to 16% decrease in the outflow peak.

The peak flows and maximum water stages in the 1.851-mile downstream channel are shown in figure 33 for TF = 0.5 hr, BBW = 360 ft, HF-HD = -2.5 ft. The peak flows with the NWS and HEC agree quite well along the channel. The waterstages however show moderately sloping profiles with the NWS and highly undulating profiles with the HEC, caused primarily by the inability of the HEC program to deal with non-prismatic channels.

The whole range of peak flows and maximum water stages in the 1.851-mile downstream channel are shown in figure 34. The peak outflow below the dam varies from 485,649 to 241,059 cfs and at the end of the 1.851-mile reach, from 435,434 to 225,483 cfs. Thus, the flow range narrows with distance downstream. The flood stages in figure 34 follow the same pattern as in figure 33.

The effect of the three different sets of cross sections (6 surveyed sections, 3 surveyed sections, and 6 sections developed from 7.5' quad-

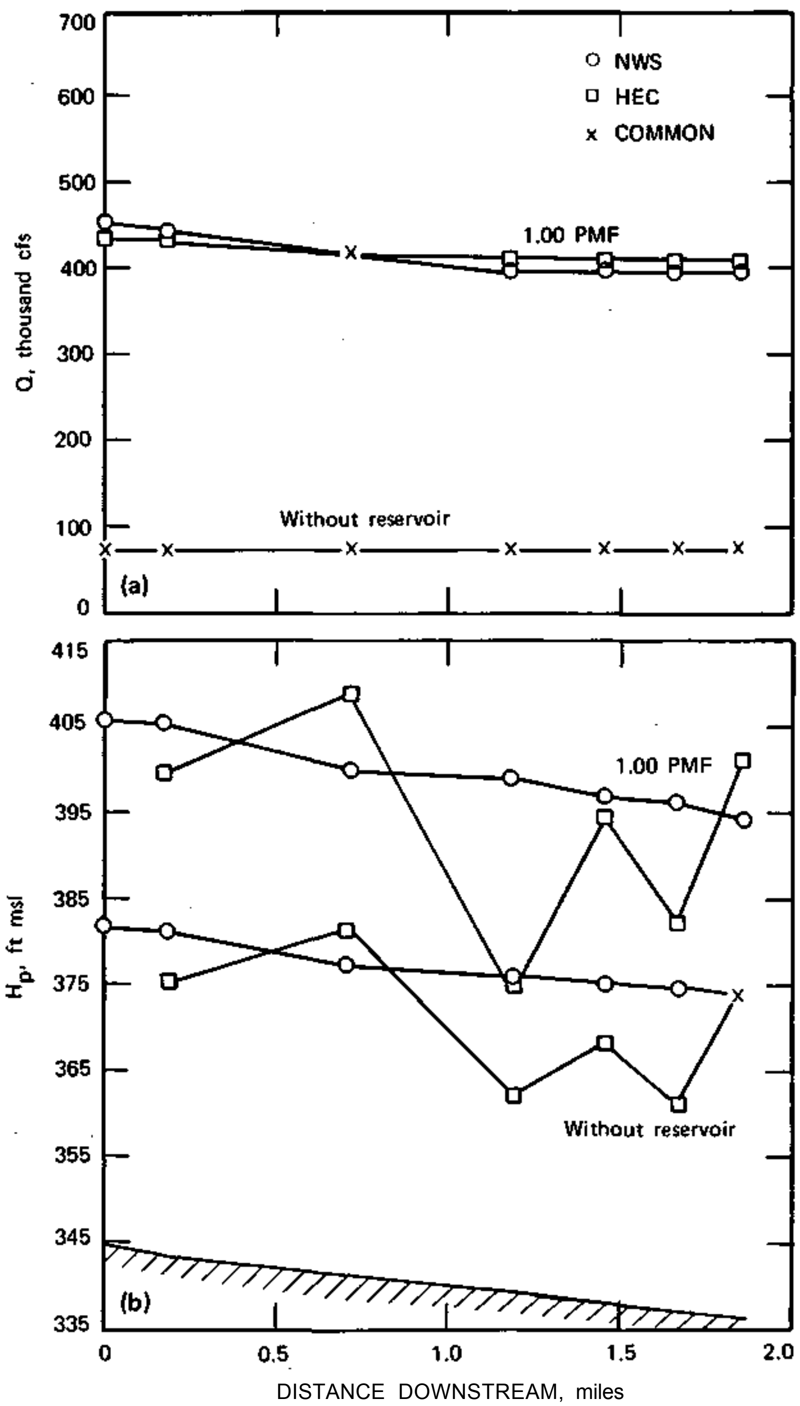


Figure 33. Peak flows and flood stages downstream of Kinkaid Lake Dam (BBW = 360 ft, TF = 0.50 hour, h_f = -2.5 ft)

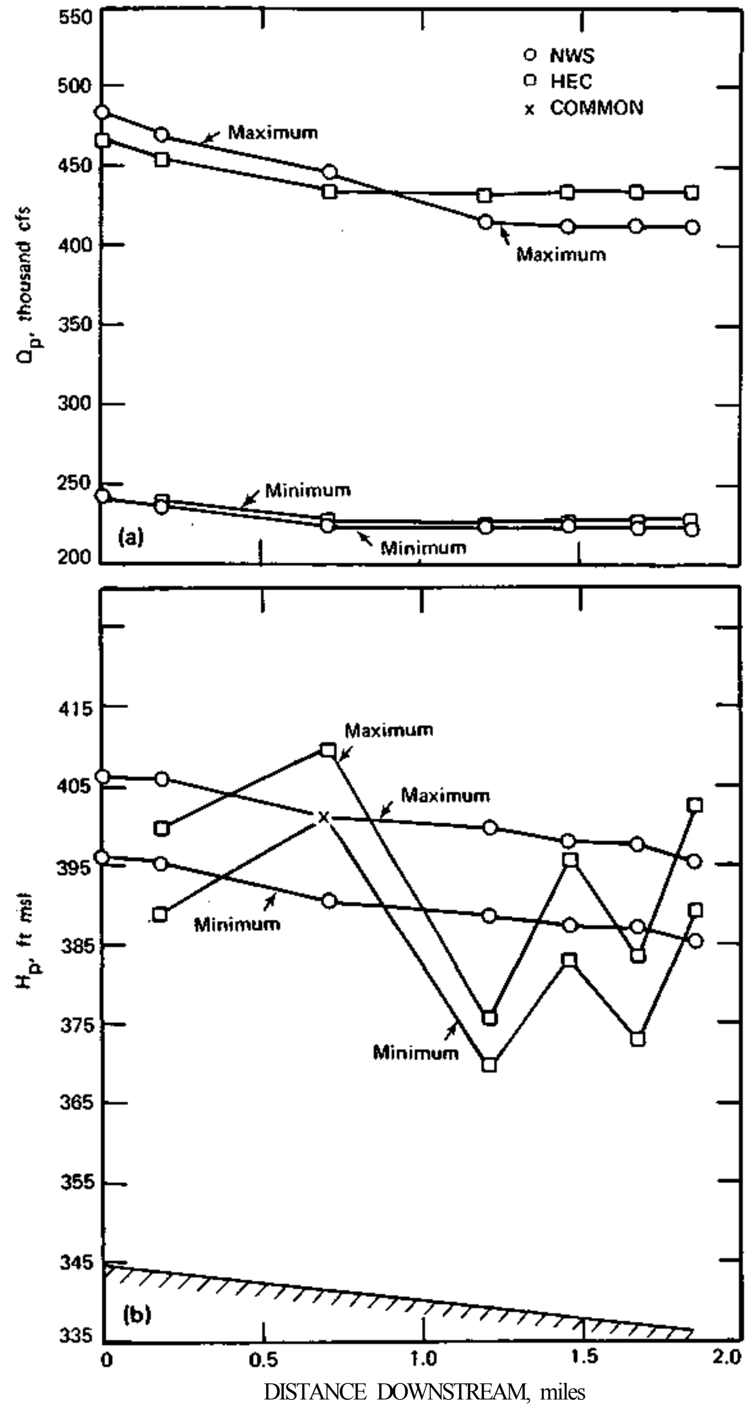


Figure 34. Maximum and minimum flood peaks and stages: Kinkaid Lake Dam

rangle maps) on the peak discharges and maximum flood stages in the downstream channel is shown in figure 35. The variation in the peak discharges increases slightly along the downstream channel. The maximum flood stages with the NWS are similar with all cross sections. The flood stages with the HEC behave as in figure 33 for the 6 surveyed and 7.5' sections, but show less undulation for the 3 surveyed cross sections, because they resulted in a more uniform channel than with the 6 cross sections. The maximum and minimum flood stages along with those for the PMF and no-reservoir condition are shown in figure 36 for four selected surveyed cross sections of the downstream channel, as calculated by the NWS.

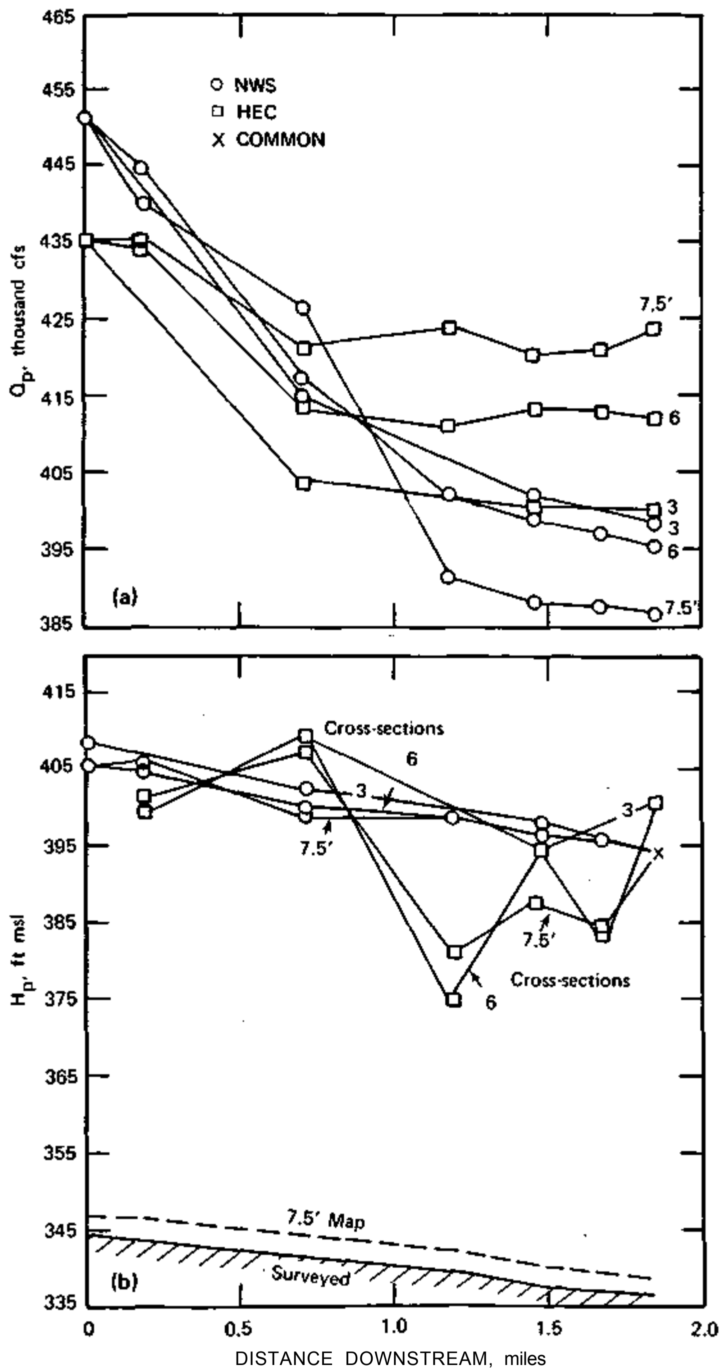


Figure 35. Peak flows and stages downstream of Kinkaid Lake Dam with surveyed and 7.5' cross sections

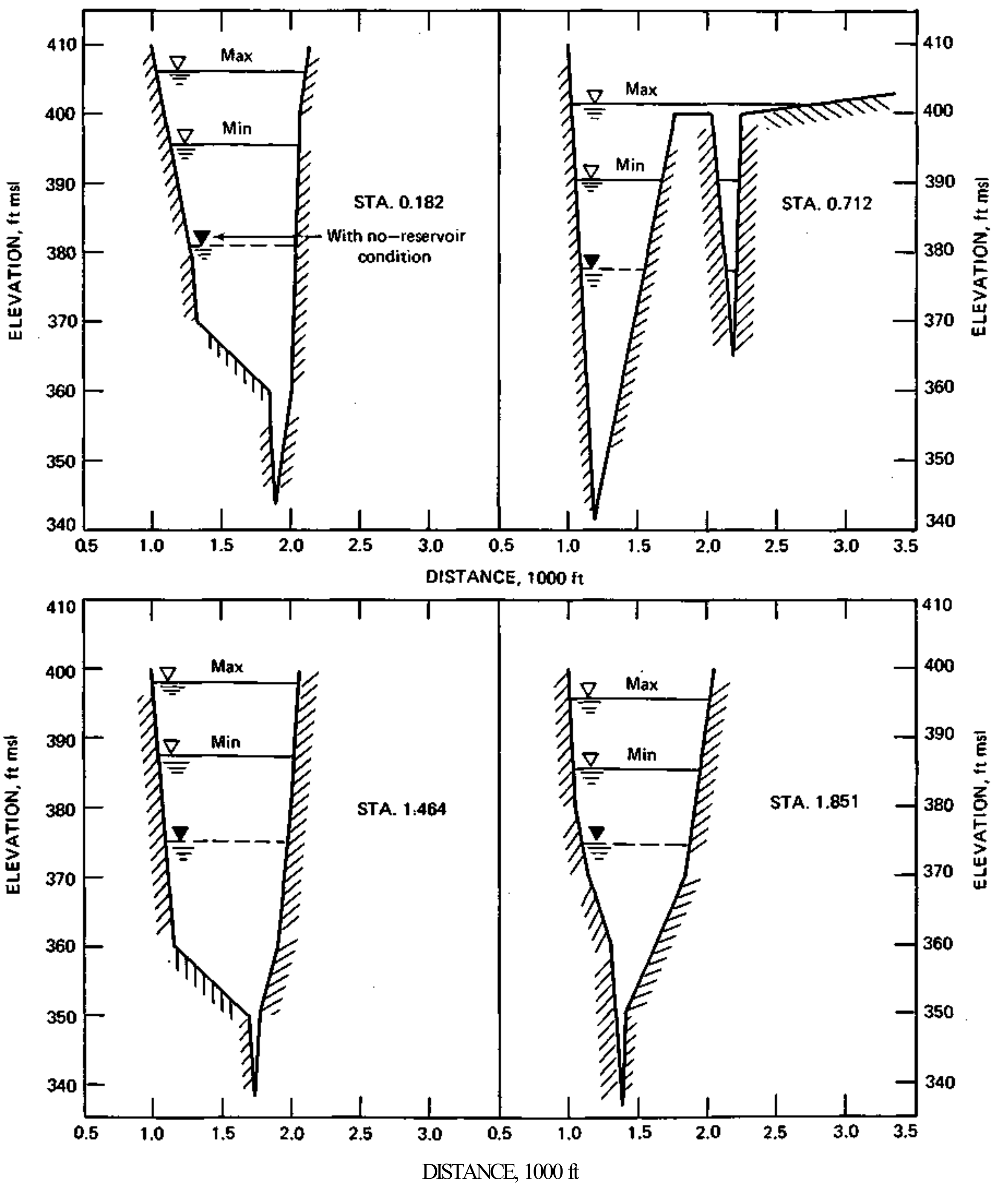


Figure 36. Range of peak flood stages downstream of Kinkaid Lake Dam

SUMMARY AND CONCLUSIONS

Historical Review

The literature survey included a detailed review of historical earthdam failures due to overtopping, as well as identification of significant dam breach parameters and their range. The approximate breach width, B, depends on the dam height, h_d. Most of the cases fell between two lines, defined by $B = 2h_d$ and $B = 5h_d$. The maximum water depth over the dam during failure by overtopping, h_f, generally lies in the range of 0.5 to 2.0 feet. The failure time, TF, from inception of the breach to its completion generally lies in the range of 0.25 to 1.0 hour. The final elevation of the breach bottom, YBMIN, is usually the original ground surface elevation in the channel. No conclusive information was available on the side slopes of the breach section. These parameters and their ranges were used to assess the variation in peak flow after dam breach and in maximum flood stages downstream.

The HEC and NWS Models

The HEC and NWS dam-break models were chosen for evaluation and simulation. The HEC model uses the Modified Puls (MP) method for the routing of a flood wave due to dam break. The MP method is based on the continuity equation transformed into a finite difference equation. The HEC model computes storage-discharge and discharge-elevation relationships for each routing reach using normal depth assumption and stream geometry for the reach. The relationships are then used in the MP method. For reservoir routing, the HEC model uses storage-outflow relation for the dam and the reservoir. The MP method uses only the continuity equation and the normal flow equation, neglecting all dynamic effects which are very important: for dam breach flood waves. The routing method in the NWS model is based on the Saint Venant equations and any assumptions implicit in those equations. These assumptions are, in general, satisfactory except for very rapidly varying flow.

In actual application the HEC model posed no problems with dam breach simulations. The NWS model was more difficult to use because of some problems experienced in simulations. A problem of nonconvergence occurred during calculations of the outflow hydrograph, initial flow conditions, and flood stages. These problems were solved by adjusting YBMIN (for compensating submergence effects), modification of initial flow, and adjustment in the distance and time steps. In one case, flow changed from subcritical to supercritical within a reach as the discharge increased. By increasing Manning's roughness coefficient, n, the flow was forced to be subcritical throughout the simulation. Some problems were experienced with the downstream boundary. This problem was eliminated by extending the last reach of the channel farther downstream.

Dam-Break Simulation

The peak and shape of the outflow hydrograph due to dam breach are governed largely by the geometry of the breach and its development with time. The actual formation of a breach in earthdams is a complex process, depending on various hydraulic, hydrological, and structural factors and parameters. This process can be expected to be highly nonlinear with time. A partial collapse may occur when the downstream face of the dam has suffered considerable erosion. Both the NWS and the HEC models use the same parameters for description of the geometry of the breach. However, the development of the breach with time is different; the NWS model uses linear growth of both the bottom width of the breach and its depth, whereas the HEC model uses constant bottom width of breach and linear growth of depth. This results, for the NWS model, in higher water levels in the reservoir at maximum breach size and therefore higher outflow peaks. The field data requirements are essentially the same for both models.

Changes in breach parameters caused changes in peak outflows, which seemed to follow some trends depending on the parameter involved. For the PMF inflow hydrograph, the increase in peak outflow, due to 50% reduction in failure time, TF, was, for example, clearly related to storage in the reservoir. This increase was from about 13-83% for dams with small storage, but only about 1-5% for dams with large storage. The increase in peak outflow due to larger breach size was 6-50% for small storage reservoirs, whereas it was 35-87% for large storage reservoirs. The increase in failure elevation resulted in outflow peak increases of about 2-21%, with most of the cases falling between 14 and 21%. No relation with dam or other reservoir parameters was apparent.

The peak outflow from the eight dams for a particular simulation case (TF — 0.50, BBW = $4h_d$, h_f = 0.5 ft, 1.00 PMF inflow hydrograph) is plotted against reservoir storage and height in figures 37 and 38, respectively. The peak outflows are better correlated with the storage (correlation coefficient is 0.96) than with the dam height (correlation coefficient is 0.70). This suggests modification of the empirical equation in the SCS method which relates the outflow peak to the dam height. A more complex relation of the peak outflow to the capacity of the reservoir, height and/or size of the dam, and drainage area or other parameters can be developed by simulating breaches of a number of dams.

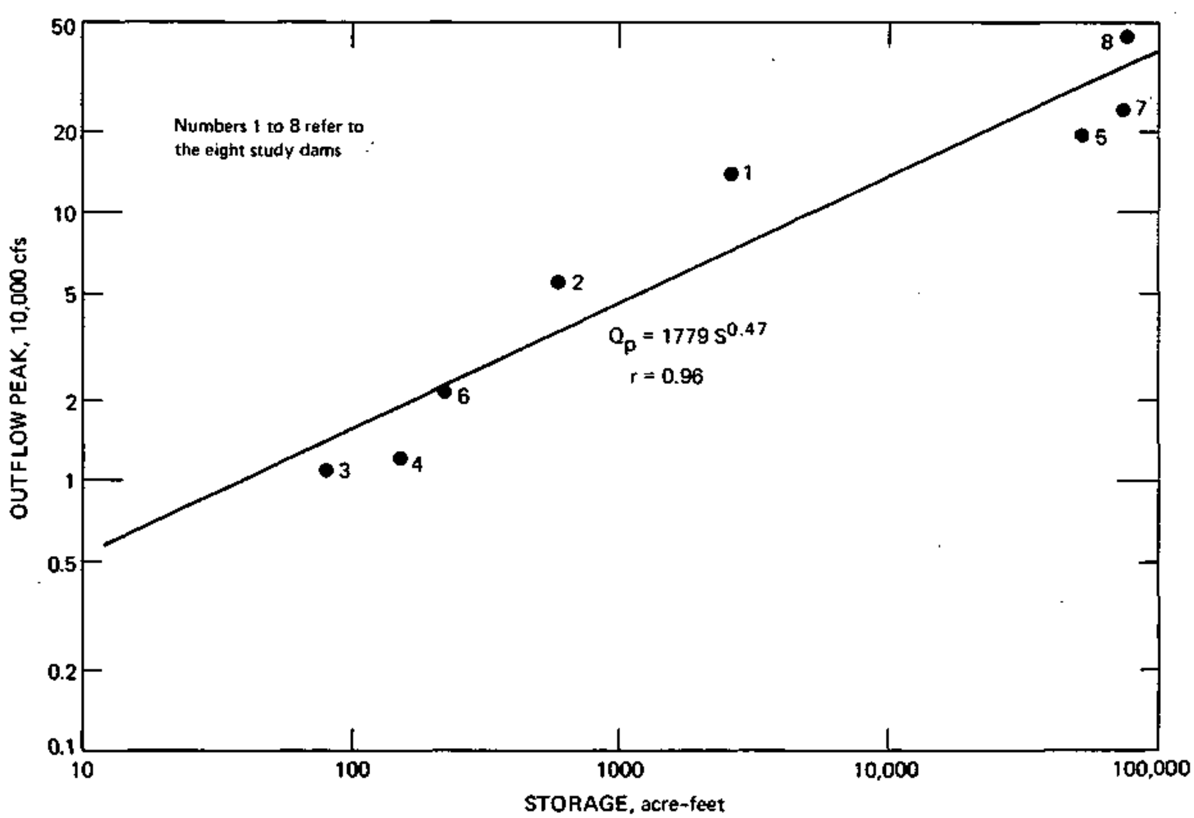


Figure 37. Outflow peak versus reservoir storage at normal pool (PMF, BBW = $4h_d$, TF = 0.50, h_f = 0.5)

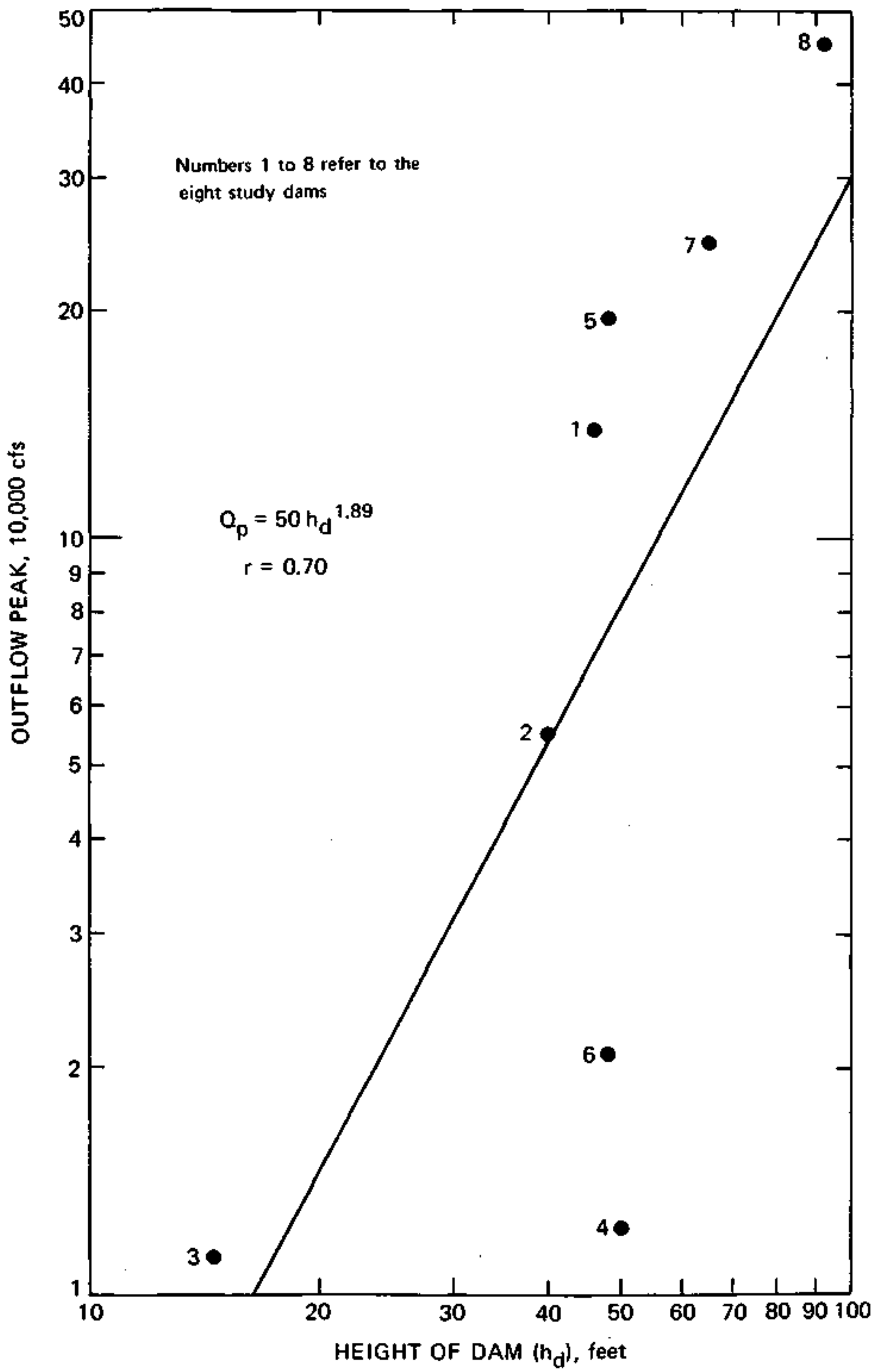


Figure 38. Outflow peak versus height of dam
(PMF, BBW = $4h_d$, TF = 0.50, h_f = 0.5)

In some cases, both the 0.50 PMF and 0.25 PMF inflow flood hydrographs overtopped the dam sufficiently to cause failures. The dam number, drainage area, storage, inflow flood peak, ratio of outflow peak (due to breach with TF = 0.50 hour, BBW = $4h_d$, and h_f = 0.5 ft) to inflow peak, and mode of failure are given below.

	Drainage area (sq mi)	Storage (ac-ft)	Inflow	flood peak (cfs)	Ratio of outflow peak to inflow peak	Failure by
I	13.13	2,600	1.00 PMF;	30,500	4.58	overtopping
II	8.52	598	1.00 PMF;	8,400	6.55	overtopping
			0.50 PMF;	4,200	12.78	overtopping
			0.25 PMF;	2,100	24.70	overtopping
III	11.7	78.9	1.00 PMF;	11,318	1.00	overtopping
			0.50 PMF;	5,659	1.05	overtopping
			0.25 PMF;	2,830	1.96	overtopping
IV	1.13	151	1.00 PMF;	3,164	3.92	overtopping
			0.50 PMF;	1,582	7.30	overtopping
			0.25 PMF;	791	14.36	overtopping
V	291.5	74,200	1.00 PMF;	150,000	1.64	piping
VI	265.0	53,504	1.00 PMF;	121,364	1.62	overtopping
VII	0.225	224	1.00 PMF;	1,243	17.10	overtopping
			0.50 PMF;	622	34.61	overtopping
			0.25 PMF;	311	68.70	overtopping
VIII	62.3	78,500	1.00 PMF;	71,000	6.38	piping

The outflow peaks and flood stages due to failure by 0.50 PMF and 0.25 PMF do not differ significantly from those due to failure by the PMF. These results suggest that small dams, with small spillway capacity, are potentially more dangerous (in populated areas) than large dams, since floods of relatively short return period could fail these dams resulting in flood peaks many times greater than the inflow flood peaks causing the dam failure.

In general, the flood stage profiles predicted by the NWS were smoother and more reasonable than those predicted by the HEC. For channels with relatively steep slope, the methods compared favorably well, whereas for the channels with mild slope, the HEC often predicted oscillating, erratic flood stages, mainly due to its inability to route flood waves satisfactorily in non-prismatic channels.

The flood stages predicted with cross sections taken from 7.5' maps compared favorably with surveyed cross sections. No systematic difference was observed, and, in general, cross sections developed from 7.5' quadrangle maps should be satisfactory for dam breach analysis.

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Notes

American Society of Civil Engineers = ASCE
Corps of Engineers = COE
International Commission on Large Dams =
ICOLD