EXECUTIVE SUMMARY

From late September through early October 1986, a storm system extending across the central plains of the United States caused flooding of unprecedented proportions in northeastern Oklahoma and southeastern Kansas, an area within the Tulsa District, U.S. Army Corps of Engineers.

This report presents hydrologic and hydraulic data, an analysis of the flooding and actions taken by the Tulsa District to control the flood waters. It also describes emergency operations performed and discusses improvements to those operations.

THE ARKANSAS RIVER SYSTEM

The Arkansas River flows 1,450 miles southeasterly from Colorado, through Kansas, Oklahoma, and Arkansas, where it empties into the Mississippi River. The Arkansas River Basin, which includes an area of 160,000 square miles, provides the potential for large flows of water caused by rainfall. The region of interest in this report is northeastern Oklahoma and southeastern Kansas. This reach of the Arkansas River has several large tributary basins, including the Canadian, Cimarron, Grand (Neosho), Illinois, and Verdigris Rivers. Within these tributary basins are 35 multi-purpose lake projects operated by the Tulsa District. Congressionally authorized purposes for these projects include flood control, hydropower, water supply, water quality, navigation, irrigation, recreation, and fish and wildlife management. The primary project purpose under discussion in this report is flood control.

Corps of Engineers lake projects in the Tulsa District are designed to contain a portion of flood flows and release excess flows. Most of the lakes are designed to completely fill their flood control storage on an average of once every 10 to 30 years. Corps lakes in the Arkansas River Basin system have a total flood control storage of about 11 million acre-feet. Approximately 75 percent of this storage is in 11 lake projects which provide most of the flood control on the main stem of the Arkansas River.

THE STORM AND RESULTING FLOOD

The rainfall that caused the September-October 1986 flood was about one-half of the average annual rainfall in some areas. In many locations, the 6-day rainfall (29 September to 4 October) was more than twice that of the previous record. Several areas reported over 20 inches of rain, and many of the rainfall amounts exceeded previous records. As a result, several lakes in the Arkansas River Basin system filled to the tops of their flood control pools, even though the lakes had 100 percent of their flood control storage available immediately prior to the rainfall. Runoff not only exceeded the flood control capacity of the Arkansas River Basin system, it exceeded stream capacities throughout the area. The result was extensive flooding. Thirty-three counties in Oklahoma, two cities outside those counties, and ten counties in Kansas were included in flood disaster area declarations made by the President of the United States.

ROLE OF KEY AGENCIES

The primary responsibility of the U.S. Army Corps of Engineers during a flood event is operation of flood control projects. This involves direction and notification of releases from flood control dams. Other emergency activities include distributing sandbags, assisting with emergency engineering inspections, and offering technical advice to local communities. Other Federal and state agencies have responsibilities for weather and river forecasting, evacuation of citizens, and rehabilitation. Close cooperation and communication between agencies is essential for efficient flood emergency management.

During the flood event of September-October 1986, there was some confusion regarding communication responsibilities of the various agencies. Every agency has operating manuals expressing its functional plans and purposes. However, some of the objectives and responsibilities of the agencies overlap and require clarification. One of the actions underway will set into motion a mechanism whereby a clearer definition of key agency roles will be achieved.

FLOOD CONTROL SYSTEM OPERATIONS

As mentioned earlier, the portion of the Arkansas River Basin under discussion includes several flood control lakes which must be operated as a system. No lake is operated independently as each has an effect on the system as a whole. The system is managed in such a way so as to minimize downstream damages. During this flood, 11 lakes in the system completely filled or exceeded their flood control storage capacity. In fact, Hulah Lake exceeded its surcharge, or safety zone, that portion **above** the top of the flood control pool.

EMERGENCY OPERATIONS

The Tulsa District staff began emergency flood operations on 29 September 1986. Contact was made with local law enforcement agencies, civil defense authorities, the media, and other interests. Corps advisory teams were sent to emergency command posts in several cities, including the city of Tulsa's Emergency Operations Center. Sandbags were dispensed to state and local governments. On-site assistance was provided for the emergency repair of two breaches in the Tulsa-West Tulsa levee system.

FLOOD DAMAGES AND DAMAGES PREVENTED

Flood damages amounting to about $283 million occurred to residential, commercial, agricultural, and public property. The damages include about $63.6 million in Tulsa County, Oklahoma and $39.7 million in Washington County, Oklahoma. Damages prevented by the flood control structures are estimated to be $725 million. Although two lives were lost in areas not controlled by flood control projects, the threat to human life was significantly reduced. Similar flooding in 1943, before the flood control structures were built, cost 26 lives.

EVALUATION OF EMERGENCY OPERATIONS PROCEDURES

Established and tested operating procedures were followed during this flood. Permission was granted by higher authority in two instances to deviate from those procedures in order to reduce the threat to loss of life and property.

Limited public knowledge of the flood control operations and procedures of the U.S. Army Corps of Engineers created misunderstanding and criticism. Concerns emerged regarding coordination between agencies and the dissemination of information. As with any event of this magnitude, questions will be asked, complaints will be filed, and lessons are to be learned.

The Corps routinely makes assessments of work performance and analyzes procedures following large flood events. This record-setting incident was no exception. Analyses of many aspects of emergency procedures have been conducted. Action has been, and will continue to be, taken in those instances where changes will enhance current methods and policies.

CONCLUSION

The flood of September-October 1986 far exceeded the flood control capabilities of the Arkansas River Basin projects. Although flood damages were severe, the Arkansas River Basin flood control system prevented considerable additional flooding and damage. An evaluation of the operation of the flood control projects indicated that no major changes are required. Areas needing strengthening have been identified. These include communications, forecasting, stream gaging, and structural modifications at some projects. Actions have been completed or are under way to make improvements. Some identified items will require further analysis and/or additional funds. The Tulsa District will continue to seek out areas of possible improvement to achieve more effective emergency operations procedures and capabilities.

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CHAPTER 1

INTRODUCTION

This report presents an analysis of events surrounding the record-breaking flood that occurred in northeastern Oklahoma and southeastern Kansas from late September through early October 1986.

Many Federal, state, and municipal agencies, as well as other organizations, were involved in the management of activities relating to this flood. The magnitude of the flooding situation prompted numerous issues to arise. This report addresses those issues, the flood, flood fighting efforts, and internal and external shortcomings which have been identified. By recognizing certain areas of difficulty, the U.S. Army Corps of Engineers, Tulsa District, has set upon a path to make future flood fighting efforts smoother and even more effective.

CHAPTER 2

BASIN INFORMATION

The Arkansas River Basin in northeastern Oklahoma and southeastern Kansas, which contains numerous sub-basins, is the area of interest in this report. Lakes, which the U.S. Army Corps of Engineers operates to provide flood control benefits, are located in each of these sub-basins. The location of these projects is shown in **Figure 2-1**. The names of the projects, their owners, and the streams on which they are located are presented in **Table 2-1**.

Except for the five locks and dams, each lake has flood control storage available. The Tulsa District operates the flood control features of all these reservoirs, including those built by the U.S. Department of Interior, Bureau of Reclamation and the State of Oklahoma's Grand River Dam Authority.

The topography of the Arkansas River Basin in Oklahoma and Kansas is a transition between the Great Plains on the west and the Ozark Mountains and central lowlands on the east. The basin has a total drainage area of about 160,000 square miles, of which 150,000 are located above Van Buren, Arkansas.

The Arkansas River runs a distance of approximately 342 miles from the Oklahoma-Kansas state line to the Oklahoma-Arkansas state line. It is characterized by a broad, sandy bed, with long, easy bends and has an average fall, in this reach, of 1.9 feet per mile. Its banks are well-defined, with a height of between 10 and 30 feet. The width of the channel varies from 600 to 3,000 feet.

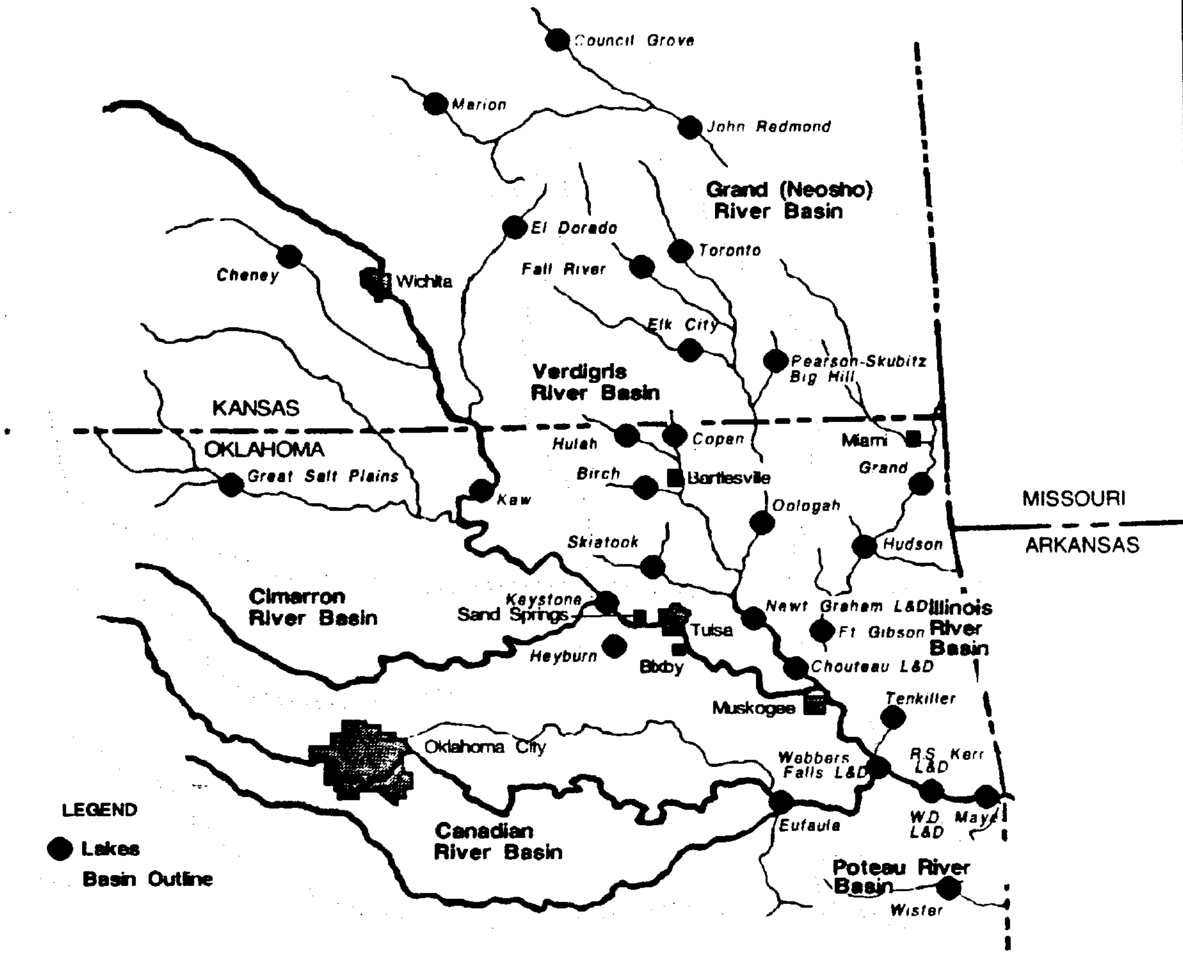


Figure 2-1 **Arkansas River Subbasin Network**

TABLE 2-1

MAJOR LAKES IN THE ARKANSAS RIVER BASIN

Construction Agency/Reservoir	Major Stream
Bureau of Reclamation	
Cheney	North Fork Ninnescah River
Meredith	Canadian River
Thunderbird	Little River
Grand River Dam Authority	
Grand (Pensacola Dam)	Grand (Neosho) River
Hudson	Grand (Neosho) River
US Army Corps of Engineers	
Arcadia	Deep Fork River
Birch	Birch Creek
Canton	North Canadian River
Chouteau Lock and Dam	Verdigris River
Copan	Little Caney River
Council Grove	Grand (Neosho) River
El Dorado	Walnut River
Elk City	Elk River
Eufaula	Canadian River
Fall River	Fall River
Fort Gibson	Grand (Neosho) River
Fort Supply	Wolf Creek
Great Salt Plains	Salt Fork of Arkansas River
Heyburn	Polecat Creek
Hulah	Caney River
John Redmond	Grand (Neosho) River
Kaw	Arkansas River
Keystone	Arkansas River
Marion	Cottonwood River
Newt Graham Lock and Dam	Verdigris River
Oologah	Verdigris River
Optima	North Canadian River
Pearson-Skubitz Big Hill	Big Hill River
Robert S. Kerr Lock and Dam	Arkansas River
Skiatook	Hominy Creek
Tenkiller Ferry	Illinois River
Toronto	Verdigris River
W. D. Mayo Lock and Dam	Arkansas River
Webbers Falls Lock and Dam	Arkansas River
Wister	Poteau River

Much of the Arkansas River channel has been straightened from the mouth of the Verdigris River to the Mississippi River to shorten the overall length and create the McClellan-Kerr Arkansas River Navigation channel. The banks have been stabilized to aid in the maintenance of depth and alignment of the navigation channel.

MAJOR TRIBUTARIES

Canadian River

The Canadian River rises in northeastern New Mexico, flows southerly and then easterly across New Mexico, Texas, and Oklahoma. It enters the Arkansas River at mile 423. The basin is 560 miles long in an east-west direction, about 85 miles in average width, and drains 47,705 square miles. Topography of the basin varies from gently sloping plains in the Texas and Oklahoma panhandle areas to rough, hilly terrain in eastern Oklahoma. Total length of the Canadian River is 906 miles, with an average fall of 8.3 feet per mile. The river banks in Texas and western Oklahoma are, on the average, very low but reach a height of 20 to 30 feet in eastern Oklahoma.

Cimarron River

The Cimarron River rises in the high plateau of northeastern New Mexico. It flows in a northeasterly direction across the Oklahoma panhandle and the extreme southeastern corner of Colorado into southwestern Kansas. Its course then changes to a southeasterly direction and flows into and across north-central Oklahoma to its junction with the Arkansas River in Keystone Lake, about 17 miles above Tulsa, Oklahoma. The fall of the river varies from

50 feet per mile near the headwaters to about 1.5 feet per mile near the mouth. The basin is approximately 500 miles in length, 50 miles in width, and has a total drainage area of 18,900 square miles.

Grand (Neosho) River

The Grand (Neosho) River drains an area of 12,520 miles in southeastern Kansas, northeastern Oklahoma, southwestern Missouri, and northwestern Arkansas. Its basin is approximately 260 miles long, 80 miles wide in the upper reach, and widens to about 90 miles near the Oklahoma-Kansas state line. The river flows a total of 480 miles, has an average fall of 2 feet per mile, and enters the Arkansas River at mile 459.5. Its meandering, well-defined channel varies in width from 50 feet in Kansas to about 400 feet in the lower reaches in Oklahoma. The banks vary in height from 15 to 30 feet. The terrain varies from rough, hilly country in the upper reaches and eastern portions of the basin to a rolling contour over the remainder of the watershed.

Illinois River

The Illinois River drains an area of about 1,660 square miles in northwestern Arkansas and northeastern Oklahoma. The drainage basin is approximately 80 miles long and averages about 20 miles in width. The northeastern part of the basin is rough and mountainous; central portion, tablelands; and the southwestern area is rugged and hilly. The river flows in a general southwesterly direction and joins the Arkansas River at mile 426.7. Total length of the river is approximately 150 miles, with an average fall of about 8 feet per mile.

Poteau River

The Poteau River drains an area of 1,888 square miles in southeastern Oklahoma and western Arkansas. The entire basin is generally mountainous. The river rises in the rugged area of west-central Arkansas. It flows westerly in western Arkansas and southeastern Oklahoma, for a distance of 65 miles, then flows in a general northeasterly direction to join the Arkansas River just west of the Oklahoma-Arkansas state line at mile 362. Total length of the river is 128 miles, with an average fall of 5.2 feet per mile.

Verdigris River

The Verdigris River watershed is about 180 miles long, 75 miles wide, and comprises an area of 8,303 square miles. The river flows in a general southerly direction 350 miles from its source in southeastern Kansas to its confluence with the Arkansas River at mile 460 near Muskogee, Oklahoma. Average fall throughout the length of the river is 2.6 feet per mile. The channel width varies from 150 to 500 feet and the banks are from 10 to 40 feet high.

PRECIPITATION

Storms of long duration, producing large total amounts of rainfall, often cover great areas of the Arkansas River Basin. The average annual rainfall in this area varies from 32 inches at Wichita, Kansas and Oklahoma City, Oklahoma to 44 inches near the Oklahoma-Arkansas state line. Average annual precipitation amounts at National Weather Service stations in the storm area are shown in **Table 2-2**.

TABLE 2-2

AVERAGE ANNUAL PRECIPITATION

National Weather Service Station	Precipitation (inches)
Elgin, Kansas	35.50
Sedan, Kansas	36.91
Chanute Airport, Kansas	39.10
Toronto Dam, Kansas	36.07
Spavinaw, Oklahoma	40.89
Stilwell, Oklahoma	43.79
Tahlequah, Oklahoma	43.18
Newkirk, Oklahoma	33.94
Redrock, Oklahoma	31.90
Perry, Oklahoma	32.82
Guthrie, Oklahoma	31.12
Oologah Dam, Oklahoma	38.03
Wetumka, Oklahoma	40.31
Dewar, Oklahoma	38.47
Poteau, Oklahoma	43.79
Webbers Falls, Oklahoma	41.05
Fort Smith, Arkansas	42.27

RUNOFF

Runoff is rainfall which does not enter the ground, does not evaporate, follows a downhill path to streams and rivers, and is a primary factor in flooding. If streams and rivers cannot contain the amount of runoff, flooding results along those rivers.

Average annual runoff in the Arkansas River Basin in eastern Oklahoma and Kansas varies from about 2 inches near Oklahoma City to nearly 15 inches near the Oklahoma-Arkansas state line. **Figure 2-2** shows the annual recorded streamflow at Lock and Dam 13 near Van Buren, Arkansas from 1923 through 1986. Runoff from the September-October 1986 flood accounted for approximately 45 percent of the total for 1986 and was about 80 percent of the median annual flow.

DESCRIPTION OF A FLOOD CONTROL DAM

A typical allocation of storage in a multiple-purpose lake is shown on **Figure 2-3**. The conservation pool contains storage for various purposes such as hydropower generation and water supply. Water from the conservation pool is withdrawn or released to achieve those purposes for which the storage is provided. Inflows into the lake allow the lake level to generally be maintained at or near the top of the conservation pool.

The flood control pool provides **temporary** storage for floodwaters. River flows entering the lake during a flood are held back from downstream areas and stored in the flood control pool. Lake releases are not normally made if the releases would cause or increase flooding downstream. When downstream

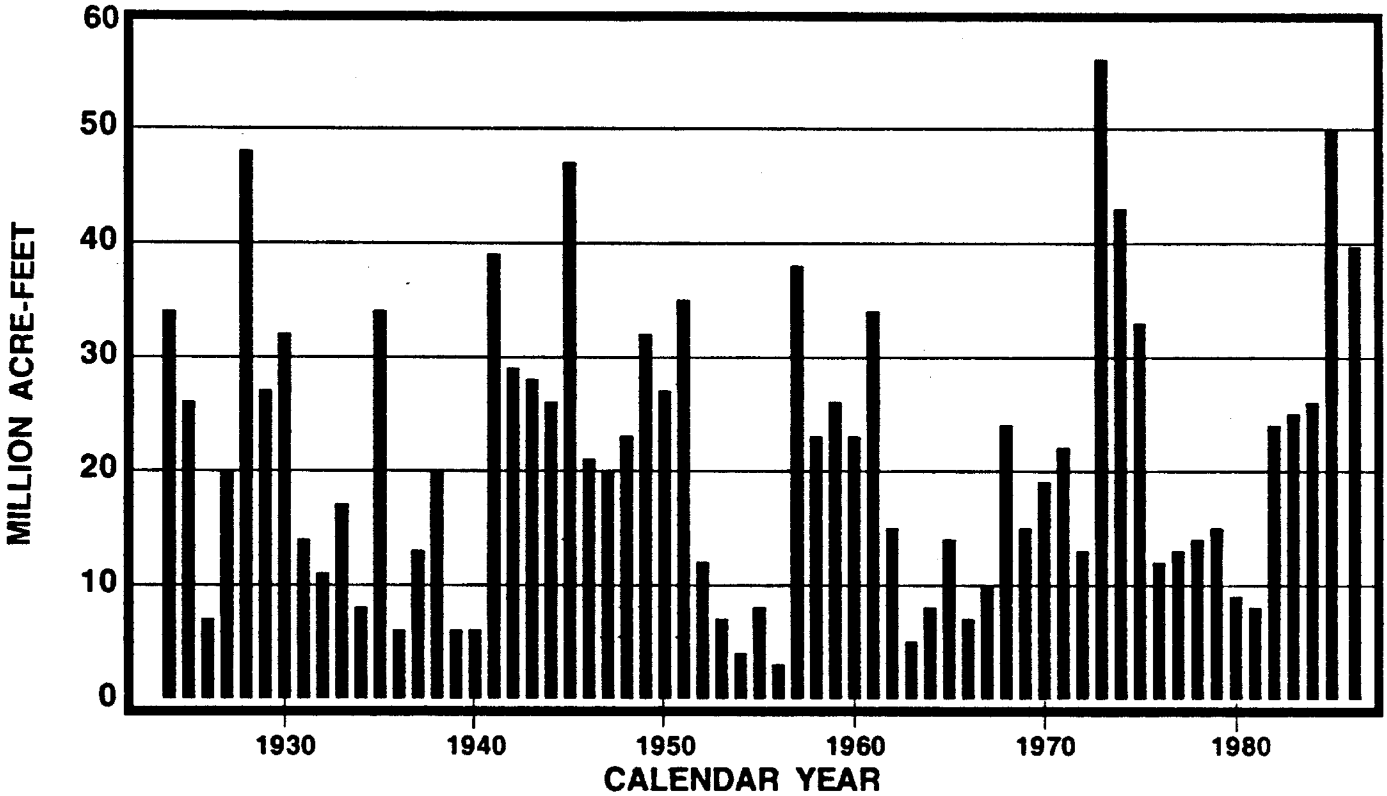
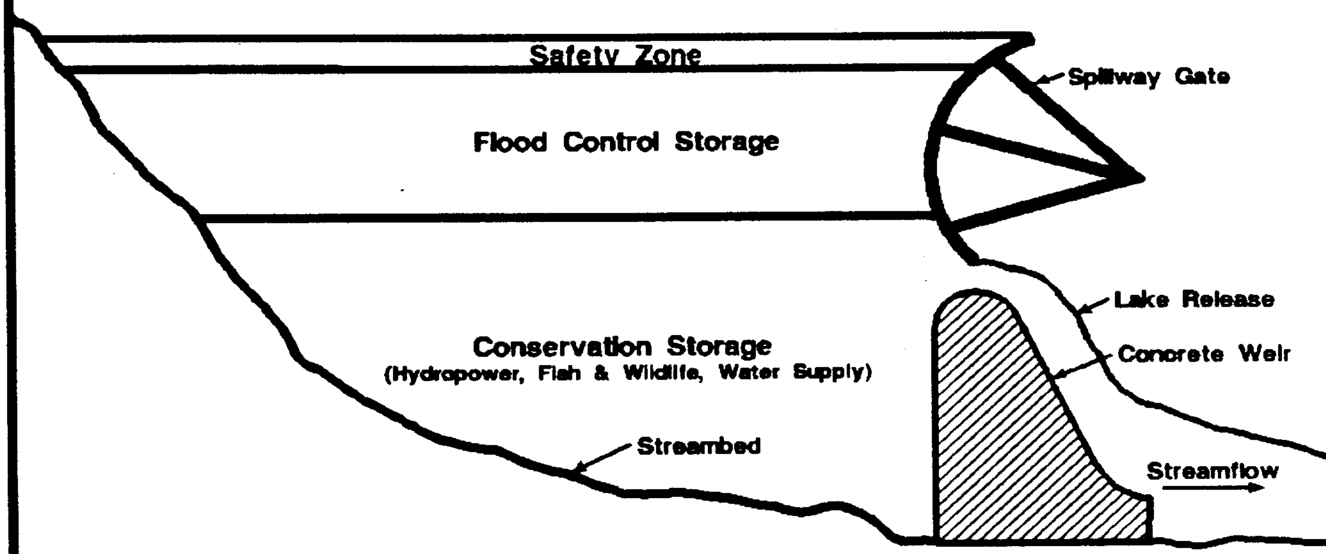


Figure 2-2 ANNUAL RECORDED FLOW
ARKANSAS RIVER AT LOCK AND DAM NO. 13, NEAR FORT SMITH, ARKANSAS



TYPICAL LAKE STORAGES

Figure 2-3

flooding subsides, water is released to drain the flood control pool as quickly as downstream conditions permit. If, however, the inflow forecast indicates that the flood control pool will completely fill before downstream flooding subsides, releases **must** be made to prevent overfilling of the lake. In this case, releases are made in a manner to minimize downstream flooding. The top of the flood control pool in a lake with a gated spillway is usually the same elevation as the top of the spillway gates in a closed position.

Several large projects with gated spillways have additional storage above the top of the flood control pool. This additional storage area is referred to as an "**induced surcharge pool**" or "**safety zone**". Since this storage lies above the top of the spillway gates, the only way it can be utilized is to raise the top of the gates. Hoisting the top of a gate into the safety zone obviously means raising the bottom of the gate as well, resulting in outflows from the lake. If the lake level rises to the top of the safety zone, releases, equal to the lesser of the lake inflow or the spillway capacity, must be made to avoid compromising the stability of the dam.

DESCRIPTION OF THE FLOOD CONTROL SYSTEM

The Tulsa District operates 35 lakes in the Arkansas River Basin. They are operated for multiple purposes: flood control, hydroelectric power, navigation, water supply, water quality, recreation, irrigation, and fish and wildlife management. Authorized purposes for each lake are shown in **Table 2-3**.

TABLE 2-3

PROJECT PURPOSES

Project	FC	HP	Rec	WQ	WS	F&WL	Nav
Arcadia Lake	X		X		X		
Birch Lake	X		X	X	X	X	
Canton Lake	X				X*		
Cheney Lake	X		X		X	X	
Chouteau Lock and Dam							X
Copan Lake	X		X	X	X	X	
Council Grove Lake	X		X	X	X		
El Dorado Lake	X		X	X	X		
Elk City Lake	X			X	X		
Eufaula Lake	X	X			X		X
Fall River Lake	X			X			
Fort Gibson Lake	X	X					
Fort Supply Lake	X				X		
Grand Lake	X	X					
Great Salt Plains Lake	X		X			X	
Heyburn Lake	X		X		X	X	
Hulah Lake	X			X	X		
John Redmond Reservoir	X		X	X	X		
Kaw Lake	X		X	X	X	X	
Keystone Lake	X	X			X	X	X
Lake Hudson	X	X					
Lake Meredith	X		X		X*	X	
Lake Thunderbird	X				X		
Marion Lake	X		X	X	X		
Newt Graham Lock and Dam							X
Oologah Lake	X				X		X
Optima Lake	X		X		X	X	
Pearson-Skubitz Big Hill Lake	X		X		X		
Robert S. Kerr Lock and Dam		X	X				X
Skiatook Lake	X		X	X	X	X	
Tenkiller Ferry Lake	X	X			X		
Toronto Lake	X			X	X		
W.D. Mayo Lock and Dam							X
Webbers Falls Lock and Dam		X					X
Wister Lake	X				X		

FC = Flood Control HP = Hydropower Rec = Recreation
WQ = Water Quality WS = Water Supply F&WL = Fish and Wildlife
Nav = Navigation

* - Includes irrigation

The Arkansas River system has very limited flood control storage and can only partially control larger floods. The projects have a total of approximately 11 million acre-feet of flood control storage. The flood control storage for each reservoir, drainage area, and inches of runoff from the drainage area required to fill the flood storage are shown in **Table 2-4**.

Eleven lake projects (see **Figure 2-4**) have primary control of flows on the main stem of the Arkansas River downstream from Keystone Dam in Oklahoma and account for approximately 75 percent of the total flood control storage available in the basin. The average frequency of filling of the flood control storage in the 11 lakes varies from once in 10 years to once in 30 years. Downstream from these lakes, there is an area of about 7,000 square miles of uncontrolled drainage area in Oklahoma (**Figure 2-4**).

TABLE 2-4

ARKANSAS RIVER BASIN FLOOD CONTROL STORAGE

Project	Contributing Drainage Area (square miles)	Flood Control Storage Acre-Feet	Flood Control Storage Inches of Runoff
Cheney	664	80,700	2.3
El Dorado	234	79,200	6.4
Kaw	6,652	919,400	2.6
Great Salt Plains	3,200	240,000	1.4
Keystone	22,351	1,180,000	1.0
Heyburn	123	48,290	7.4
Toronto	730	179,800	4.6
Fall River	585	234,500	7.5
Elk City	634	239,500	7.1
Big Hill	37	13,100	6.6
Oologah	4,339	965,600	4.2
Hulah	732	258,900	6.6
Copan	505	184,300	6.8
Birch	66	39,000	11.1
Skiatook	354	178,000	9.4
Council Grove	246	63,800	4.9
Marion	200	60,200	5.6
John Redmond	3,015	559,000	3.5
Grand	10,298	525,000	1.0
Hudson	11,533	244,200	0.4
Fort Gibson	12,492	919,200	1.4
Tenkiller	1,610	576,700	6.7
Meredith	16,000	462,200	0.5
Thunderbird	256	76,600	5.6
Optima	2,341	100,500	0.8
Fort Supply	1,494	86,800	1.1
Canton	7,600	265,800	0.7
Arcadia	105	64,430	11.5
Eufaula	8,405	1,468,000	3.3
Wister	993	386,800	7.3

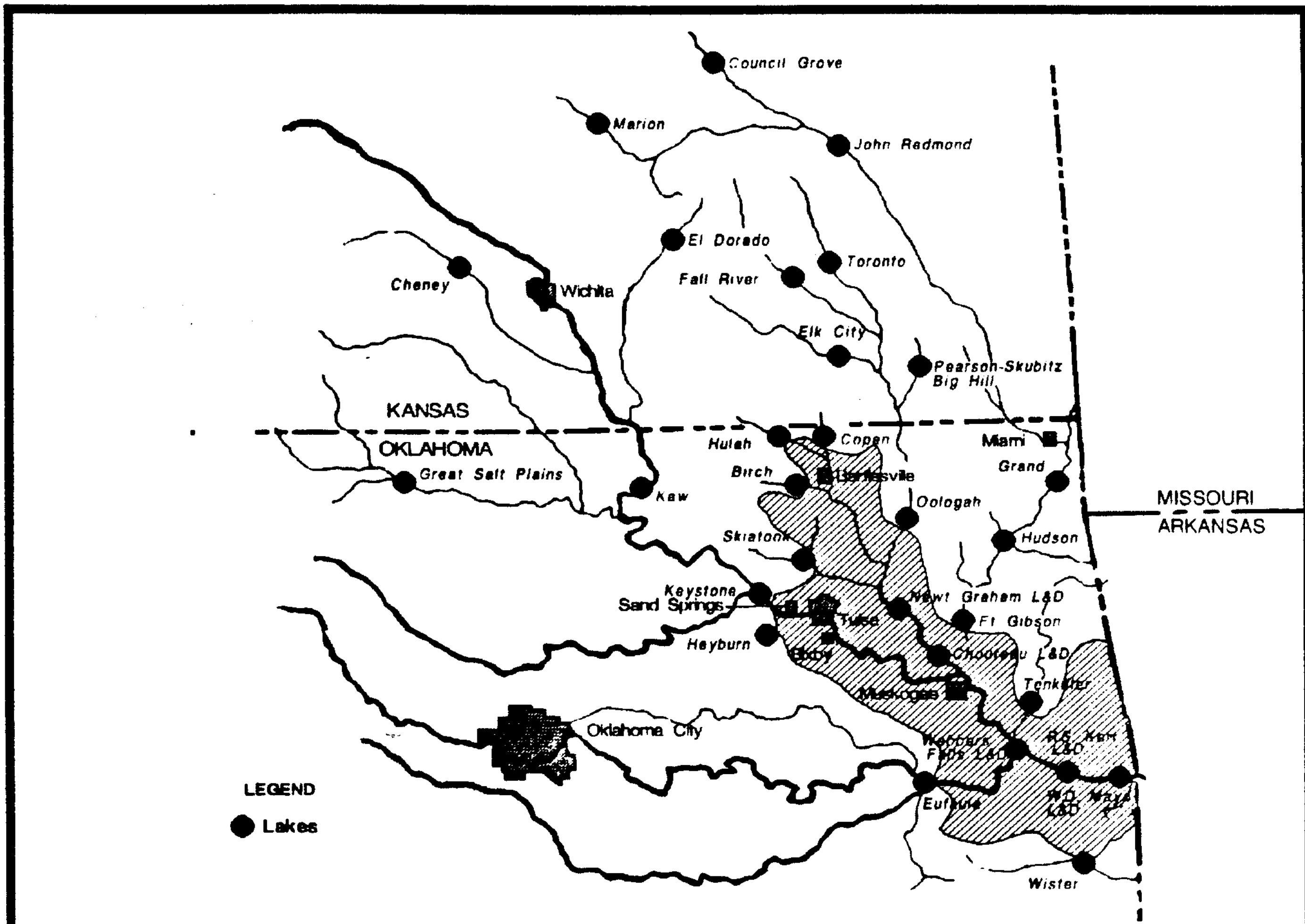


Figure 2-4 **Uncontrolled Drainage Area Arkansas River Basin, Oklahoma**

CHAPTER 3

STORM DESCRIPTION

The rainfall which drenched a large portion of northeastern Oklahoma and southeastern Kansas from 29 September to 4 October 1986 was the result of a storm caused by the combination of **three** meteorological events (see **Figure 3-1**).

1. There was a high-pressure system over the southeastern United States. The clockwise circulation around this high pressure system provided an abundant supply of warm, moist air from the Gulf of Mexico which served as a blocking mechanism to prevent movement of the storm.

2. A strong, upper-level low pressure system was situated over the southwestern United States. The counter-clockwise winds of the low pressure system picked up remnants of Hurricane Paine which had formed earlier off the western coast of Mexico.

3. A jet stream, with winds in excess of 100 miles per hour, blew from southwest to northeast across Oklahoma. This jet stream provided the "steering mechanism" for moisture from the low and high pressure systems to meet in Oklahoma and Kansas.

NATIONAL WEATHER SERVICE SUMMARY OF THE STORM

The National Weather Service office in Tulsa, Oklahoma summarized the meteorological events for the flood of September-October 1986 as follows:

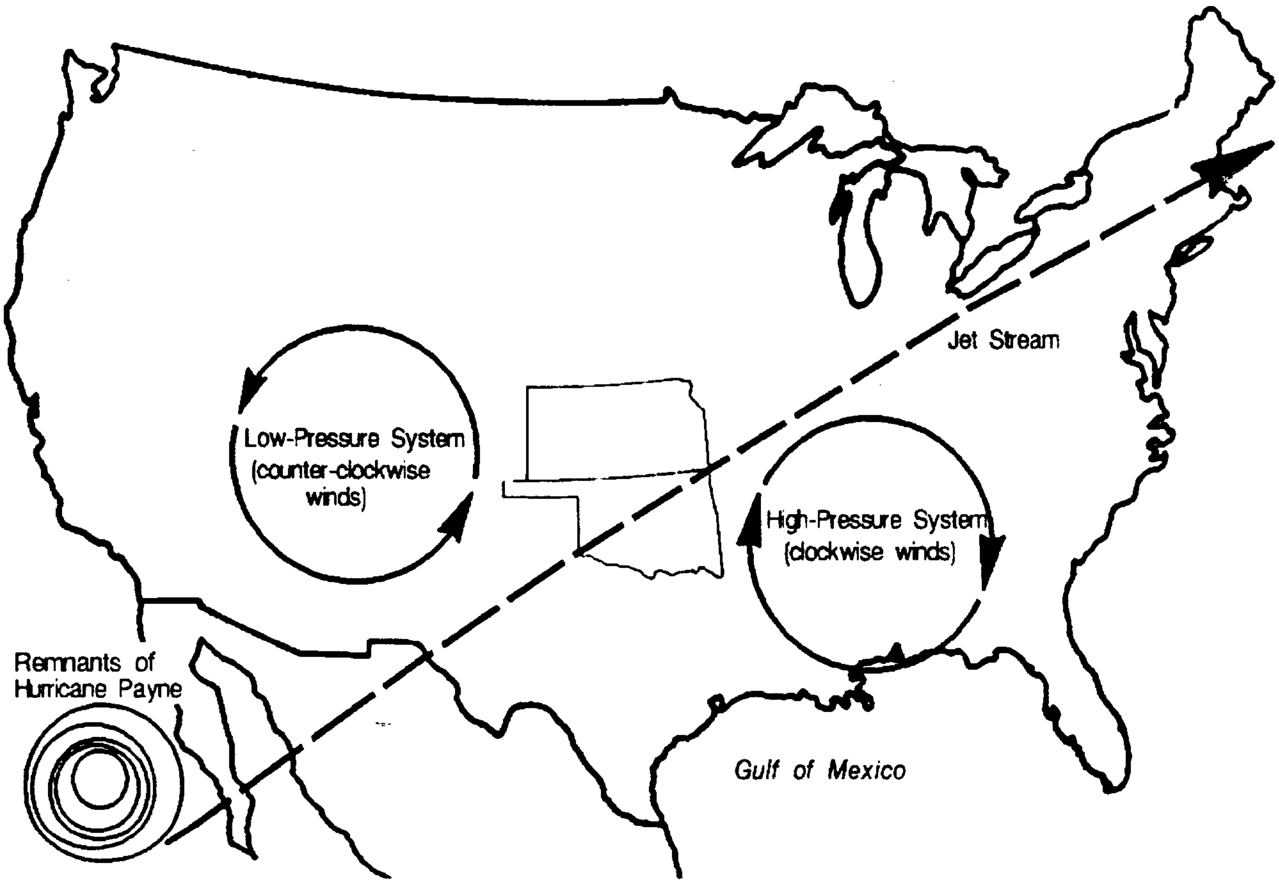


Figure 3-1 **STORM SYSTEM**

HEAVY RAINS - 29 SEPTEMBER THROUGH 4 OCTOBER 1986

...Introduction

A major heavy rain period and resulting floods affected a large part of Oklahoma during a 6-day period from 29 September through 4 October 1986. About 20 to 25 inches of rain fell on some sections of northeast Oklahoma in this time period. The large volume of water was more than half the rainfall expected in northeast Oklahoma during a full year. In part of north-central Oklahoma the rainfall exceeded the average rainfall for the whole year. About half of the rainfall (8 to 10 inches) occurred from 7 p.m. Thursday (2 October) to 7 a.m. Friday (3 October).

...The Floods Begin

A series of short-term heavy rains triggered scattered flash floods early Monday morning (29 September), and in less than 24 hours another round of heavy rains caused additional flash flooding in parts of northeast Oklahoma. Small scale upper storms continued daily until 1 October. Flash flooding was occurring in many counties in central and northeast Oklahoma, and most counties were completely saturated by late Wednesday (1 October).

...The Hurricane

The final blow to the flood of September-October 1986 started off the coast of Mexico in the form of Hurricane Paine. Moving slowly to the north, Hurricane Paine was being picked up by the strong, upper wind system flowing from southwest to northeast on course for Oklahoma. As most people are aware, tropical storms are noted for their ability to carry large amounts of moisture...the fuel that keeps them going. This was the same in the case of Hurricane Paine. The moisture was heading for Oklahoma. During the morning hours of Thursday, 2 October 1986, it looked like a history-making event was about to occur for parts of Oklahoma.

...The Weather Features

1. A large, nearly stationary high pressure system was over the southeast United States. The flow around this blocking system kept a supply of warm, moisture-laden air pumping into Oklahoma from the Gulf of Mexico.

2. A strong slow-moving, upper-level storm system was in the western United States. A zone of high speed winds was between the storm system in the west and the high pressure in the southeast part of the United States. This jet stream was over part of Oklahoma.

3. A frontal system was nearly stationary from the Great Lakes southwest across Kansas into north central Oklahoma.

4. Hurricane Paine was off the Mexican coast.

...The Main Event

The remains of Hurricane Paine moved progressively faster to the north and northeast on 1 and 2 October. Helped by the strong upper winds, the moisture from Hurricane Paine flowed into Oklahoma, combined with the frontal system in Oklahoma, and moved across the saturated counties in north central Oklahoma and south central Kansas.

RAINFALL DATA

Some of the heavier daily rainfall totals for the period are shown on **Table 3-1**. This table also shows 6-day record rainfall for these stations. An isohyetal rainfall map with the total rainfall is shown in **Figure 3-2**.

TABLE 3-1

RAINFALL TOTALS AT SELECTED LOCATIONS

Station Name	24-Hour Rainfall (inches) * 29 Sep	30 Sep	1 Oct	2 Oct	3 Oct	4 Oct	6-Day Total	Previous 6-Day Record Rainfall**
Cedar Vale, KS	4.10	4.75	3.00	4.00	6.82	--	**22.67**	9.38 May 1961
Newkirk, OK	4.81	3.22	3.42	4.00	5.50	.50	**21.45**	9.29 Jan 1961
Fort Scott, KS	2.50	4.08	0.85	2.19	8.60	2.75	**20.97**	9.97 Jul 1958
Sedan, KS	2.72	6.68	1.21	0.03	8.74	0.77	**20.15**	8.42 Oct 1983
Elk City Lake, KS	2.06	5.98	2.66	0.02	8.10	1.15	**19.97**	11.14 Jun 1977
Ponca City, OK	5.76	2.71	0.35	4.06	6.58	0.20	**19.66**	7.73 Sep 1959
Elgin, KS	2.18	7.79	1.46	0.06	6.56	0.83	**18.88**	10.38 Oct 1984
Walnut, KS	1.60	4.82	2.24	0.15	7.56	1.82	**18.19**	9.74 Jun 1977
Redrock, OK	6.00	7.40	0.30	--	4.45	--	**18.15**	11.44 Jul 1959
Moran, KS	4.43	2.33	0.90	2.53	6.25	1.60	**18.04**	8.01 Jun 1977
Galesburg, KS	1.10	5.69	1.84	0.01	7.85	1.42	**17.91**	6.77 Oct 1981
Foraker, OK	3.14	7.34	0.55	0.10	6.30	--	**17.43**	10.25 Nov 1979
Enid, OK	2.50	4.00	0.63	0.01	9.06	1.02	**17.22**	15.73 Oct 1973
Billings, OK	3.15	4.33	T	T	7.88	1.33	**16.69**	9.17 Sep 1973
Wagoner, OK	T	6.48	7.41	2.71	--	--	**16.60**	10.34 Jul 1960

T = Trace

* Data published by the National Oceanic and Atmospheric Administration.
** Data furnished by Oklahoma Climatological Survey.

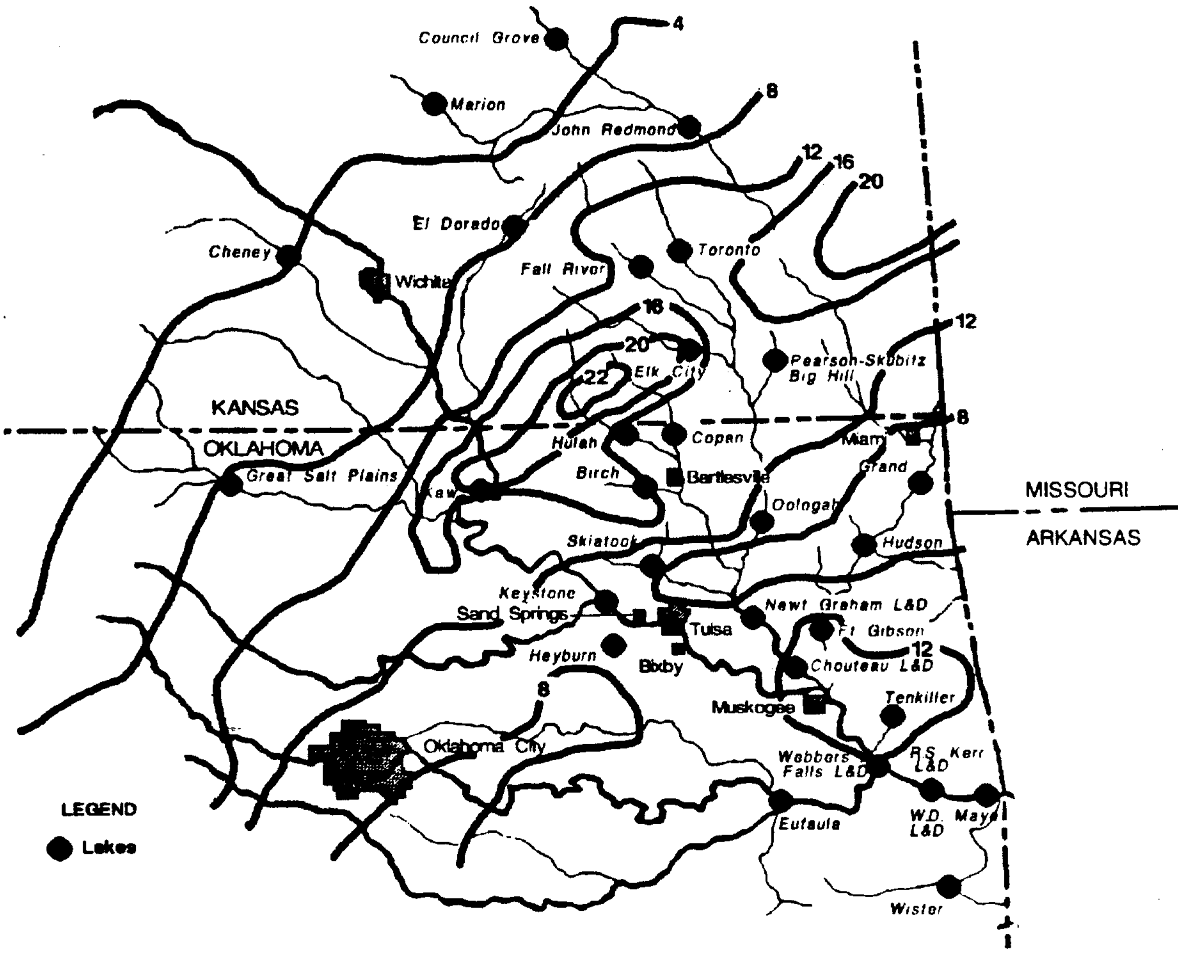


Figure 3-2 **Rainfall Totals in the Report Area**

29 September - 4 October 1986

CHAPTER 4

FLOOD DESCRIPTION

The meteorological events which led to an unleashing of record amounts of water into the Arkansas River Basin have been described in Chapter 3. The resultant flood damages prompted the President of the United States to issue two disaster area declarations: the first, **FEMA-778-DR**, for Oklahoma on 14 October 1986, and the second, **FEMA-780-DR**, for Kansas on 22 October 1986. Thirty-three counties, the cities of Norman and Shawnee in Oklahoma and ten counties in Kansas were included in these declarations (see **Table 4-1** and **Figure 4-1**). Counties outside the area presented in this report are included to provide a measure of the total extent of flooding.

This event established new, record high, flood levels at seven stream gaging sites. Some of the previous records had stood since the 1920's. Flows at several locations exceeded those which would be expected to happen only about once in a hundred years.

Perhaps the most notable characteristic of this flood was its widespread coverage. Virtually every stream in northeastern Oklahoma and southeastern Kansas rose out of its banks at some time during the first week of October. The flood levels experienced at Muskogee, Oklahoma on the Arkansas River and points downstream were the highest since 1957. Record high flooding resulted in the Tulsa and Bartlesville, Oklahoma metropolitan areas.

Without the system of flood control lakes, the flooding along the Arkansas River, from Muskogee downstream, would have been similar to that which occurred in 1943 causing considerable damage and loss of life. Flows

TABLE 4-1

DECLARED DISASTER AREAS

Oklahoma Counties	Oklahoma Cities, County	Kansas Counties
Adair *	Norman, Cleveland *	Allen *
Beckham	Shawnee, Pottawatomie *	Bourbon *
Blaine *		Chautauqua *
Caddo		Cherokee *
Canadian *		Cowley *
Cherokee *		Elk *
Custer *		Labette *
Garfield *		Montgomery *
Grady		Neosho *
Grant *		Wilson *
Greer		
Kay *		
Kingfisher *		
Kiowa		
Logan *		
McClain *		
Major *		
Muskogee *		
Noble *		
Nowata *		
Okfuskee *		
Okmulgee *		
Osage *		
Ottawa *		
Pawnee *		
Payne *		
Rogers *		
Sequoyah *		
Tillman		
Tulsa *		
Wagoner *		
Washington *		
Washita		

* - Areas in the Arkansas River Basin

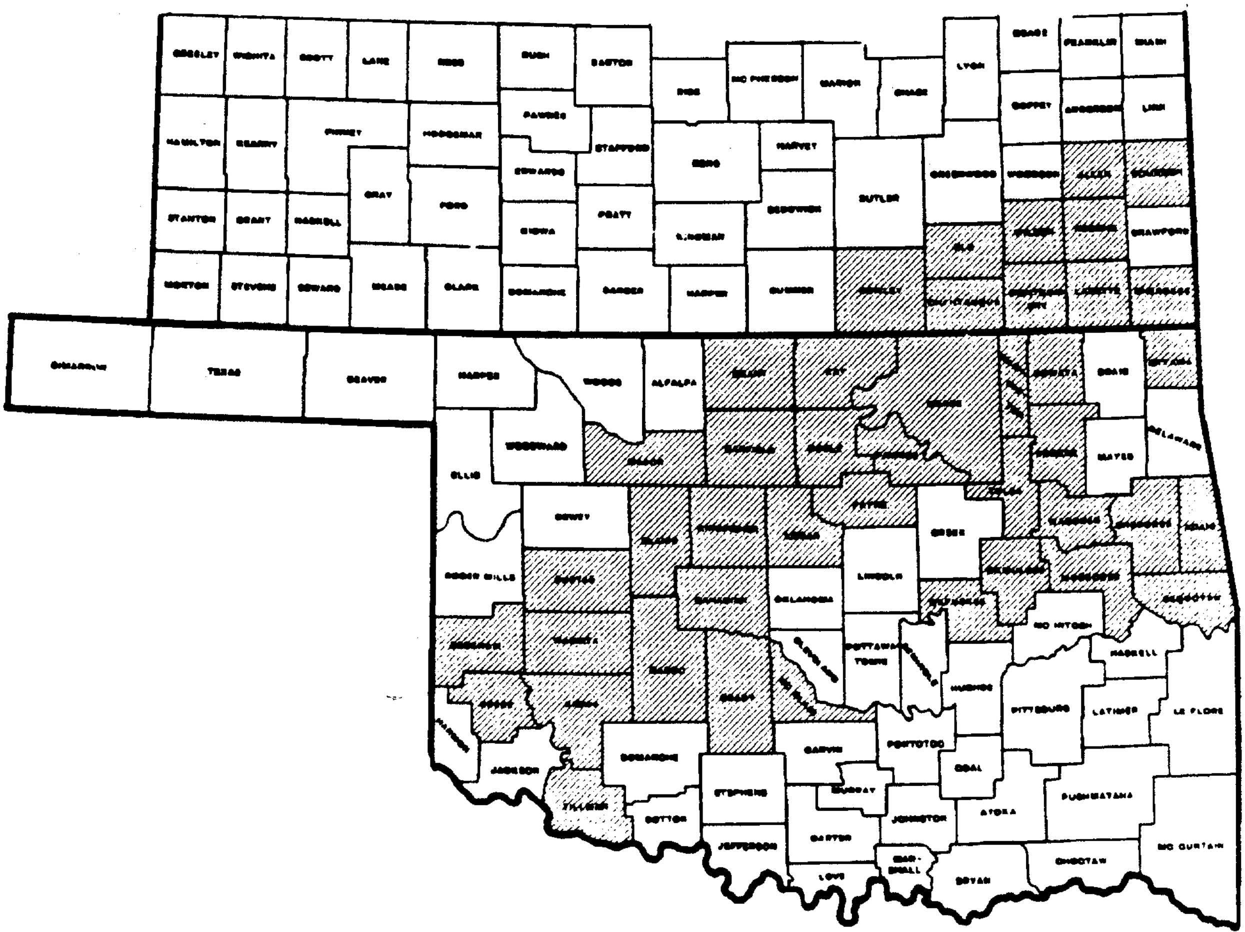


Figure 4-1 **Declared Disaster Areas**

through the Tulsa and Bartlesville areas would have been about twice the previous record high flows. **Table 4-2** shows flood levels reached at selected stream gaging sites during the September-October 1986 flood.

Appendix A contains 20 charts showing stages and flow rates from 21 September through 31 December 1986. Rivers at specific gage locations are covered in the first 6 of these; flood control lakes in the last 14. Flow rates charted for the reservoirs show both inflows and releases.

Appendix B contains aerial photographs taken at or near the peak of the flooding of several of the affected areas and flood profiles.

TABLE 4-2

FLOW AND STAGE DATA AT SELECTED GAGE SITES IN OKLAHOMA AND KANSAS

Gage Name	Stream	Bank-full Stage (feet)	Unreg-ulated Stage (feet)	Exper-ienced Stage (feet)	Stage Red-uction (feet)	Unreg-ulated Flow (cfs)	Exper-ienced Flow (cfs)	Date of Crest During Flood	Flood of Record Stage (feet)	Flood of Record Flow (cfs)	Flood of Record Date
Coyville	Verdigris	28.0	39.3	31.9	7.4	60,000	8,900	10/03/86			
Altoona	Verdigris	23.0	31.8**	28.8	3.0	81,400	48,400	10/04/86	31.09	71,000	07/12/57
Fall River	Fall River	16.0	30.4	8.7	14.4	42,000	2,300	10/03/86			
Fredonia	Fall River	17.0	38.9**	32.3	6.6	70,600	30,800	10/03/86	36.17	49,000	04/16/45
Elk City	Elk River	20.0	34.1	26.3	7.8	100,700	27,500	10/03/86			
Independence	Verdigris River	30.0	53.5**	47.0	6.5	206,900	109,300	10/04/86	47.60	114,000	05/19/43
Oologah	Verdigris River	39.0	68.5	46.6	21.9	175,100	49,800	10/05/86			
Copan	Little Caney	21.0	31.0	28.7	2.3	83,400	50,800	10/03/86			
Hulah	Caney	32.0	40.9	39.6	1.3	90,700	58,000	10/03/86			
Hulah	Caney	32.0	36.6	0.0	4.6	17,000		10/08/86			
Bartlesville	Caney	13.0	33.1**	27.7*	5.4	176,000	107,800	10/04/86	25.30		10/03/26
Ramona	Caney	26.0	32.1**	31.1	1.0	139,500	90,200	10/05/86	31.70		05/19/43
Avant	Bird Creek	11.3		30.5			27,600	09/30/86			
Avant	Bird Creek	11.3	32.5**	23.3	9.2	31,700	16,100	10/03/86	32.03	32,300	03/11/74
Skiatook	Hominy	22.5	37.4	0.0	14.9	16,300		10/03/86			
Sperry	Bird Creek	21.0	31.8	30.9	0.9	67,700	50,000	10/01/86	32.60	90,000	10/03/59
Inola	Verdigris	42.0	55.9**	52.9	3.0	350,700		10/08/86	54.90	224,000	05/21/43
Council Grove	Grand (Neosho)	14.3	15.8	6.7	1.5	3,800	16	10/02/86			
Council Grove	Grand (Neosho)	14.3	16.4	10.0	2.1	4,300	1,000	10/11/86			
Burlington	Grand (Neosho)	23.0	33.6	11.9	10.6	51,700	4,500	10/03/86			
Iola	Grand (Neosho)	15.0	(1)	31.8		71,200	34,900	10/03/86	43.00	436,000	07/13/51
Parsons	Grand (Neosho)	22.0	29.6	27.2	2.4	73,100	40,500	10/04/86	40.20	410,000	07/14/51
Commerce	Grand (Neosho)	15.0	28.1	26.2	1.9	142,400	122,700	10/06/86	34.03	267,000	07/15/51
Canton Out	N. Canadian	10.0	11.9	4.1	1.9	3,800	200	10/03/86			
El Reno	N. Canadian	9.5	16.6	16.0	0.6	16,000	7,500	10/05/86	18.20	12,500	09/21/65
Wetumka	N. Canadian	11.0	16.1	13.7	2.4	23,400	21,900	10/01/86	26.90		11/02/74

TABLE 4-2 (Continued)

Gage Name	Stream	Bank-full Stage (feet)	Unreg-ulated Stage (feet)	Exper-ienced Stage (feet)	Stage Red-uction (feet)	Unreg-ulated Flow (cfs)	Exper-ienced Flow (cfs)	Date of Crest During Flood	Flood of Record Stage (feet)	Flood of Record Flow (cfs)	Flood of Record Date
Wetumka	N. Canadian	11.0	11.7	10.3	0.7	12,400	9,600	10/08/86			
Tecumseh	Little River	11.0		15.2			3,400	09/31/86	25.58		01/09/32
Tecumseh	Little River	10.0	16.2	10.2	6.0	7,800	400	10/02/86			
Winfield	Walnut	30.0	33.6	32.8	0.8	44,400	40,900	10/04/86	41.00	94,400	11/18/28
Cheney	Ninnescah	9.0	13.1	9.3	3.8	9,100	700	10/02/86			
Cheney	Ninnescah	9.0	14.8	6.2	5.8	21,100	60	10/08/86			
Peck	Ninnescah	12.0	15.5	12.6	2.9	13,000	7,780	10/03/86	26.40	70,000	06/09/23
Peck	Ninnescah	12.0	14.5	5.5	2.5	10,900	1,200	10/08/86			
Kaw	Arkansas	944.0	956.0	947.0	8.8	190,400	39,000	10/03/86			
Tonkawa	Salt Fork	17.0	27.1	26.5	0.6	72,200	64,800	10/03/86	28.98	97,300	10/11/73
Ralston	Arkansas	16.0	26.3**	22.8	3.5	388,700	178,800	10/04/86	23.80	200,000	06/11/23
Tulsa	Arkansas	15.0	31.3**	25.3*	6.0	447,800	306,000	10/05/86	22.08	244,000	06/13/23
Heyburn	Polecat	16.0	22.7	16.5	6.2	6,600	1,840	10/01/86			
Sapulpa	Polecat	19.0	28.8	28.1	0.7	20,500	15,600	10/01/86			
Jenks	Polecat	610.0	617.0	615.0	1.1	12,000	8,500	10/01/86			
Muskogee	Arkansas	26.0	52.8**	39.6	13.2	738,400	375,000	10/06/86	48.20	700,000	05/21/43
Gore	Illinois	13.0	26.2	9.5	16.7	130,000	7,200	10/01/86			
Sallisaw	Arkansas	24.0	40.5**	34.2	6.3			10/01/86	37.90	850,000	05/11/43
Van Buren	Arkansas	22.0	37.8	34.7	3.1	755,000	370,000	10/09/86	38.10	650,000	04/16/43
Arkansas City	Arkansas	17.0	(1)	20.3			34,700	10/03/86	25.55	73,100	05/18/57
Augusta	Walnut	19.0	(1)	24.6			17,900	10/04/86	37.23		06/08/79
Blackwell	Chikaskia	26.0	(2)	34.3*			46,000	10/03/86	34.00	100,000	06/10/23
Pawnee	Black Bear	17.0	(2)	27.3			16,000	10/04/86	31.43	30,200	10/03/59
Dover	Cimarron	17.0	(2)	25.6			114,000	10/03/86	26.00		05/16/57
Perkins	Cimarron	11.0	(2)	26.5*			159,000	10/04/86	22.03		05/19/82
Haskell	Arkansas	19.0	(1)	22.8			260,000	10/05/86	26.02		
Cherryvale	Big Hill	15.0	(1)	15.4			1,620	10/03/86	23.02	36,000	07/03/76
Lenapah	Verdigris	30.0	(1)	38.3			81,000	10/05/86	40.44	137,000	05/20/43
Claremore	Verdigris	35.0	(1)	44.1			72,500	10/07/86	55.05	182,000	05/21/43
Catoosa	Verdigris	566.7	(1)	553.0				10/08/86	579.57		05/21/43
Florence	Cottonwood	22.0	(1)	21.1			8,800	10/03/86	32.57		07/11/51

TABLE 4-2 (Continued)

Gage Name	Stream	Bank-full Stage (feet)	Unreg-ulated Stage (feet)	Exper-ienced Stage (feet)	Stage Red-uction (feet)	Unreg-ulated Flow (cfs)	Exper-ienced Flow (cfs)	Date of Crest During Flood	Flood of Record Stage (feet)	Flood of Record Flow (cfs)	Flood of Record Date
Plymouth	Cottonwood	28.0	(1)	33.4			17,900	10/04/86	37.80		07/11/5
Chanute	Grand	23.0	(1)	35.3			52,800	10/04/86	40.90		07/13/5
Quapaw	Spring	22.0	(2)	33.2			101,900	10/02/86	43.40	190,000	05/19/4
Tiff City	Elk	15.0	(2)	20.1			32,000	10/01/86	28.40	137,000	04/19/4
Big Cabin	Big Cabin	34.0	(2)	42.9			32,900	10/01/86	44.58	40,100	11/04/7
Watts	Illinois	13.0	(2)	24.5			49,600	10/01/86	25.96	68,000	07/25/6
Tahlequah	Illinois	11.0	(2)	22.5			66,000	10/01/86	27.94	150,000	05/10/5
Eldon	Illinois	18.0	(2)	25.6*			138,000	10/01/86	23.80		04/05/4
Calvin	Canadian	15.0	(1)	9.8			37,400	10/06/86	21.00		08/07/0
Seiling	Canadian	11.0	(1)	12.9			6,200	10/03/86	16.40		10/15/2
Watonga	Canadian	12.0	(1)	19.2*			14,700	10/03/86	14.17		10/02/5
Harrah	N. Canadian		(1)	18.9*			18,400	10/04/86	18.14	7,630	06/04/7
Beggs	Deep Fork	17.0	(1)	25.1			14,800	10/02/86	34.55	66,800	05/11/4
Whitefield	Canadian	16.0	(1)	9.2			6,200	09/30/86	23.50	281,000	05/10/4
Poteau	Poteau	20.0	(1)	7.0			1,660	10/09/86	39.00	100,000	06/18/3
Panama	Poteau	24.0	(1)	23.5			9,700	10/09/86	44.60		06/18/3

Notes:
(1) Unregulated stage and flow data not available.
(2) No upstream projects.
* Indicates that the experienced stage exceeded the stage of the flood of record.
** Indicates that the unregulated stage would have exceeded the stage of the flood of record.

Definitions:

cfs = cubic feet per second
Stage = height of the water surface above an established reference elevation.
Bankfull = the stage which occurs when a channel is full to its banks.
Unregulated Flow = the flow rate which would occur without upsteam dams.
Unregulated Stage = the stage which would occur without upstream dams.
Experienced Stage = the stage which occurred.

TABLE 4-2 (Continued)

Stage Reduction = the result of unregulated stage minus experienced stage.
Observed Flow During Flood = the peak amount of water observed flowing in a channel during flood.
Date of Crest During Flood = the date of maximum stage, as recorded at a gage, during flood.
Flood of Record = flood of greatest proportions to date (limited to those with written records).

CHAPTER 5

SYSTEM FLOOD CONTROL OPERATIONS

SYSTEM DESIGN OPERATION

The system flood control operation plan is described in detail in the Arkansas River Basin Water Control Master Manual, dated July 1980, with revisions dated July 1986. Water control manuals detailing individual project water control plans have been prepared as appendices to the master manual.

The water control plans were developed based on system and individual project authorizations and design; downstream channel capacities and damage centers; historical and hypothetical hydrologic data; and other considerations. The flood control operation is, in general, based on releases of water from projects which, when combined with local uncontrolled runoff, will not exceed, insofar as possible, certain stages at specific locations on the Arkansas River and tributaries below the reservoirs.

No releases are made from a flood control project that would add to downstream flooding occurring or forecast, unless the flood control storage capacity is exceeded or forecast to be exceeded. In this event, releases may be required, even during downstream flooding, in order to protect the integrity of the dam. Regulating stations used in the operation of projects and corresponding regulating stages and discharges are shown in **Table 5-1**.

Existing operational water control plans, developed for the Arkansas River system projects, were used during the September-October 1986 flood, with two notable deviations discussed later in this report.

TABLE 5-1

SELECTED ARKANSAS RIVER SYSTEM REGULATING STATIONS

Station	River	Applicable Lakes	Regulating Stages (feet)	Regulating Discharge (cfs)
Ralston	Arkansas	Kaw	16	72,000
Tulsa	Arkansas	Keystone	15	110,000
Haskell	Arkansas	Keystone	19	140,000
Hulah	Caney	Hulah	32	8,000
Bartlesville	Caney	Hulah and Copan	13	10,500
Ramona	Caney	Hulah and Copan	26	9,000
Altoona	Verdigris	Toronto	23	10,300
Fredonia	Fall	Fall River	15.5	6,500
Independence	Verdigris	Toronto, Fall River, and Elk City	30	21,000
Lenepah	Verdigris	Toronto, Fall River, and Elk City	30	32,400
Oologah	Verdigris	Oologah	39	30,000
Claremore	Verdigris	Hulah, Copan, and Oologah	35	30,000
Inola	Verdigris	Hulah, Copan, and Oologah	42	65,000
Ft.Gibson	Grand (Neosho)	Fort Gibson	23	100,000
Muskogee	Arkansas	Keystone, Hulah, Copan, Oologah, and Fort Gibson	28	150,000
Gore	Illinois	Tenkiller	12	10,800
Whitefield	Canadian	Eufaula	16	40,000
Sallisaw	Arkansas	Keystone, Hulah, Copan, Oologah, Fort Gibson, Tenkiller,and Eufaula	24	150,000
Poteau	Poteau	Wister	20	6,600
Panama	Poteau	Wister	24	9,000
Van Buren	Arkansas	Keystone, Hulah, Copan, Oologah, Fort Gibson, Tenkiller, Eufaula, and Wister	*	**

* Stages vary from 22.0 to 25.5 feet
** Discharge varies from 105,000 to 150,000 cfs

A revision to the system water control plan, often referred to as the "Fine Tuning Plan", went into effect in July 1986. This revision deals with the manner in which the lower portion of the system flood control storage will be emptied. Since there was no flood control storage being used immediately prior to this flood, the provisions of the Fine Tuning Plan had no impact. The system flood storage from this event had been reduced to about 18 percent by 10 November 1986. It was then the Fine Tuning Plan for evacuating the remainder of the storage was followed.

Implementation of the water control plans requires the collection and analyses of a vast amount of data to form the basis for operational decisions. Data collected for operation of the river system must provide answers to such questions as: How much water is entering the system? How much water can the reservoirs hold? How long can the incoming water be held before releases must be made? If releases are made, what will be the impact downstream?

Weather forecasts, streamflow data, and amount of rainfall are used to develop discharge rating curves and inflow forecasts. These are described in the following.

Weather Forecasts

The National Weather Service is the main source of weather forecasts. The Reservoir Control Section of the Tulsa District has direct computer access to all weather forecasts issued by the National Weather Service. It also has computer access to radar data from the National Weather Service office in Norman, Oklahoma. Data from the weather satellite are also obtained regularly in the Reservoir Control Section. Additional briefings on weather conditions and forecasts are received directly from National Weather Service personnel during major flood events.

Streamflow Data

The U.S. Geological Survey (USGS), in cooperation with the Tulsa District, operates and maintains a series of gages within the Arkansas River Basin. Data for gages above Van Buren, Arkansas are presented in Table 5-2.

Data collection platforms (DCP) have been installed at 159 of the stream gaging stations. These DCP's have sensors which measure rainfall, river stage (depth), and lake elevation. Some DCP's have additional sensors which measure wind speed and direction; water pH, conductance, and temperature; and barometric pressure. Rainfall, river stage, and lake elevation are the primary parameters used for flood flow forecasting.

Data collection platforms used by the Tulsa District have been programmed to read sensors at hourly intervals and transmit this data, via satellite, to a computer facility owned and operated by the National Oceanic and Atmospheric Administration (NOAA) near Washington, D.C. A report is generated from these data every four hours, regardless of current hydrologic conditions. A 4-hour wait for information could affect critical operations; therefore, a DCP is also programmed to transmit data whenever one of its parameters exceeds a threshold value. For example: If a gage measures more than 1/2 inch of rain in an hour, or a river stage value exceeds a predetermined amount, a transmission may be made.

These data are transferred via telephone hookups from the NOAA computer to the Tulsa District water control computer. Once the data are received locally, river stage data is converted to river flow data (by using stage versus discharge relationships, known as rating curves) and lake elevation data are converted to storage volumes.

TABLE 5-2

PERMANENT STREAM GAGES

USGS ID	USGS District		Gage Name	River Basin	Gage Type
7140000	KSGS		Kinsley	Arkansas	Full
7141300	KSGS	S	Great Bend	Arkansas	Full
7143300	KSGS	S	Lyons	Arkansas	Full
7143330	KSGS	S	Hutchinson	Arkansas	Full
7144200	KSGS		Valley Center	Arkansas	High
7144550	KSGS	S	Derby	Arkansas	Full
7144790	KSGS	S	Cheney Lake	Ninnescah	Pool
7145200	KSGS	S	Murdock	Ninnescah	Full
7145500	KSGS	S	Peck	Ninnescah	Full
7146500	KSGS	S	Arkansas City	Arkansas	Full
7146622	KSGS	S	El Dorado Lake	Walnut	Pool
7146623	KSGS		El Dorado tailwater	Walnut	Full
7146830	KSGS	S	El Dorado	Walnut	Full
7146895	KSGS	S	Augusta	Walnut	High
7147070	KSGS	S	Towanda	Walnut	Full
7147800	KSGS	S	Winfield	Walnut	Full
7148130	OKGS	S	Kaw Lake	Arkansas	Pool
7150000	OKGS	S	Great Salt Plains Lake	Salt Fork Ark	Pool
7150500	OKGS	S	Jet	Salt Fork Ark	Full
7151000	OKGS	S	Tonkawa	Salt Fork Ark	Full
7152000	OKGS	S	Blackwell	Salt Fork Ark	Full
7152500	OKGS	S	Ralston	Arkansas	Full
7153000	OKGS	S	Pawnee	Arkansas	Full
7159100	OKGS	S	Dover	Cimarron	Full
7160000	OKGS	S	Perkins	Cimarron	Full
7164200	OKGS	S	Keystone Lake	Arkansas	Pool
7164210	OKGS		Keystone tailwater	Arkansas	Full
7164500	OKGS	S	Tulsa - Arkansas River	Arkansas	Full
7165000	OKGS	S	Heyburn Lake	Polecat	Pool
7165570	OKGS	S	Haskell	Arkansas	Full
7165900	KSGS	S	Toronto Lake	Verdigris-Upper	Pool
7166000	KSGS	S	Coyville	Verdigris-Upper	Full
7166500	KSGS	S	Altoona	Verdigris-Upper	Full
7168000	KSGS	S	Fall River	Verdigris-Upper	Full
7168500	KSGS	S	Fall River Lake	Verdigris-Upper	Pool
7169500	KSGS	S	Fredonia	Verdigris-Upper	Full
7170050	KSGS	S	Elk City Lake	Verdigris-Upper	Pool
7170060	KSGS		Elk City tailwater	Verdigris-Upper	Full
7170500	KSGS	S	Independence	Verdigris-Upper	Full
7170695	KSGS	S	Big Hill Lake	Verdigris-Upper	Pool
7170700	KSGS	S	Cherryvale	Verdigris-Upper	Full
7171000	OKGS	S	Lenapah	Verdigris-Lower	Full
7171300	OKGS	S	Oologah Lake	Verdigris-Lower	Pool
7171400	OKGS		Oologah tailwater	Verdigris-Lower	Full

TABLE 5-2 (Continued)

USGS ID	USGS District		Gage Name	River Basin	Gage Type
7172000	KSGS		Elgin	Verdigris-Lower	Full
7172500	OKGS	S	Hulah Lake	Verdigris-Lower	Pool
7174300	OKGS		Hulah tailwater	Verdigris-Lower	Full
7174300	OKGS	S	Copan Lake	Verdigris-Lower	Pool
7174310	OKGS		Copan tailwater	Caney River	Full
7174500	OKGS	S	Barltesville	Verdigris-Lower	Full
7174600	OKGS		Okesa	Verdigris-Lower	Full
7175500	OKGS	S	Ramona	Verdigris-Lower	Full
7175550	OKGS	S	Collinsville	Verdigris-Lower	Stage
7176000	OKGS	S	Claremore	Verdigris-Lower	Full
7176460	OKGS	S	Birch Lake	Verdigris-Lower	Pool
7176465	OKGS		Birch tailwater	Verdigris-Lower	Full
7176500	OKGS	S	Avant	Verdigris-Lower	Full
7177400	OKGS	S	Skiatook Lake	Verdigris-Lower	Pool
7177410	OKGS		Skiatook Lake tailwater	Verdigris-Lower	Full
7177500	OKGS	S	Sperry	Verdigris-Lower	Full
7178450	OKGS	S	Catoosa	Verdigris-Lower	Stage
7178600	OKGS	S	Inola	Verdigris-Lower	Stage
7178620	OKGS	S	L & D 18 - Newt Graham	Verdigris-Lower	Stage
7178625	OKGS		L & D 18 tailwater	Verdigris-Lower	Stage
7178645	OKGS	S	L & D 17 - Chouteau	Verdigris-Lower	Stage
7178670	OKGS		L & D 17 tailwater	Verdigris-Lower	Stage
7179500	KSGS	S	Council Grove Lake	Neosho-Upper	Pool
7179500	KSGS	S	Council Grove	Neosho-Upper	Full
7179710	KSGS	S	Dunlap	Neosho-Upper	High
7179730	KSGS	S	Americus	Neosho-Upper	Full
7179794	KSGS	S	Marion Lake - below	Grand-Upper	Full
7179795	KSGS	S	Marion Lake	Grand-Upper	Pool
7180200	KSGS	S	Marion Levee	Grand-Upper	Full
7180400	KSGS	S	Florence	Grand-Upper	Full
7182250	KSGS	S	Plymouth	Grand-Upper	Full
7182450	KSGS	S	John Redmond Lake	Neosho-Upper	Pool
7182510	KSGS	S	Burlington	Neosho-Upper	Full
7183000	KSGS	S	Iola	Neosho-Upper	Full
7183200	KSGS	S	Chanute	Neosho-Upper	Full
7183500	KSGS	S	Parsons	Neosho-Upper	Full
7185000	OKGS	S	Commerce	Neosho-Lower	Full
7186000	MOGS	S	Waco	Grand-Lower	Full
7187000	MOGS	S	Joplin	Grand-Lower	Full
7188000	OKGS	S	Quapaw	Grand-Lower	Full
7189000	OKGS	S	Tiff City	Grand-Lower	Full
7190000	OKGS	S	Grand Lake	Grand-Lower	Pool
7191000	OKGS	S	Big Cabin	Grand-Lower	Full
7191400	OKGS	S	Hudson Lake	Grand-Lower	Pool
7193000	OKGS	S	Fort Gibson Lake	Grand-Lower	Pool
7193500	OKGS		Fort Gibson tailwater	Grand-Lower	Full
7194500	OKGS	S	Muskogee	Arkansas	Stage
7194550	OKGS	S	L & D 16 - Webbers Falls	Arkansas	Stage

TABLE 5-2 (Continued)

USGS ID	USGS District		Gage Name	River Basin	Gage Type
7194551	OKGS		L & D 16 tailwater	Arkansas	Stage
7195500	OKGS	S	Watts	Illinois	Full
7196500	OKGS	S	Tahlequah	Illinois	Full
7197000	OKGS	S	Eldon	Illinois	Full
7197500	OKGS	S	Tenkiller Lake	Illinois	Full
7197520	OKGS		Tenkiller tailwater	Illinois	Full
7198000	OKGS	S	Gore	Illinois	Full
7229200	OKGS	S	Purcell	Canadian	Full
7230500	OKGS	S	Tecumseh	Canadian	Full
7231500	OKGS	S	Calvin	Canadian	Full
7232500	OKGS	S	Guymon	N. Canadian	Full
7234000	OKGS	S	Beaver	N. Canadian	Full
7236500	OKGS	S	Fort Supply Lake	N. Canadian	Pool
7237000	OKGS		Fort Supply tailwater	N. Canadian	Full
7237500	OKGS	S	Woodward	N. Canadian	Full
7238000	OKGS	S	Seiling	N. Canadian	Full
7238500	OKGS	S	Canton Lake	N. Canadian	Pool
7239000	OKGS	S	Canton outflow	N. Canadian	Full
7239200	OKGS	S	Watonga	N. Canadian	Full
7239500	OKGS	S	El Reno	N. Canadian	Full
7241000	OKGS	S	Overholser Lake - below	N. Canadian	Full
7241550	OKGS	S	Harrah	N. Canadian	Full
7242000	OKGS	S	Wetumka	N. Canadian	Full
7242350	OKGS	S	Arcadia	Deep Fork	Full
7242380	OKGS	S	Warwick	Deep Fork	Full
7243500	OKGS	S	Beggs	Deep Fork	Full
7244800	OKGS	S	Eufaula Lake	Canadian	Pool
7244900	OKGS		Eufaula tailwater	Canadian	Full
7245000	OKGS	S	Whitefield	Canadian	Full
7246310	OKGS	S	L & D 15 - R.S. Kerr	Arkansas	Stage
7246400	OKGS		L & D 15 tailwater	Arkansas	Stage
7246700	OKGS	S	L & D 14 - W.D. Mayo	Arkansas	Stage
7246710	OKGS		L & D 14 tailwater	Arkansas	Stage
7248000	OKGS	S	Wister Lake	Poteau	Pool
7248500	OKGS		Wister tailwater	Poteau	Full
7249000	OKGS	S	Poteau	Poteau	Full
7249419	OKGS	S	Panama	Poteau	Full
7250500	OKGS	S	Van Buren	Arkansas	Stage

TABLE 5-2 (Continued)

Key:

S = Gage transmits its data via the National Oceanic and Atmospheric Administration NESS satellite system.

Gage Type:
- Full = A published station with measurements made through the full range of flows.
- High = Measurements are made at high flow conditions only.
- Stage = No stream flow measurements are made, but a continuous stage is monitored.
- Pool = The gage is a lake pool elevation gage.

USGS District which operates each respective gage:
- OKGS - Oklahoma
- KSGS - Kansas
- MOGS - Missouri

All river gages are susceptible to damage from lightning, debris, and sediment during floods. DCP's allow for quick detection of malfunction and subsequent repair.

Rainfall Data

Rainfall data is obtained from the National Weather Service. Observers telephone data to National Weather Service offices in the region, who then encode and transfer it to the Tulsa District water control computer via a dedicated telephone line. Observer data generally consists of reports at 7 a.m., 1 p.m., and 7 p.m. Data from recording rainfall stations are available at various locations and are used to determine rainfall distribution over the basin.

DISCHARGE RATING CURVES

Discharge rating curves, relating flows to stages, are developed by measuring the amount of water flowing past gages for various river stages. Stage versus flow data are then plotted to graphically display the rating curve. When upper limits of the known rating curves are exceeded, flows are estimated by extending the rating curves until USGS personnel can obtain actual field measurements. These field measurements are then used to extend the rating curves and forecasts are adjusted accordingly.

INFLOW FORECASTS

Forecasts of the amount of water which will enter each lake are obtained by using computer programs developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), Davis, California. These models use rainfall amount and distribution data, loss rate parameters, base flow data, and several hydrologic parameters which represent the watershed and its response to rainfall. A hydrograph---a graphic representation of stage, flow, velocity, or other characteristics of water at a given point and a given time---is generated by the model. These hydrographs are compared with observed or measured data to verify accuracy. Inflow forecasts are then used to predict lake levels and assist in making decisions on release rates from each lake.

SYSTEM OPERATION DURING FLOOD OF 1986

The preceding portion of this chapter provides an overview of the operations necessary to manage the Arkansas River Basin system. The following discusses system operation during this flood.

As stated before, 11 lakes in the system completely filled or exceeded their flood control storage capacity. Maximum floods of record were experienced on the Arkansas River at and above Tulsa; on the Caney River at and above Bartlesville; on the Verdigris River above Oologah Lake; and other locations.

EMERGENCY OPERATION ACTIVITIES

One of the first actions of the Tulsa District in any emergency is to activate its Emergency Operations Center (EOC). The EOC is responsible for overall coordination of emergency activities.

The EOC was activated on 29 September 1986 and operated on a 24-hour basis throughout the flood event. Coordination was established with state and local officials, civil defense offices, police and fire agencies, and the American Red Cross. The District provided engineering advice pertaining to water releases and their effects on downstream areas. Liaison personnel were assigned to the Tulsa County (Oklahoma) Emergency Operations Centers in the cities of Tulsa, Sand Springs, Jenks, and Bixby on a 24-hour basis to provide technical advice and assistance.

Situation reports were prepared twice daily for submission to higher authority. Information copies were sent to the Fifth U.S. Army; the national and Regions VI and VII offices of the Federal Emergency Management Agency (FEMA); and to the state civil defense office.

More than 500,000 sandbags from Corps project offices were distributed to 17 Oklahoma and 2 Kansas cities. Local supplies were not adequate to meet the needs of all requesting communities. Sandbags were, therefore, transported from other states to meet the high demand.

High watermarks were established in six Oklahoma cities and throughout Tulsa County. Aerial photographs were taken along the Arkansas, Verdigris, and Caney Rivers at the peak of the flood. Video teams were dispatched to assist in recording the flood. Inspection teams were sent to evaluate the Jenks and Caney levees. Water pumps were furnished to the cities of Tulsa, Bixby, and Sand Springs in Oklahoma and Caney in Kansas.

FLOOD CONTROL PROJECTS OPERATIONS

Operations at selected flood control projects are presented here. Significant water management decisions and the rationale behind those decisions are also discussed. Plots of the pool elevation and outflow and inflow hydrographs are shown in **Appendix A**; **Table 5-3** presents the maximum pool level of the lakes during the flood event.

TABLE 5-3

PERTINENT POOL LEVELS

Project	Top of Conser-vation Pool	Top of Flood Control Pool	Top of Sur-charge Pool	Previous Max. Pool of Record Elev	Previous Max. Pool of Record Date	Max. Pool of Sep-Oct 1986 Elev	Max. Pool of Sep-Oct 1986 Date
Cheney	1421.6	1429.0	None	1429.20	Nov 02 1979	1424.37	Oct 06
El Dorado	1339.0	1347.5	1353.0	1344.03	Oct 15 1985	1343.58	Oct 10
Kaw	1010.0	1044.5	1047.5	1027.27	Jun 06 1982	**1045.51**	Oct 06*
Great Salt Plains	1125.0	1138.5	None	1134.38	Jul 02 1951	1129.43	Oct 05
Keystone	723.0	754.0	757.0	754.86	Oct 06 1974	**755.82**	Oct 06*
Heyburn	761.5	784.0	None	776.78	Nov 04 1974	769.79	Oct 01
Toronto	901.5	931.0	936.0	928.38	Sep 17 1961	**931.43**	Oct 04*
Fall River	948.5	987.5	990.0	987.18	Jul 13 1951	981.09	Oct 10
Elk City	796.0	825.0	830.0	826.32	Jul 05 1976	**830.38**	Oct 04*
Big Hill	858.0	867.5	869.5	861.85	Feb 23 1985	**869.19**	Oct 03*
Oologah	638.0	661.0	666.0	659.31	Apr 26 1973	**664.91**	Oct 09*
Hulah	733.0	765.0	767.0	764.89	Jun 23 1957	**769.42**	Oct 03*
Copan	710.0	732.0	738.0	725.59	Mar 07 1985	**735.35**	Oct 04*
Birch	750.5	774.0	778.5	763.01	Feb 26 1985	**769.03**	Oct 05*
Skiatook	714.0	729.0	None	683.15	Nov 20 1985	**707.66**	Oct 14*
Newt Graham	532.0	-	None	540.00	Feb 23 1985	535.99	Oct 12
Chouteau	511.0	-	None	517.75	Nov 06 1974	**519.30**	Oct 08*
Council Grove	1274.0	1289.0	1294.0	1284.70	Oct 121985	1280.18	Oct 13
Marion	1350.5	1358.5	1360.0	1356.68	Oct 13 1973	1351.36	Oct 14
John Redmond	1039.0	1068.0	1073.0	1066.84	Oct 17 1973	1063.97	Oct 09
Grand	745.0	755.0	None	755.27	May 25 1957	754.97	Oct 06
Hudson	619.0	636.0	None	635.55	Nov 08 1974	**635.93**	Oct 04*
Fort Gibson	554.0	582.0	None	581.88	Jul 12 1961	**582.02**	Oct 05*
Webbers Falls	490.0	-	None	490.80	Jul 12 1976	**491.45**	Oct 01*
Tenkiller	632.0	667.0	671.0	666.36	Jun 05 1957	665.25	Oct 09
Meredith	2941.3	2985.0	3004.9				
Thunderbird	1039.0	1049.4	None	1047.36	Oct 22 1983	1043.23	Oct 06
Optima	2763.5	2779.0	2796.0				
Fort Supply	2004.0	2028.0	None	2026.53	Jun 25 1957	2004.30	Oct 07
Canton	1601.5	1638.0	1640.0	1628.05	May 25 1951	1614.85	Oct 31
Arcadia	1006.0	1029.5	1033.0				
Eufaula	585.0	597.0	600.0	596.92	Apr 25 1973	592.78	Oct 14
Robert S. Kerr	460.0	-	None	461.56	Mar 30 1985	460.61	Oct 01
W D Mayo	413.0	-	None	423.42	Nov 25 1973	**427.60**	Oct 07*
Wister	474.6 - 478.0	502.5	510.5	505.73	May 27 1957	477.99	Oct 29

* = New maximum pool of record established during Sep-Oct 1986 flood.

The following projects are included:

Arkansas River Mainstem

Kaw Lake

Keystone Lake

Grand (Neosho) River Basin

Grand Lake O'the Cherokees/Lake Hudson/Fort Gibson Lake

Illinois River Basin

Tenkiller Lake

Verdigris River Basin

Elk City Lake

Fall River Lake

Hulah and Copan Lakes

Oologah Lake

Pearson-Skubitz Big Hill Lake

Toronto Lake

Canadian River Basin

Eufaula Lake

Arkansas River Mainstem

Kaw Lake

The flood control pool at Kaw Lake was empty on 29 September. Heavy rains of the next 4 days caused the pool to fill. Releases were delayed until the afternoon of 5 October to avoid adding to the crest of the flood on the Arkansas River at Ralston and the peak inflow at Keystone Lake.

As the lake level rose into the induced surcharge pool, the discharge was periodically increased until channel capacity was reached (approximately 22,000 cfs). While downstream river conditions through the Ponca City area were monitored, the discharge was gradually increased to 39,000 cfs on 6 October. The increase in release did not result in any significant damage downstream.

A release rate of 39,000 cfs was maintained until 13 October in order to regain a reasonable amount of flood control capability as quickly as possible. The discharge was reduced to 22,000 cfs on 15 October.

Keystone Lake

The flood control pool at Keystone Lake was empty on Sunday, 28 September. Moderate releases for hydropower had been made the previous week. From the morning of 29 September to the morning of 30 September, heavy rains fell on the uncontrolled drainage area below Keystone Dam. These rains caused flooding from local runoff in the Bixby area and made flooding along the Arkansas River in the Fort Smith, Arkansas area imminent.

More than 6 inches of rain had fallen at Keystone and Fort Gibson Lakes. To avoid aggravating this downstream flooding problem, no releases were made. At this point, a moderate rise into the flood control pool was forecast.

From 3 to 7 inches of additional rain fell on much of the downstream uncontrolled area by the morning of 1 October. It was forecast that the Arkansas River at Van Buren would rise 7 feet above flood stage from uncontrolled runoff alone. Additional rain, from storms triggered by the remnants of Hurricane Paine approaching the area, was forecast for eastern

Oklahoma and Kansas on 2 October. Downstream flooding, coupled with the forecast for possible additional heavy rain over the area, continued to preclude making releases.

Radar reports on the evening of 2 October, however, indicated heavy rainfall occurring upstream of Keystone Lake. It became evident during that night that the flood control pool would fill and releases would be required, regardless of downstream conditions. Releases began the morning of Friday, 3 October and were increased to 110,000 cfs by 2:45 p.m. Forecasts later that day indicated that a flood of record was developing on the Cimarron and Arkansas Rivers which would require an even greater release rate.

Earlier forecasts showed a possible inflow of as much as 410,000 cfs; revised forecasts showed that the peak inflow might be about 350,000 cfs. The adequacy of the downstream levee system through Tulsa and Jenks, Oklahoma became a serious concern. If the inflow forecast was low, induced surcharge storage might fill prior to the arrival of the peak inflow. This would require passing the peak inflow, possibly leading to a catastrophic failure of the levee system, which was designed to withstand 350,000 cfs.

An "upper-limit" inflow forecast was developed to bracket the probable inflow and assure that the peak inflow would not have to be passed downstream. This "upper-limit" forecast showed the peak inflow could be as high as 409,000 cfs. Computer analysis showed that if the "upper-limit" flow materialized, it would be necessary to release between 320,000 and 340,000 cfs by Saturday afternoon, 4 October. The discharge was periodically increased to a maximum of 300,000 cfs at 4:35 p.m. on 4 October.

During the evening of 4 October, a streamflow measurement at the Perkins gage showed less water in the Cimarron River than earlier indicated by the gage. Releases from Keystone Lake could, therefore, be reduced. On Sunday, 5 October, the discharge was periodically reduced from 300,000 to 170,000 cfs, where it was maintained until Tuesday, 7 October. The release was further reduced to 120,000 cfs on 7 October.

The actual peak inflow into Keystone Lake was 344,000 cfs, occurring at noon on 5 October. The pool reached its maximum elevation of 755.82 at 9:00 a.m. on 6 October. Had Kaw Lake not been in place, the inflow to Keystone Lake would have been about 448,000 cfs.

Grand (Neosho) River Basin

Grand Lake O'the Cherokees/Lake Hudson/Fort Gibson Lake

The flood control pools of this three-lake system were empty prior to the heavy rains of 29-30 September. Small releases from Fort Gibson Lake had been started on 29 September. They were shut off on the 30th because of imminent downstream flooding on the Arkansas River. Releases necessary to equalize the percentage of flood control storage used in each of the three lakes were made from Grand Lake and Lake Hudson. It was anticipated that releases of about one-half channel capacity below Fort Gibson could be started on 2 or 3 October. These would follow the crest of the flood on the Arkansas River and allow the flood control pools to just fill.

Heavy rains which fell on the watershed during the evening of 2 October required much larger releases from Fort Gibson. Releases had been increased to 122,700 cfs by the evening of 3 October.

The three flood control pools were full, and inflows were passed through the system by 5 October.

Illinois River Basin

Tenkiller Lake

The flood control pool at Tenkiller Lake rose to 94 percent full during the flood. Early inflow forecasts proved to be quite accurate. Hydropower releases were shut off on 1 October, and no further releases were made until 9 October, well after the crest of the flood on the Arkansas River had passed.

Verdigris River Basin

Elk City Lake

The flood control pool at Elk City Lake was empty on 26 September. Rains began the morning of 29 September, and the lake began to rise into its flood control pool. As heavy rains continued, flooding was predicted downstream at Independence, Kansas; therefore, no releases were made at that time.

The pool elevation had reached the crest of the uncontrolled spillway (elevation 825.25) by 2:00 p.m. on 3 October. As the pool level continued to rise, releases through the uncontrolled spillway increased. The pool level reached elevation 825, the top of the flood control pool. At that time, the two conduit gates were opened at the rate of about 4 feet per hour, until they were fully opened (16 feet each) at 12:15 a.m. on 4 October. The pool crested at elevation 830.38 feet at 9:00 a.m. on 4 October, .38 foot above the top of the surcharge pool.

The maximum release rate was 27,500 cfs. The maximum gate setting obtained was continued as the pool fell. At 10:50 a.m. on 6 October, the release was reduced to below channel capacity on the Elk River below the lake.

The river stage at Independence, Kansas had fallen below flood stage on 9 October. Combined releases, to evacuate the flood control pools, were made from Elk City, Fall River, and Toronto Lakes at a rate which would keep the river stage at Independence at or below flood stage.

Fall River Lake

The Fall River Lake flood control pool was empty on 26 September. The lake elevation was 948.45 feet; the top of the conservation pool is 948.5 feet. The pool began to rise on 29 September from heavy rains. No releases were made because of downstream flooding.

Once water levels downstream on the Fall River and at Independence, Kansas on the Verdigris River had fallen below flood stage, releases were started at 10:35 a.m. on 10 October.

The maximum pool elevation was 981.09 feet, with 74 percent of its flood control storage used. The maximum release rate was 4,625 cfs on 11 October. The Fall River channel capacity is 6,500 cfs below Fall River Dam.

Hulah and Copan Lakes

Flood control pools at Hulah and Copan Lakes were essentially empty on Sunday, 28 September. Releases were being made only for water supply and water quality. Heavy rains on 29 and 30 September caused the Caney River downstream from Hulah and Copan to rise above floodstage, as recorded at the Bartlesville and Ramona gages. Inasmuch as there was downstream flooding and no forecast that the flood control pools would fill, no releases were made.

Very heavy rains from storms generated by remnants of Hurricane Paine on Thursday evening and Friday morning caused both flood control pools to fill on Friday morning, 3 October. Releases from both lakes were started that same morning. They were increased throughout the day in a manner to provide as much warning time as possible to residents in the Bartlesville area. Because of flooding in Bartlesville, the spillway gates at Copan were opened only as needed to prevent their overtopping.

A significant deviation from the approved operating plan was made at Hulah Lake. The flood control pool filled at 7:30 a.m. on 3 October. By noon, the induced surcharge pool was full. To prevent the lake level from rising above the top of the induced surcharge pool, the operating plan calls for an immediate increase in discharge until it is equal to the inflow. This would have meant increasing the outflow from 26,000 cfs to about 120,000 cfs in a matter of minutes. Such a procedure would have caused downstream flooding significantly greater than actually occurred, and about 12 hours earlier, in Bartlesville. A structural analysis showed that the pool could be allowed to rise 3 feet above the top of the induced surcharge pool, if absolutely necessary. This strategy averted the aforementioned sudden increase in outflow. With this additional storage available, the outflow at Hulah Lake was increased only as required to keep the lake from overtopping the spillway gates.

The outflows from Hulah and Copan Lakes were increased throughout the day on 3 October and peaked at a combined discharge of 108,800 cfs on the morning of 4 October. Outflows were reduced as inflows dropped off. The combined outflow was about 37,000 cfs by midnight, 4 October.

The combined outflow was reduced to 14,000 cfs by 6 October and was maintained between 12,000 to 14,000 cfs until 4 October, permitting the recovery of a moderate amount of flood control capability.

Oologah Lake

The flood control pool at Oologah Lake was empty on Friday, 26 September. Heavy rains on Friday night and again on Monday, 29 September, resulted in a moderate rise. To minimize downstream flooding occurring on the Arkansas River, no releases were made because it was forecast that the flood control pool would only fill to about 50 percent. However, very heavy rains occurred on the upper Verdigris River watershed Thursday evening, 2 October, which resulted in a subsequent forecast that the flood control pool would completely fill.

To minimize the crest of the flood at Claremore, Oklahoma and because of the large discharges required at Hulah and Copan Lakes, releases from Oologah Lake were delayed as long as possible. As the flood control pool filled, releases from the gated saddle spillway began on 6 October. As the lake rose into its induced surcharge pool, releases were increased only as required to keep the top of the spillway gates slightly above the pool elevation.

The Verdigris River crested on 7 October at the Claremore gage primarily from high flows coming down the Caney River. The outflow from Oologah Lake was then increased, maintaining the crest at the Claremore gage. This was necessary because a large volume of water released from upstream lakes in Kansas would be flowing into Oologah Lake. Additionally, a long time would be required to regain even a small portion of flood control storage. Even with the increased outflow, the lake level did not recede to the top of its flood control pool until 14 October.

The discharge was later reduced such that the Verdigris River at Claremore dropped below flood stage on 22 October.

Pearson-Skubitz Big Hill Lake

The pool elevation at Big Hill Lake was 857.85 feet on 26 September; the top of the conservation pool is 858 feet. Rains began in the drainage basin above Big Hill Lake on 29 September, and the pool level rose rapidly. It crested at elevation 869.19 feet at 10:00 p.m. on 3 October, just .31 feet lower than the crest of the uncontrolled spillway (elevation 869.5 feet) and 1.69 feet above the top of the flood control pool (elevation 867.5 feet). The outlet works at Big Hill consists of an ungated morning-glory drop inlet. The maximum release rate was 1,020 cfs.

Toronto Lake

The pool elevation at Toronto Lake was elevation 901.22 on 26 September; the top of the conservation pool is 901.5. Heavy rains started on 29 September and the lake began to rise into its flood control pool. No releases were made because of downstream flooding along the Verdigris River. Releases through the spillway tainter gates were started at 7:20 p.m. on 3 October to prevent water from flowing over them. The maximum release was 9,800 cfs on 4 October. The pool elevation crested at 931.43 feet at 4 p.m. on 4 October.

When the pool had fallen enough to permit lowering of the spillway gates and still keep the tops above the pool level, each was lowered 1/2 foot. Releases were continued at or near channel capacity of 6,500 cfs until 11 October. The release rate was reduced on that date to help balance the flood storage at Toronto with other projects on the Verdigris River system.

Canadian River Basin

Eufaula Lake

Rainfall was not as great above Eufaula Lake as at many of the other reservoirs. Only 61 percent of the flood control pool was filled. Hydropower releases being made on 29 September were shut off. No further releases were made until 14 October, at which time they were begun to evacuate the flood control pool in a balanced manner with the rest of the Arkansas River Basin projects.

DEVIATION FROM THE SYSTEM WATER CONTROL PLAN

The approved operating plan, as described in the Arkansas River Basin Water Control Master Manual, specifies that storage in the flood control pools of the system will be evacuated at a rate not to exceed 150,000 cfs at Van Buren, Arkansas. A significant deviation from this policy was made.

Rather than hold the flood control pools full for an extended period while the flows at Van Buren reduced to 150,000 cfs, lake releases were made which followed the crest of the flood on the Arkansas River. Although the result was a more gradual reduction of downstream flooding, it permitted sufficient evacuation of the flood control pools so a moderate amount of additional rainfall could be controlled and not add to the flood damages already incurred.

The flow at Van Buren was gradually reduced from approximately 370,000 cfs on 7 October to about 150,000 cfs on 22 October, at which time the normal plan of operation was resumed.

CHAPTER 6

FLOOD DAMAGES AND FLOOD DAMAGES PREVENTED

In spite of the dedicated efforts of everyone who responded to the flood emergency, all damages could not be prevented. Urban and rural areas alike incurred damages from uncontrolled runoff and releases from projects which had exceeded their flood control capacity. Had it not been for the flood control dams, however, warning time would have been decreased and the depth of flood water would have been much greater. Because of controlled releases and the efforts of hundreds of public and private volunteers, many of whom worked around the clock, the threat to life and property was significantly reduced.

FLOOD DAMAGES

The Tulsa District assessed flood damages in 19 cities and 49 counties in Oklahoma; 16 cities and 14 counties in Kansas; and 35 flood control projects. Flood damage information was obtained from various sources: information-gathering consultant firms; field surveys; state and local officials; the Federal Emergency Management Agency; the American Red Cross; and other agencies involved in disaster assistance.

Table 6-1 presents flood damage assessment values for urban areas; roads, bridges, and rural structures; and crops. In some cases, county totals are broken down into damage totals for particular cities.

Areas in Oklahoma with the greatest dollar amount of damage were: Washington County (Bartlesville), $37.2 million; Sand Springs, $32.5 million; and Bixby, $13.4 million.

TABLE 6-1

FLOOD DAMAGE ASSESSMENT
(Damages in $1,000's)

State County/City*	County Area (square miles)	Damages Urban	Road, Bridges, and Rural Structures	Crops	Total
OKLAHOMA					
Adair	577	-	503.0	50.0	553.0
Alfalfa	864	-	350.0	2,086.0	2,436.0
Beckham	904	-	200.0	880.0	1,080.0
Blaine	920	-	226.0	3,361.0	3,587.0
Caddo	1,286	-	541.0	1,000.0	1,541.0
Canadian	901	-	203.0	3,940.0	4,143.0
Cherokee (Tahlequah)	748	450.0	169.0	170.0	789.0
Cleveland (Norman)	529	540.0	18.0	125.0	683.0
Craig	763	-	10.0	4,744.0	4,754.0
Creek	930	-	208.0	655.0	863.0
Custer	981	-	282.0	4,168.0	4,450.0
Delaware	720	-	15.0	1,071.0	1,086.0
Dewey (Oakwood)	1,007	142.0	498.0	1,560.0	2,200.0
Garfield	1,060	-	672.0	4,684.0	5,356.0
Grady	1,106	-	187.0	1,100.0	1,287.0
Grant	1,004	-	271.0	2,162.0	2,433.0
Greer	638	-	786.0	2,600.0	3,386.0
Harmon (Hollis)	537	250.0	-	500.0	750.0
Hughes	806	-	-	50.0	50.0
Jackson (Altus)	817	175.0	-	3,000.0	3,175.0
Kay	921	-	1,081.0	7,400.0	10,291.0
Ponca City		250.0	-	-	-
Tonkawa		60.0	-	-	-
Blackwell		1,500.0	-	-	-
Kingfisher (Kingfisher)	906	1,300.0	2,655.0	6,571.0	10,526.0
Kiowa	1,019	-	179.0	7,938.0	8,117.0
Lincoln	964	-	-	300.0	300.0
Logan	748	-	474.0	5,898.0	6,372.0
McClain	582	-	78.0	575.0	653.0
McIntosh	599	-	-	50.0	50.0
Major	958	-	194.0	510.0	704.0
Mayes (Salina)	644	50.0	-	525.0	575.0
Muskogee	815	-	747.0	3,000.0	3,747.0
Noble	736	-	290.0	4,815.0	5,105.0
Nowata (Nowata)	540	100.0	574.0	824.0	1,498.0
Okfuskee	628	-	138.0	130.0	268.0
Oklahoma	708	-	82.0	203.0	285.0
Okmulgee	698	-	272.0	1,499.0	1,771.0
Osage (Skiatook)	2,265	500.0	377.0	550.0	1,427.0
Ottawa (Miami)	465	11,616.0	266.0	1,487.0	13,369.0
Pawnee (Pawnee)	551	100.0	328.0	847.0	1,275.0
Payne (Stillwater)	691	120.0	678.0	4,785.0	5,583.0
Pottawatomie	783	-	-	3,849.0	3,849.0

TABLE 6-1 (Continued)

State County/City*	County Area (square miles)	Damages Urban	Road, Bridges, and Rural Structures	Crops	Total
Roger Mills	1,146	-	195.0	50.0	245.0
Rogers	683	-	33.0	640.0	673.0
Seminole	639	-	-	345.0	345.0
Sequoyah	678	-	227.0	970.0	1,197.0
Tillman	901	40.0	200.0	3,500.0	3,740.0
Tulsa	572	-	7,555.0	3,434.0	63,559.0
Bixby		13,399.0			
Sand Springs		32,496.0			
Tulsa		6,675.0			
Wagoner	559	-	367.0	2,667.0	3,034.0
Washington (Bartlesville)	423	37,238.0	668.0	1,828.0	39,730.0
Washita	1,006	-	748.0	1,700.0	2,448.0
KANSAS					
Allen					
Humbolt	505	-	1,466.0	1,909.0	3,375.0
Lola					
Bourbon	300	-	3,850.0	2,730.0	6,580.0
Butler	1,443	-	145.0	176.0	321.0
Chautauqua	644	-	2,792.0	600.0	3,392.0
Elgin	-	200.0	3.0	-	203.0
Peru	-	54.0	1.0	-	55.0
Niotaze	-	87.0	1.0	-	88.0
Sedan	-	136.0	2.0	-	138.0
Cedarvale	-	20.0	-	-	20.0
Cherokee	590	-	1,002.0	3,500.0	4,502.0
Baxter Springs	-	63.0	1.0	-	64.0
Cowley	1,128	-	360.0	375.0	735.0
Crawford	595	-	1,535.0	4,200.0	5,735.0
Elk	650	-	120.0	687.0	807.0
Greenwood	1,135	-	890.0	590.0	1,480.0
Labette	653	-	1,235.0	1,900.0	3,135.0
Parsons	-	200.0	3.0	-	203.0
Oswego	-	60.0	1.0	-	61.0
Montgomery	646	-	672.0	2,300.0	2,972.0
Independence	-	445.0	7.0	-	452.0
Coffeyville	-	100.0	2.0	-	102.0
Neosho	576	-	1,221.0	3,013.0	4,234.0
Chanute	-	70.0	1.0	-	71.0
Erie	-	100.0	2.0	-	102.0
Wilson	575	-	1,310.0	3,200.0	4,510.0
Altoona	-	210.0	3.0	-	213.0
Fredonia	-	70.0	1.0	-	71.0
Neodesha	-	1,020.0	15.0	-	1,035.0
Woodson	498	-	1,075.0	1,500.0	2,575.0

* = Table shows flood damages to counties and selected cities within counties. A city is shown parenthetically when only one is listed in that county.

Total flood damages from the storm event amounted to approximately $283 **million**. **Tables 6-2** through **6-5** are summary sheets presenting the actual flood damage values for four reaches in the area. The reaches are as follows:

- From Hulah and Copan damsites on the Caney River to the Verdigris River.
- From Keystone dam to Snake Creek on the Arkansas River.
- From Snake Creek to the Oklahoma-Arkansas state line.
- At Miami, Oklahoma, on the Grand (Neosho) River.

These reaches account for about 55 percent of the total actual flood damages experienced in the 49 counties in Oklahoma and 14 counties in Kansas.

FLOOD DAMAGES PREVENTED

Tables 6-2 through **6-5** also present estimates of damage that would have occurred without the Arkansas River Basin flood control projects (uncontrolled damages) for the four reaches listed above.

Through the use of computer models and a data base of property values in the Arkansas River Basin flood plain, the Tulsa District determined the amount of damages which were prevented by the flood control projects. **Table 6-6** shows these damage prevented values.

Total damages prevented by flood control projects amount to approximately **$725 million**. The flood control system also prevented additional loss of life. There were two lives lost in uncontrolled flooding areas. However, during a similar event, the 1943 flood, there were 26 lives lost with no flood control structures in place.

TABLE 6-2

SUMMARY OF ACTUAL AND UNCONTROLLED FLOOD DAMAGES FROM HULAH AND COPAN DAM SITES ON THE CANEY RIVER TO THE VERDIGRIS RIVER (Damages in Dollars)

Properties	Actual Damages		Uncontrolled Damages	
	Units	Damages	Units	Damages
Single Family Residential and Contents	1,462	$39,566,000	3,237	$135,523,000
Multiple Family Residential and Contents	18	312,000	39	1,053,000
Mobile Homes and Contents	60	441,000	153	1,189,000
Commercial and Contents	38	4,880,000	41	5,741,000
Industrial and Contents	28	3,170,000	29	6,237,000
Streets and Roadways (city/town)		56,000		66,000
Highways and Bridges		9,742,000		12,898,000
Agricultural		5,209,000		8,825,000
Public and Quasi-Public Property (schools/parks)		661,000		778,000
Utilities (lines, poles, and property)		1,091,000		1,471,000
Total Damages		$65,128,000		$173,781,000

TABLE 6-3

SUMMARY OF ACTUAL AND UNCONTROLLED FLOOD DAMAGES
FROM KEYSTONE DAM TO SNAKE CREEK ON THE ARKANSAS RIVER
(Damages in Dollars)

Properties	Actual Damages		Uncontrolled Damages	
	Units	Damages	Units	Damages
Single Family Residential and Contents	1,170	$39,000,000	7,719	$346,000,000
Multiple Family Residential and Contents	139	960,000	5,124	67,000,000
Mobile Homes and Contents	444	5,000,000	882	10,000,000
Commercial and Contents	79	3,393,000	350	69,000,000
Industrial and Contents	4	1,600,000	180	82,000,000
Streets and Roadways (city/town)	19	227,000	126	2,000,000
Highways and Bridges	5	50,000	37	1,000,000
Agricultural		3,434,000		7,000,000
Public and Quasi-Public Property (schools/parks)	13	1,435,000	41	19,000,000
Utilities (lines, poles, and property)		933,000		9,000,000
Total Damages		$56,032,000		$612,000,000

APPENDIX B

AERIAL PHOTOGRAPHS OF

FLOOD AREAS AND FLOOD PROFILES

(Bound Separately)

TABLE 6-4

SUMMARY OF ACTUAL AND UNCONTROLLED FLOOD DAMAGES
FROM SNAKE CREEK TO THE OKLAHOMA - ARKANSAS STATE LINE ON THE ARKANSAS RIVER
(Damages in Dollars)

Properties	Actual Damages		Uncontrolled Damages	
	Units	Damages	Units	Damages
Single Family Residential and Contents	90	$2,056,000	562	$13,641,000
Multiple Family Residential and Contents	0	0	56	1,256,000
Mobile Homes and Contents	65	478,000	264	2,340,000
Commercial and Contents	9	165,000	83	4,726,000
Industrial and Contents *	60	1,698,000	288	10,787,000
Streets and Roadways (city/town)		374,000		567,000
Highways and Bridges		1,000,000		2,000,000
Agricultural		18,219,000		33,595,000
Public and Quasi-Public Property (schools/parks)	13	3,125,000	25	5,459,000
Utilities (lines, poles, and property)		207,000		993,000
Total Damages		$27,322,000		$75,354,000

* Includes 278 oil wells.

TABLE 6-5

SUMMARY OF ACTUAL AND UNCONTROLLED FLOOD DAMAGES
AT MIAMI, OKLAHOMA, ON THE NEOSHO RIVER
(Damages in Dollars)

Properties	Actual Damages		Uncontrolled Damages	
	Units	Damages	Units	Damages
Single Family Residential and Contents	208	$4,378,000	393	$9,700,000
Mobile Homes and Contents	26	116,000	32	207,000
Commercial and Contents	48	4,224,000	66	7,688,000
Industrial and Contents				
Streets and Roadways (city/town)		53,000		138,000
Highways and Bridges		138,000		150,000
Agricultural				
Public and Quasi-Public Property (schools/parks)	30	2,626,000	34	3,626,000
Utilities (lines, poles, and property)		50,000		106,000
Total Damages		$11,585,000		$21,615,000

TABLE 6-6

SUMMARY OF DAMAGES PREVENTED BY FLOOD CONTROL PROJECTS
(Damages Prevented in Dollars)

Subbasin/Project	Damages Prevented
Arkansas River Mainstem	
Canton	$210,000
Cheney	5,708,000
El Dorado	11,941,000
Eufaula	413,000
Fort Supply	5,000
Great Salt Plains	11,519,000
Heyburn	198,000
Kaw	198,113,000
Keystone	213,306,000
Thunderbird	560,000
Tulsa-West Tulsa Levee	135,144,000
Cimarron River Basin	
Keystone (also a mainstem lake)	see above
Grand (Neosho) River Basin	
Council Grove	240,000
Fort Gibson	6,619,000
Grand	4,354,000
Hudson	1,674,000
Iola Levee (Kansas)	1,320,000
Marion	40,000
John Redmond	3,014,000
Illinois River Basin	
Tenkiller	241,000
Verdigris River Basin	
Birch	145,000
Copan	47,428,000
Elk City	1,865,000
Fall River	1,340,000
Hulah	63,705,000
Oologah	12,436,000
Pearson-Skubitz Big Hill	298,000
Skiatook	1,769,000
Toronto	1,240,000
Total	$724,845,000 *

* - Includes $34.4 million damages prevented in the State of Arkansas by Tulsa District projects.

CHAPTER 7

ISSUES AND ACTIONS

Several questions and concerns were raised during and following the flood. Many of these have been addressed through responses to Congressional inquiries, letters, and meetings with concerned parties. **Table 7-1** lists and summarizes these issues. This chapter provides further discussion of some of these issues and details many of the ongoing efforts of the Tulsa District to improve flood control operations.

COMMUNICATIONS

Issue: One of the major problems encountered during the flood operations was in the area of communications. The Tulsa District offices were deluged with telephone calls from public officials, the news media, and the general public requesting information. Every effort was made to be responsive and provide the best, most up-to-date information available; however, there was considerable criticism that conflicting, faulty, unclear, and untimely information was received. Delineation of responsibilities of the Corps and/or other agencies for providing information, issuance of warnings, and notification to affected areas was unclear.

Action: The Tulsa District has established a Public Information Center (PIC), to be activated during emergency operations, to respond to requests for information. A diagram of the PIC is shown at **Figure 7-1**. Dedicated communication telephone lines have been installed to meet these needs. The Public Affairs Office will coordinate activities of the PIC so queries are handled as quickly as possible. The Public Affairs Office will also continue

TABLE 7-1

STATUS OF AFTER ACTION ISSUES
SEPTEMBER-OCTOBER 1986 FLOOD

Page	Description Action Item/Issue	Comments	Status
7-1	Perceived Communications Breakdown With Public Officials, News Media, and General Public	Completed	A public information center (PIC) has been established. PIC was activated during May 1987 flood.
7-5	Forecasting Procedures	Ongoing	Enhanced RADAR is scheduled for Oklahoma area in fiscal year 1988. New work group proposed to be established for making forecast in fiscal year 1988.
7-6	Access and Damages to Stream Gages	Ongoing	Funds of $250,000 available this fiscal year. Scheduled for completion in fiscal year 1988.
7-8	Electric Service and Personnel Access at Keystone Dam	Ongoing	Evaluation to be completed October 1987.
7-9	Availability of Flood Fighting Materials(Pumps, Riprap, Sandbags)	Ongoing	Pumps now available; riprap and sandbag evaluation and relocation to be completed in fiscal year 1988.
7-9	Keystone Traffic Control	Complete	During severe flooding, highway crossing dam will be closed.
7-10	Kaw Dam Control Room Flooding and Tailwater Staff Gage Too Low	Ongoing	Control room flooding alternatives to be completed in October 1987. Higher tailwater staff gage has been installed.
7-10	Induced Surcharge Limits	Complete	Evaluation has been made.

TABLE 7-1 (Continued)

Page	Description Action Item/Issue	Comments	Status
7-10	Power Sources at Projects	Ongoing	Evaluation scheduled for completion in October 1987.
7-11	Gate Operating Equipment Accessibility	Ongoing	Evaluation scheduled for completion in October 1987.
7-11	Keystone Powerhouse Stability During High Water	Ongoing	Evaluation scheduled for completion in October 1987.
7-11	Satellite Data Collection Backup	Ongoing	Installation completed at three gages. Evaluation to be completed in fiscal year 1988.
7-12	Interim Flood Area Maps	Ongoing	Maps will be completed in October 1988.
7-12	Flood Control-Bank Protection Measures for Bartlesville	Ongoing	Study scheduled for completion in July 1988.
7-13	System Operation Plan	Ongoing	Completion scheduled in July 1990.
7-14	Purchase of Land Below Oologah Spillway	Ongoing	Studies are complete recommending purchase of lands. Tulsa District is seeking authority to proceed with acquisition.
7-14	Backup for Water Control Computer	Ongoing	Scheduled for completion in fiscal year 1988.
7-14	Review of Reservoir Regulation Plans for Keystone, Hulah, and Copan	Ongoing	Study scheduled for completion in July 1990.

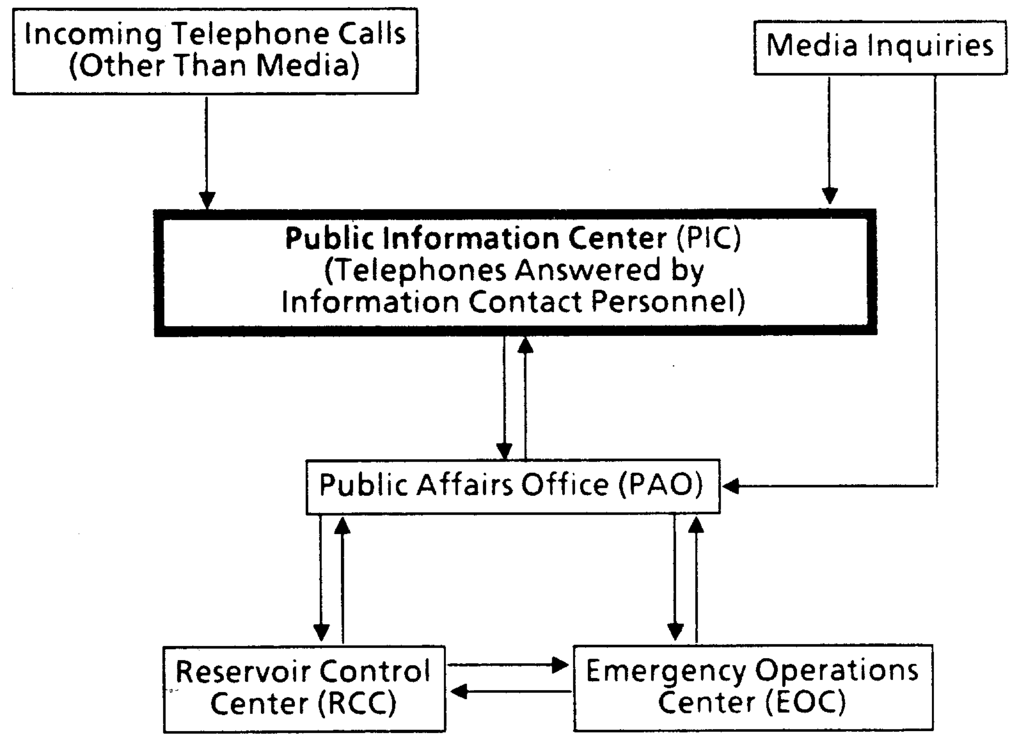


Figure 7-1 **Emergency Flood Operations Public Information Procedure**

to coordinate with technical subject experts as needed for briefing material and regularly schedule media conferences. Telephone numbers into the Reservoir Control Section have been changed to provide more dedicated telephone capability to vital flood fighting operations. The PIC was activated for the first time during flooding that occurred in late May, 1987. Reaction from the public and other involved agencies was favorable, concluding that communications and availability had been considerably improved.

Personnel working in the Corps Emergency Operations Center (EOC) will continue to provide liaison with state and local civil defense, FEMA, and others involved in flood operations. An interagency group, with the purpose of developing a working agreement to clearly define respective responsibilities, has been formed, including all involved local, state, and Federal agencies.

FORECASTING

Issue: Considerable discussion has centered around forecasting procedures and capabilities required to predict lake inflows. Questions have also been raised concerning the use of radar information to enhance or supplement rainfall data required for forecasting.

Action: A review of all reservoir forecasting procedures has been conducted. This review included methodology of basic data gathering, automated application of climatological data, dependability of watershed runoff models, coordination with other elements, and organizational structure required to support forecasting efforts. As a result of this review, additional personnel will be assigned to improvement of watershed models and reservoir control. A new work unit will be formed with a primary mission of improving and maintaining forecasting models and providing increased forecasting support during flood events.

The use of radar may be a significant enhancement for determining spatial distribution of rainfall when correlated to ground truth observance. Radar, to date, cannot be relied upon for rainfall totals. The Corps receives digital radar data from the Oklahoma City National Weather Services (OKC-NWS). An agreement exists between the Corps and OKC-NWS to supply the Tulsa District access to the RADAP II facility until such time as the NEXRAD (Next Generation Radar) system becomes functional. Oklahoma City is to receive the first NEXRAD installation within 25 months of the final test, which is scheduled for the spring of 1988. NEXRAD is viewed as a possible, significant improvement in obtaining rainfall information through radar. The Tulsa District has initiated correspondence with higher authority in an effort to secure dedicated communication ports to NEXRAD.

STREAM GAGES

Issue: Stream gages are located on bridges or on banks near streams. Gages are susceptible to damage by floating debris, erosion, lightning, and vandalism. These conditions are worsened during major floods. Flooding, particularly of roads, makes accessibility of gages for repair or measurement extremely difficult and dangerous. These problems were evident during the September-October 1986 flood.

Action: Several meetings have been held with the Oklahoma and Kansas offices of the U.S. Geological Survey (USGS) to discuss possible improvements to the gaging system. The USGS investigated the possibility of installing a cableway for the measurement of high flows on the Cimarron River near the Perkins gage, south of Stillwater, Oklahoma. This was found not to be feasible because of the width of the river when in flood stage. A new gage will be located at a better site, 7 miles downstream from Perkins, near Ripley, Oklahoma.

A list of 21 stream gages, critical to the operation of reservoirs, has been compiled. The Corps and USGS will install permanent staff gages at these critical gage sites. These staff gages will be used to manually obtain river stage readings in the event automated gages on bridges are washed out or become inaccessible. Twelve automated gages will be moved off bridges and relocated to high locations, thereby improving their accessibility and reducing the possibility of loss during major floods.

Methods of improving streamflow measurements and discharge rating curves are being investigated. Mathematical models, based on surveyed cross sections, will be used to extend discharge rating curves for the critical stream gaging stations. A sonic ranger device, which uses sound waves to measure river stages, will be investigated for possible use at some locations.

Three new data collection platforms (DCP) were installed in the Tulsa District by the USGS in June 1987, bringing the total in the Tulsa District to 159. They are located on the Cimarron River near Guthrie, Oklahoma; on the Caney River near Elgin, Kansas; and on the Elk River near Elk Falls, Kansas.

Funds in the amount of $250,000 have been received to initiate these improvements this year. It is estimated that $600,000 will be needed in 1988 to complete the improvements presently proposed.

FLOOD CONTROL STRUCTURES

Record releases from the flood control structures and record high lake and river elevations caused several concerns at the projects. None was serious enough to impair project operation, or threaten life; however, action was required to eliminate any potential threat to continued effective operation of the projects.

Keystone Dam

Issue: A high level of water was experienced at the Keystone powerhouse. Large flood releases from Keystone Dam caused flooding of the main transformer supplying power to the dam, including power needed to operate the gates. The high water also limited employee access to the powerhouse and damaged some powerhouse equipment.

Action: Flooding of the main transformer is not a critical situation. Secondary power is available from the Public Service Company of Oklahoma (PSO). There is also a diesel-powered auxiliary generator located above the powerhouse in the dam structure capable of supplying sufficient power to operate the flood gates and emergency lighting. Electrical difficulties with the gates and lighting have been lessened by the replacement of a stub power line from PSO. The power line will be completely eliminated with the expected October 1987 installation of a large transformer at an approximate cost of $15,000. A direct current source of temporary power is also available from powerhouse batteries. Auxiliary power sources will continue to be used during severe flood conditions. The sealing of openings around conduits and doors has reduced the probability of water entering the powerhouse. A secondary employee access way will be constructed along the top of the parking lot wall with steps leading to the walk. Equipment cabinets will be raised three feet above the maximum water level observed during the flood. The milestone date for completion of these actions is October 1987.

Issue: Sandbags and riprap used for emergency repairs were not readily accessible during high water. Pumps needed for removing water from the powerhouse were not available.

Action: All Tulsa District Area Engineers have been asked to evaluate stockpile locations to guarantee easy accessibility during high water conditions. These evaluations and subsequent relocations, where needed, will be conducted during fiscal year 1987-88. Storage areas for sandbags will also be evaluated. These areas must also be easily accessible as well as weather-proof. Approval for funds to construct a separate storage area required at Keystone Dam has been requested. Pumps are now available in the vicinity of the powerhouse. Regular maintenance and operation checks will be conducted on each piece of equipment.

Issue: Sightseeing was a major problem. Heavy congestion on Highway 151 crossing Keystone Dam impeded emergency vehicle movement.

Action: The highway will be closed to public traffic during severe flooding. Temporary barricades will be placed at different locations around the lake as needed.

Kaw Dam

Issue: High water occurred at Kaw Dam. The control room and access stairways to the tainter gates narrowly avoided flooding when water reached the top of the surcharge pool. The spillway feeder circuit switchgear and standby generator are located in the control room; therefore, had flooding occurred, the tainter gates could have become inoperative. In addition, the tailwater staff gage was overtopped, making tailwater elevation readings impossible.

Action: Temporary measures have been taken to floodproof the structure. An architect/engineer firm has been hired to investigate alternatives to permanently correct these potential flooding problems. The study will be completed in October 1987. A higher tailwater staff gage has been installed.

The following items have also be identified by the Tulsa District for further analysis and possible action.

- Induced Surcharge Limits

A review of the induced surcharge operations used at several projects with gated spillways has been completed. This review identified the allowable safe induced surcharge for each project based on structural or operational limitations.

- Power Sources at Projects

Twenty projects in the Tulsa District have gated spillways. The adequacy of power sources during emergency operations at each of these projects is being evaluated. Considerations include location of power lines as well as existing and backup power sources. This evaluation is scheduled to be completed in October 1987.

- Gate Operating Equipment Accessibility

Some dams have catwalks which do not provide safe access to gate operating equipment during induced surcharge operation. Studies are underway to determine appropriate corrections. These may include the installation of, or modification to, remote operating equipment and/or other structural modifications. The studies will be completed in October 1987.

- Keystone Powerhouse Stability During High Water

An analysis to determine powerhouse stability and the degree of protection that should be provided to it under high tailwater conditions is in process and scheduled for completion in October 1987. Flooding of the powerhouse would not affect operation of the spillway gates, but would affect power outputs from the dam and be expensive to repair.

A structural analysis of the powerhouse to determine its stability during exceptionally high releases will be completed in October 1987. Preliminary indications are that the structure must be allowed to flood when releases exceed 350,000 cfs. It must be emphasized, however, that the powerhouse concern has no effect on the safety of the dam.

- Satellite Data Collection Backup

For test purposes, telephone modems have been installed at three stations: Tulsa and Sperry, Oklahoma and Winfield, Kansas. These modems allow the District to interrogate data in the event access cannot be made by means of the satellite. An inventory of available telephone lines at key gages has been completed. This backup system is currently undergoing a reliability evaluation. If these test sites are successful and it is determined that backups are required, then modems will be installed at other key gage sites.

- Interim Flooded Area Maps

The Tulsa District has requested funds for the preparation of interim, flooded area (below Keystone Lake) maps, covering a range of Keystone Dam flow releases. Maps will be completed in about a year after funds are received. They will outline the approximate flood area for Arkansas River flows ranging from 170,000 cfs to 480,000 cfs and will include the areas of Bixby, Broken Arrow, Jenks, Tulsa, and Sand Springs, Oklahoma. These maps could be used as guides by the respective communities to develop evacuation plans for various release rates.

The Tulsa District has recommended that an update of the Tulsa Flood Insurance Study be undertaken. This update should include surveys of the existing channel geometry and revised flood frequency studies, taking into account effects of the flood of September-October 1986. Flood frequency studies should include the effects future sedimentation in Kaw and Keystone Lakes will have on various frequency flood releases.

- Flood Control-Bank Protection Measures for Bartlesville

A reconnaissance study is currently underway which will address the flooding problems and potential solutions associated with the Caney River, including the reach through Bartlesville. It is scheduled for completion in May 1988. Two local protection reconnaissance studies specifically for Bartlesville have also been initiated.

Studies of the flood problem on Turkey Creek and flooding in the Kennilworth Addition are scheduled for completion in January 1988 and July 1988, respectively. These studies will define the existing flooding conditions, determine the feasibility of flood prevention measures, develop local cooperation requirements, and estimate construction costs of project development.

- System Operation Plan

The current Arkansas River Basin flood control system operating plan is under review in a joint feasibility study with the states of Oklahoma and Arkansas. The study is being accomplished in two phases. The first phase, expected to be completed in March 1988, is evaluating the taper portion of the plan used to transition from a flood control operation to a normal operation. The second phase will investigate possible changes to the system flood control operation and is scheduled for completion in July 1990.

A meeting of the Arkansas River Basin Coordinating Committee was held in Dallas, Texas on 28 January 1987. This committee is made up of various Federal, state, and local officials having an interest in the Arkansas River system operation. The purpose of this meeting was to discuss the system operating plan, past performance of the plan, and possible changes. The general consensus of the committee was that no changes should be made to the current operating plan until studies under way are completed and a need for change is warranted.

- Purchase of Land Below Oologah Spillway

Land below the spillway gates at Oologah Lake was damaged extensively during the flood. Flowage easements exist over these lands; however, studies are underway to determine the need to purchase additional land in this area. These studies are scheduled to be completed on October 30, 1987.

- Computer Backup System

A water control computer located at the U.S. Army Corps of Engineers, Southwestern Division (SWD) offices in Dallas, Texas will be used as a backup to the water control computer system in the Tulsa District. Steps are currently being taken to (1) make the SWD computer functionally equivalent to the Tulsa District computer, (2) install high speed communication capability between the SWD and Tulsa District water control computers, and (3) install necessary Tulsa District forecasting models and software on the SWD computer. Item 1 will be completed by October 1987, items 2 and 3 will be completed by January 1988.

In the event of a partial breakdown of the Tulsa District water control computer, the SWD computer would be accessible to maintain operations. In the event of complete loss of the Tulsa District computer, the SWD water control computer would still be accessible by using PC terminals.

- Review of Reservoir Regulation Plans for Keystone, Hulah and Copan

Subsequent to the September-October, 1986 flood the Tulsa District has reviewed the approved regulation plans for Keystone, Hulah and Copan.

The approved operating plans were followed during the September-October flood with the exception of the induced surcharge operation at Hulah Dam. The operation at Hulah utilized an additional 2.4 feet of surcharge storage. This operation prevented making large releases when the top of the designated surcharge pool was reached and prevented considerable downstream damages.

The current regulation plans state that no releases will be made if there is downstream flooding occurring or forecasted, unless the flood control storage is full or forecasted to fill. Following the September-October, 1986 flood there was some concern expressed that releases should be made earlier, based on forecasted rainfall, to keep the lakes at a lower level. Such an operation would not be desirable in most instances. Rainfall forecasts are very inaccurate for this area. The exact location, whether the rainfall is concentrated above or below the projects, and the amounts become critical and are unpredictable. Pre-releasing, based on forecasts, would in most cases result in additional damages downstream. For extremely large floods, which exceed the design flood control capability of the projects, the benefits of earlier releases would be minor because of the short time frame available to evacuate flood control storage. There is also concern about liability should releases be made early causing additional damages downstream and no further rainfall occurs or occurs downstream rather than upstream of the projects.

Current regulation plans appear appropriate at this time, however, a feasibility study currently underway for the Arkansas River Basin will investigate possible changes to the reservoir regulation plans.

CHAPTER 8

CONCLUSION

Vivid memories of the flood of September-October 1986 will remain for some time to come. It was an unprecedented, record-breaking event -- the worst flood ever experienced in several areas of northeastern Oklahoma.

The Arkansas River Basin flood control system was pressed to its limit during this flood. Because of physical and economic considerations during design, projects in the system have limited flood control capability. Various lakes fill their flood control storage on an average frequency of once every 10 to 30 years. During this event, 11 lakes equalled or exceeded their flood control capacities. In spite of the magnitude of this flood, the flood control system still provided significant benefits.

Damages resulting from the flood totaled about **$283 million**. Although damages were severe in some locations, it is estimated that the flood control projects prevented damages of about **$725 million**. More importantly, the controlled project releases provided advance warning time and undoubtedly saving many lives. The 1943 flood resulted in the loss of 26 lives. This flood exceeded the 1943 flood in most of the Arkansas River Basin, yet no lives were lost in areas downstream from Corps flood control lakes.

Lessons are to be learned from any experience. The flood of 1986 is no exception. The need for improvement in communications and coordination has been recognized. The Tulsa District has taken action to accomplish these improvements. The District intends to commit available resources to the further enhancement of flood fighting operations so that they may continue to be conducted efficiently, within legal authorities, so that damages and human suffering are minimized.

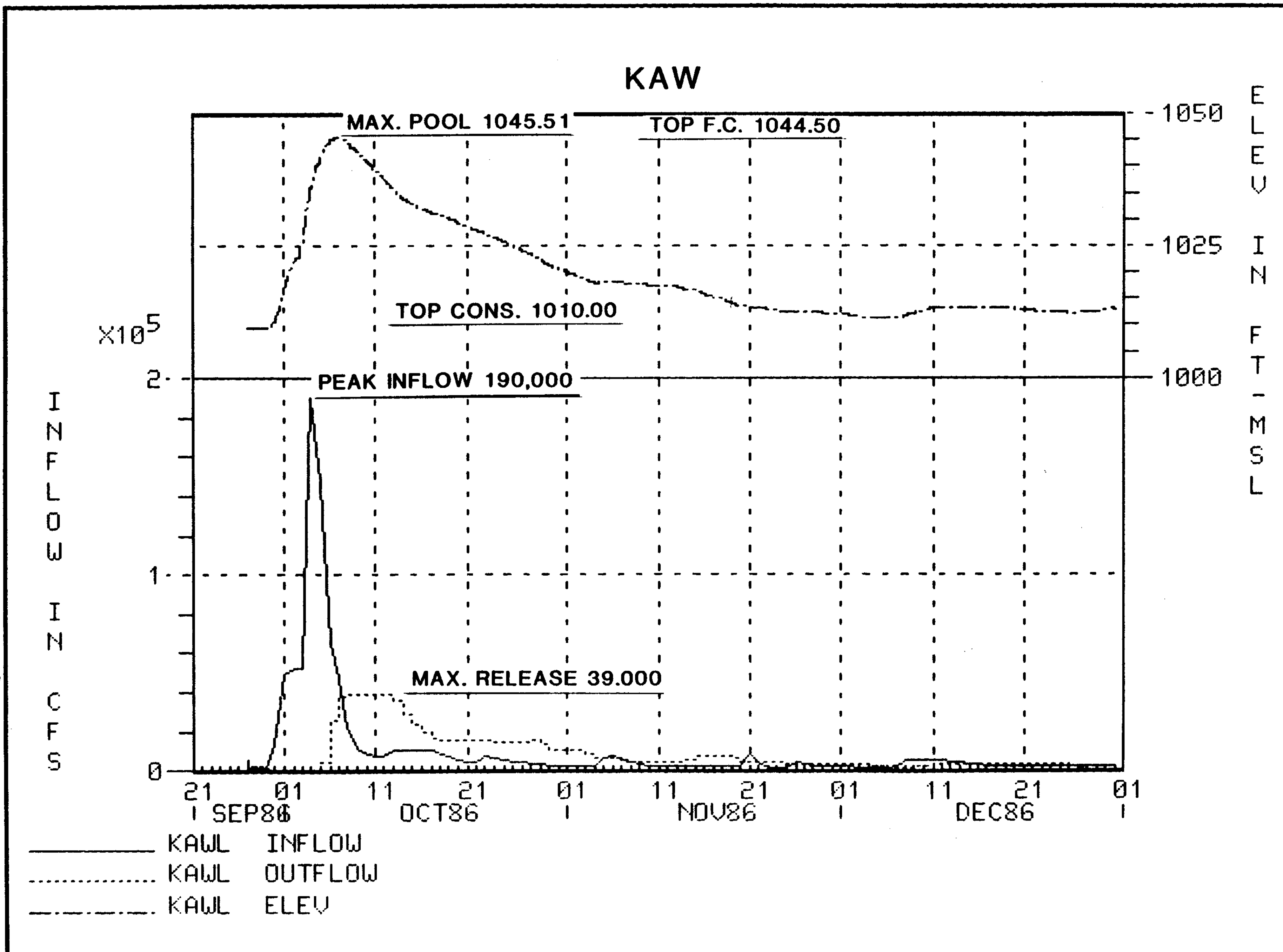
This report should serve as an important management tool to promote better understanding, closer coordination, and improved cooperation for future flood fighting operations.

Questions pertaining to this document may be addressed to:

District Engineer
U.S. Army Corps of Engineers
Tulsa District
P.O. Box 61
Tulsa, OK 74121-0061

APPENDIX A

STAGES AND FLOW RATES



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TOP CONS. 1010.00
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MAX. RELEASE 39.000
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1
0
1050
1025
1000
INFLOW IN CFS
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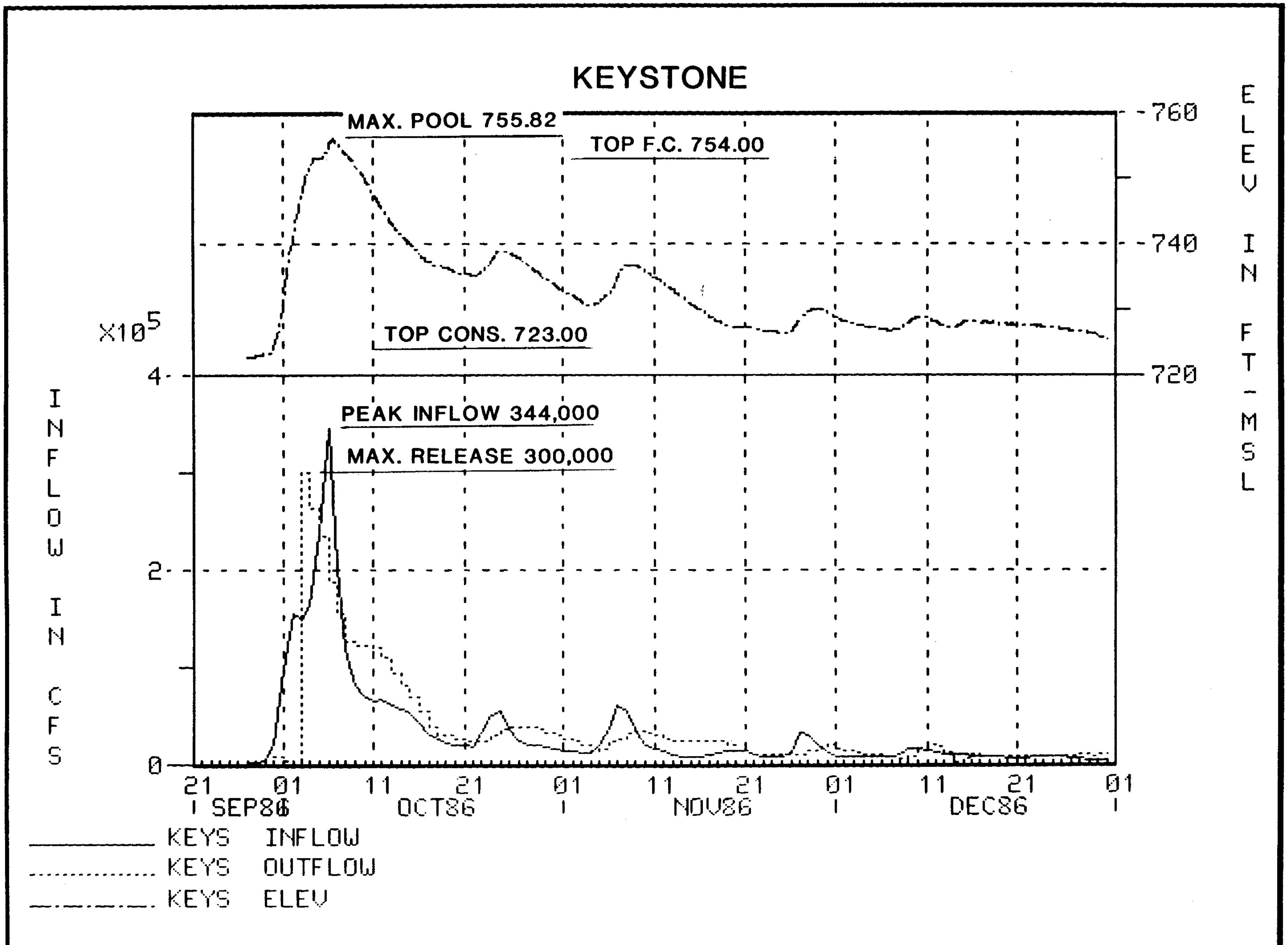
KAWL ELEV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TOP CONS. 723.00
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MAX. RELEASE 300,000
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0
INFLOW IN CFS
760
740
720
ELEV IN FT-MSL
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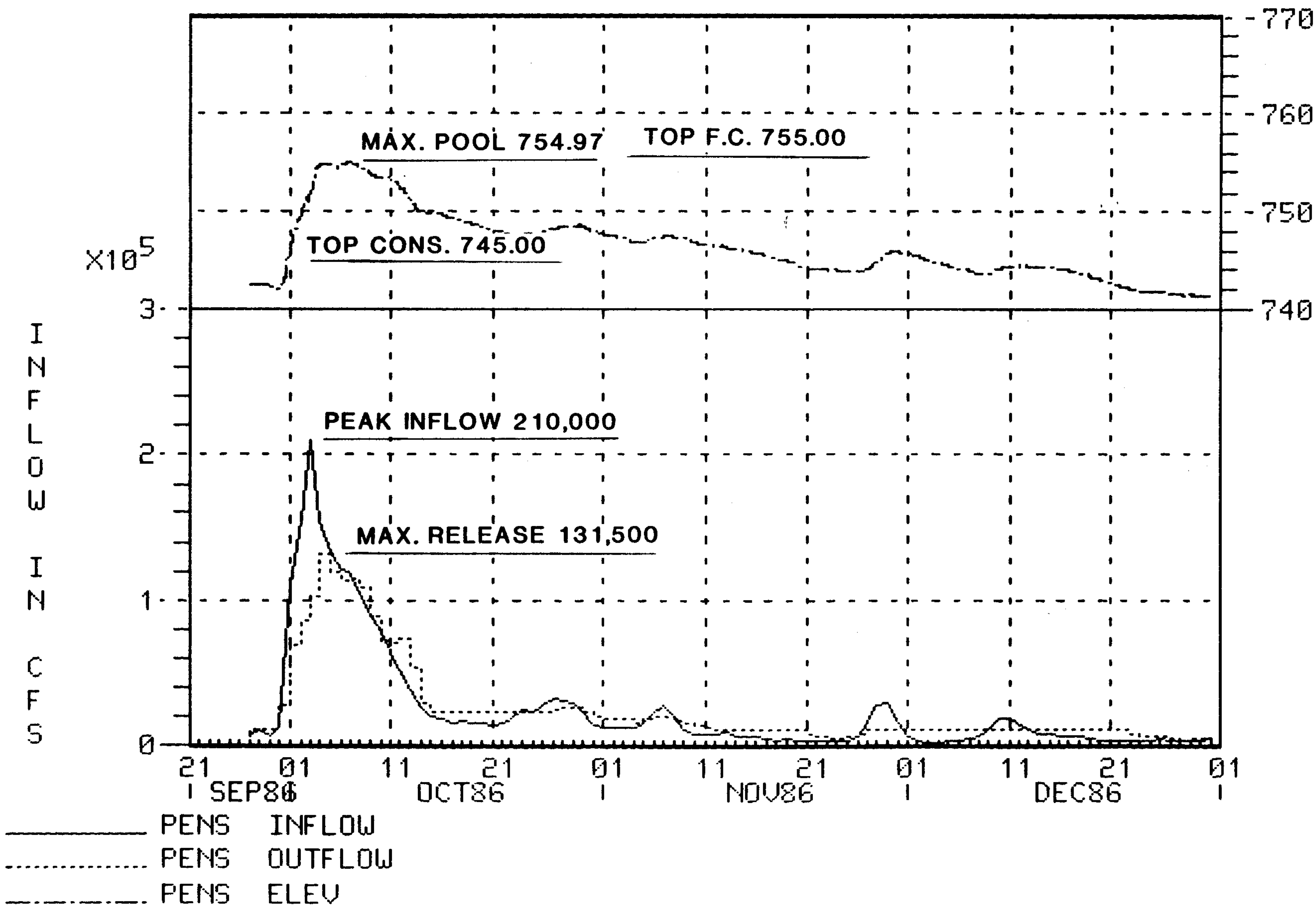
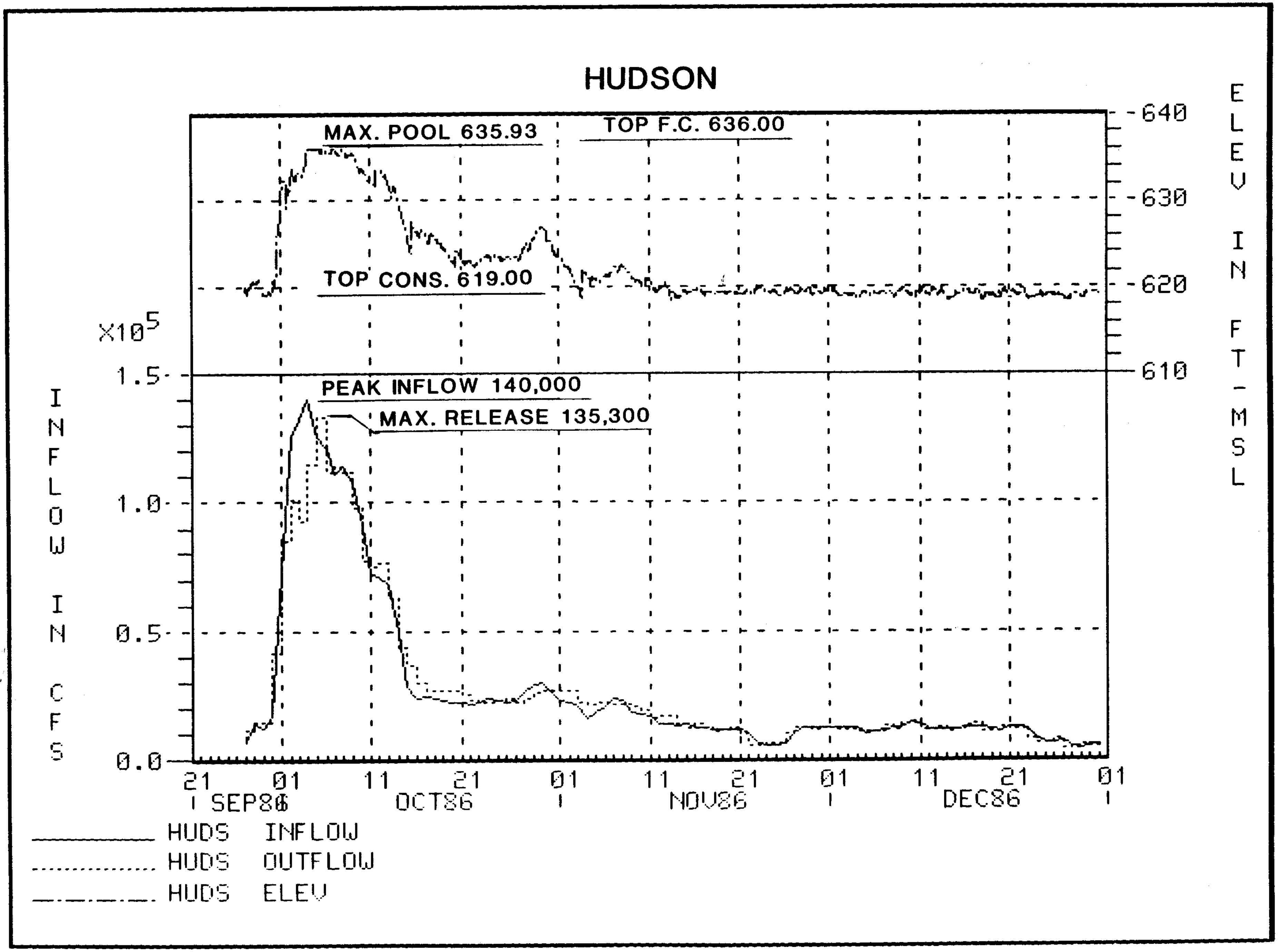
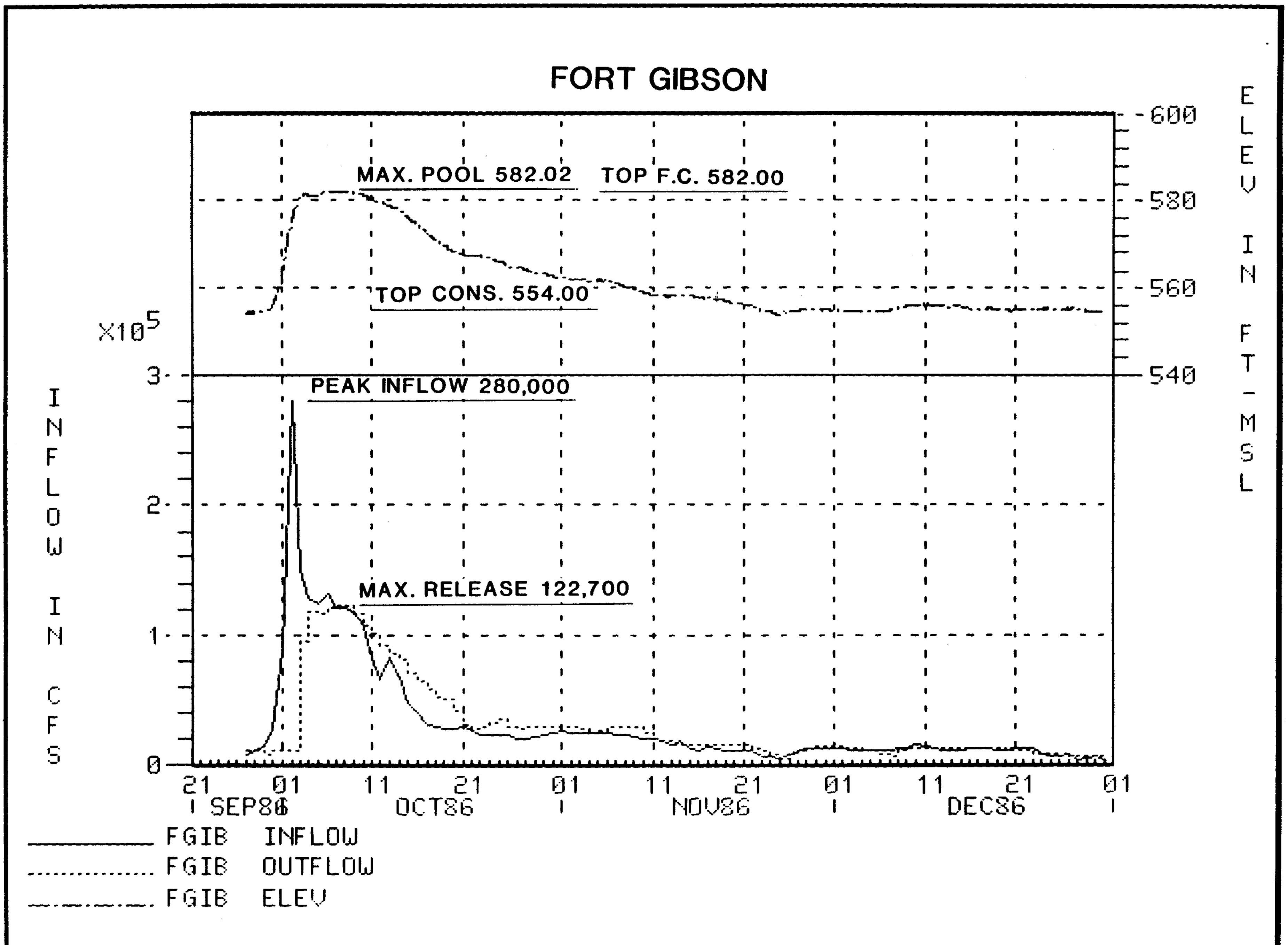
01
11 OCT86
21
01
11 NOV86
21
01
11 DEC86
21
01
KEYS INFLOW
KEYS OUTFLOW
KEYS ELEV

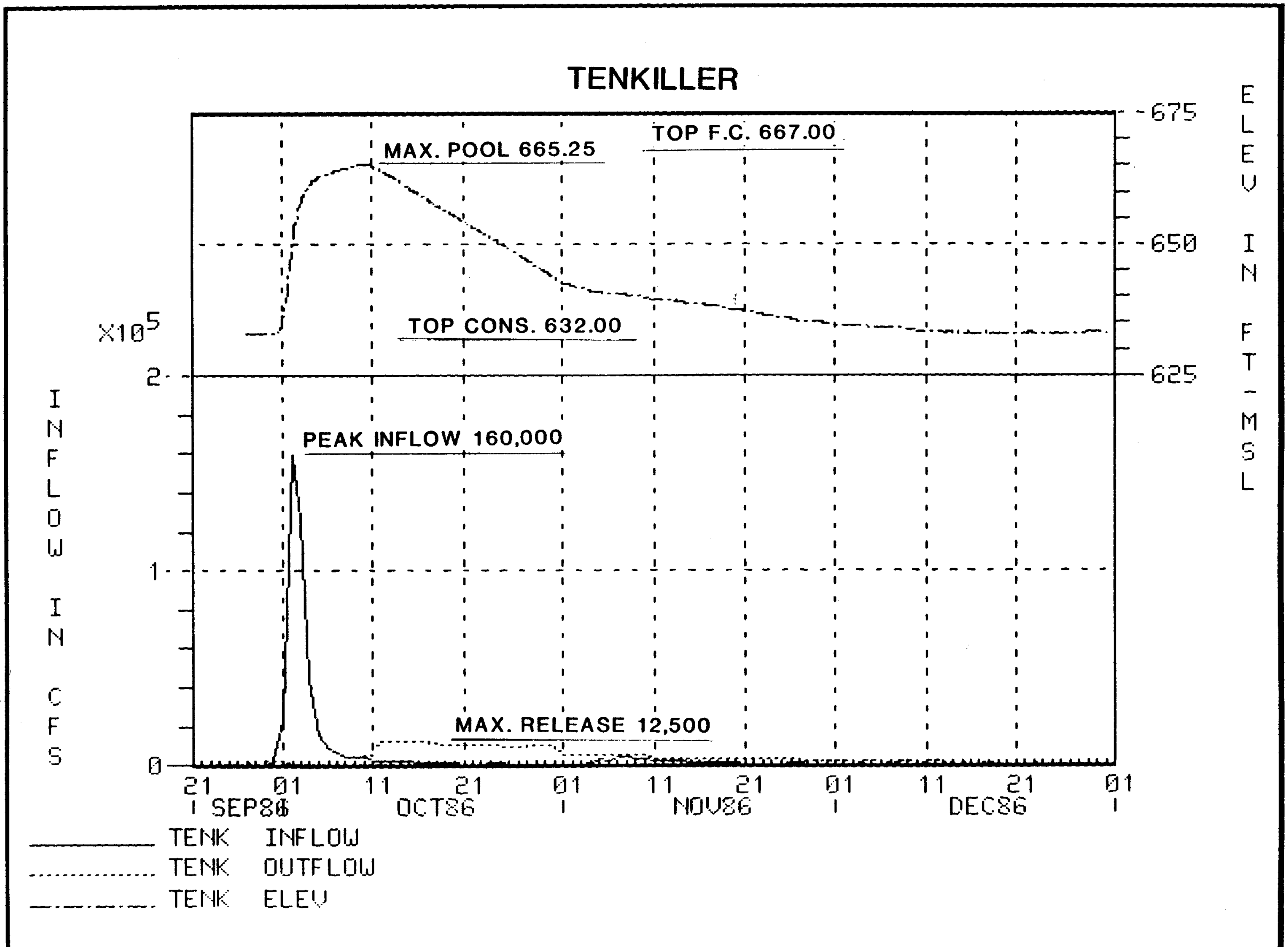
GRAND LAKE



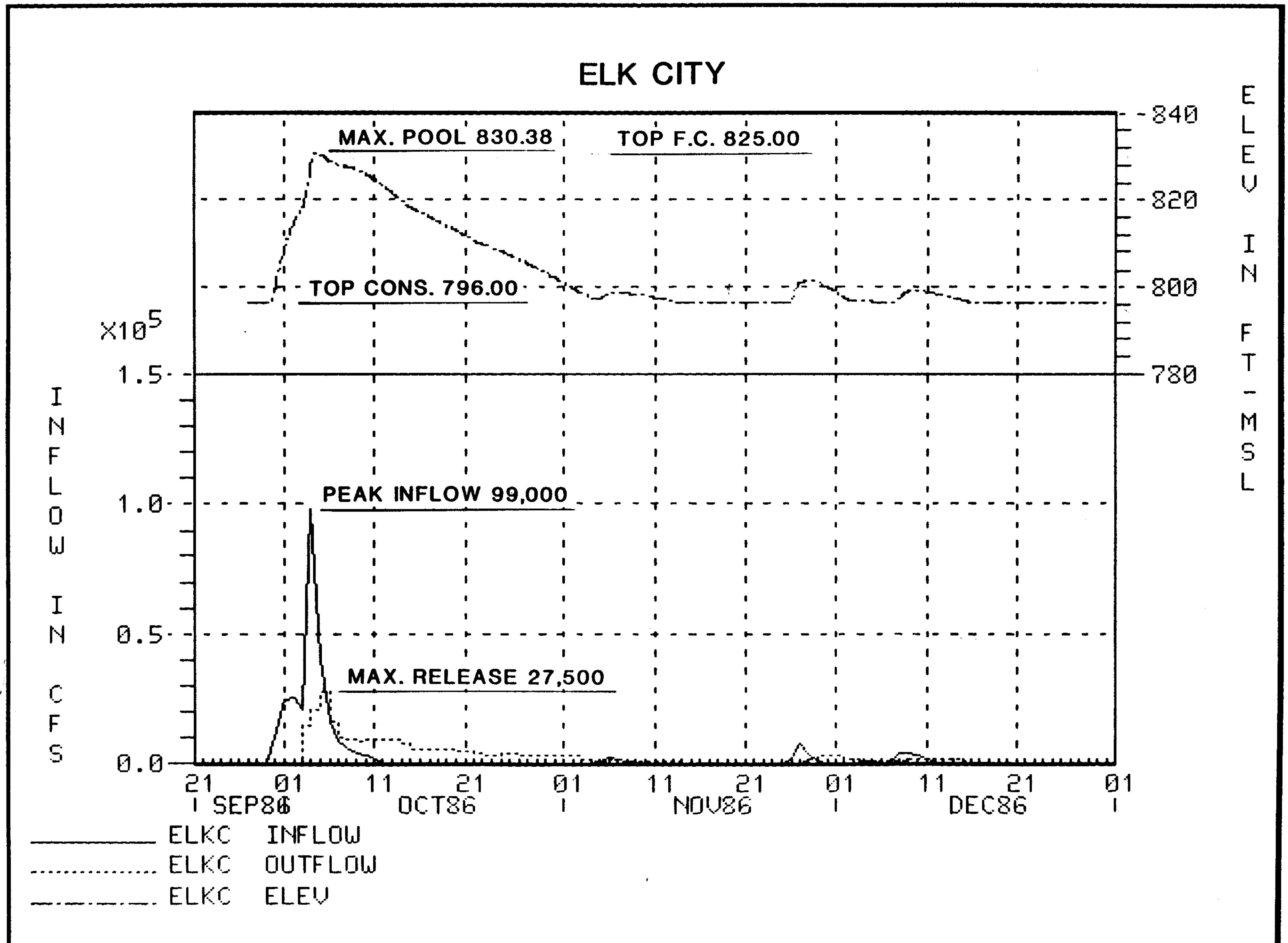
MAX. POOL 754.97
TOP F.C. 755.00
TOP CONS. 745.00
PEAK INFLOW 210,000
MAX. RELEASE 131,500
X10^5
3
2
1
0
INFLOW IN CFS
770
760
750
740
ELEV IN FT-MSL
21 SEP86
01
11 OCT86
21
01
11 NOV86
21
01
11 DEC86
21
01
PENS INFLOW
PENS OUTFLOW
PENS ELEV


HUDSON
MAX. POOL 635.93
TOP F.C. 636.00
TOP CONS. 619.00
PEAK INFLOW 140,000
MAX. RELEASE 135,300
X10^5
1.5
1.0
0.5
0.0
INFLOW IN CFS
640
630
620
610
ELEV IN FT-MSL
21
01
11
21
01
11
21
01
11
21
01
SEP86
OCT86
NOV86
DEC86
HUDS INFLOW
HUDS OUTFLOW
HUDS ELEV

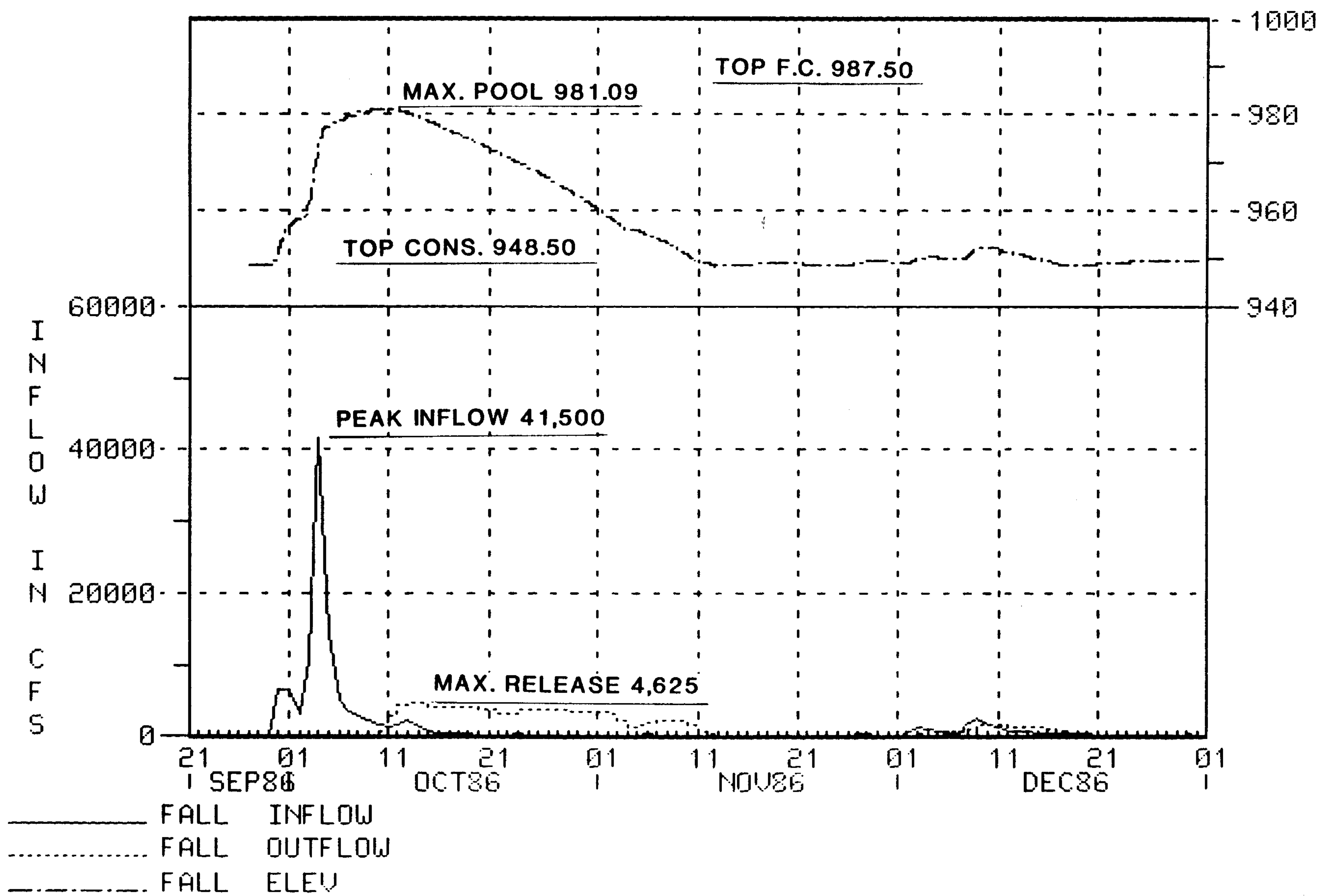

FORT GIBSON
MAX. POOL 582.02
TOP F.C. 582.00
TOP CONS. 554.00
PEAK INFLOW 280,000
MAX. RELEASE 122,700
X10^5
3
2
1
0
600
580
560
540
INFLOW IN CFS
ELEV IN FT-MSL
21
01
11
21
01
11
21
01
11
21
01
SEP86
OCT86
NOV86
DEC86
FGIB INFLOW
FGIB OUTFLOW
FGIB ELEV



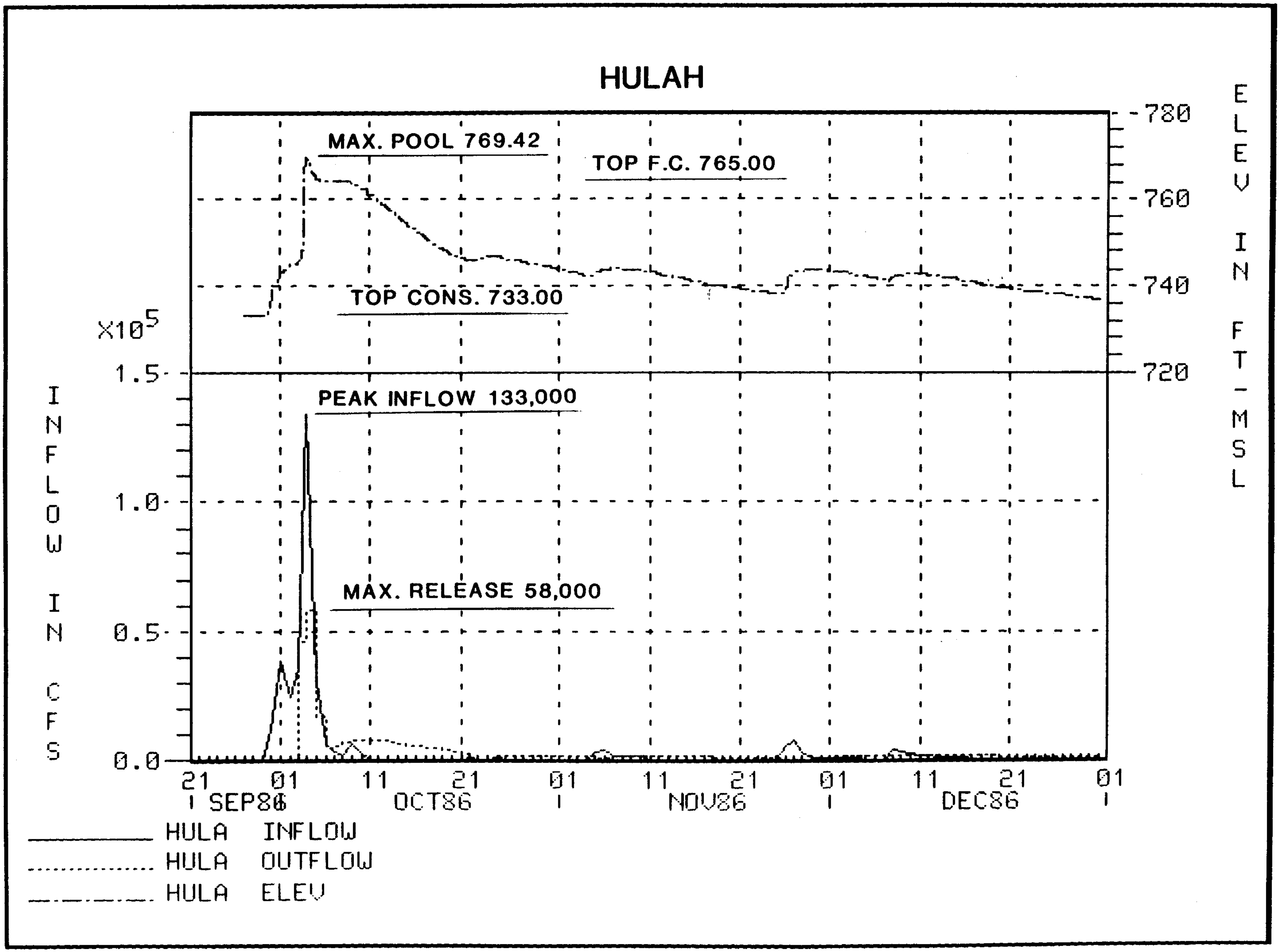
TENKILLER
MAX. POOL 665.25
TOP F.C. 667.00
TOP CONS. 632.00
PEAK INFLOW 160,000
MAX. RELEASE 12,500
X10^5
2
1
0
675
650
625
INFLOW IN CFS
ELEV IN FT-MSL
21 SEP86
01
11 OCT86
21
01
11 NOV86
21
01
11 DEC86
21
01
TENK INFLOW
TENK OUTFLOW
TENK ELEV


ELK CITY
MAX. POOL 830.38
TOP F.C. 825.00
TOP CONS. 796.00
PEAK INFLOW 99,000
MAX. RELEASE 27,500
X10^5
1.5
1.0
0.5
0.0
INFLOW IN CFS
840
820
800
780
ELEV IN FT-MSL
21 SEP86
01
11
21 OCT86
01
11
21 NOV86
01
11
21 DEC86
01
ELKC INFLOW
ELKC OUTFLOW
ELKC ELEV

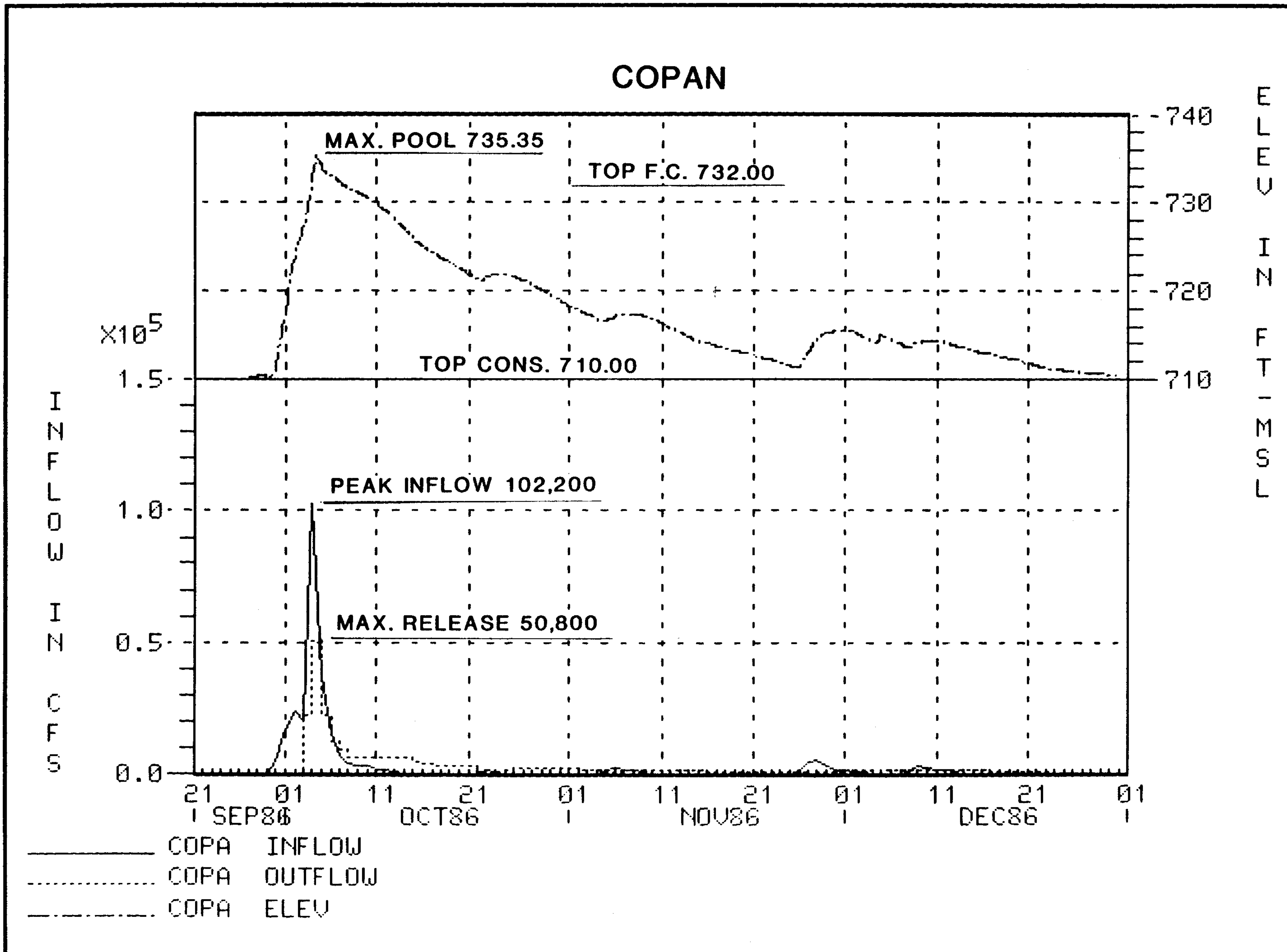
FALL RIVER



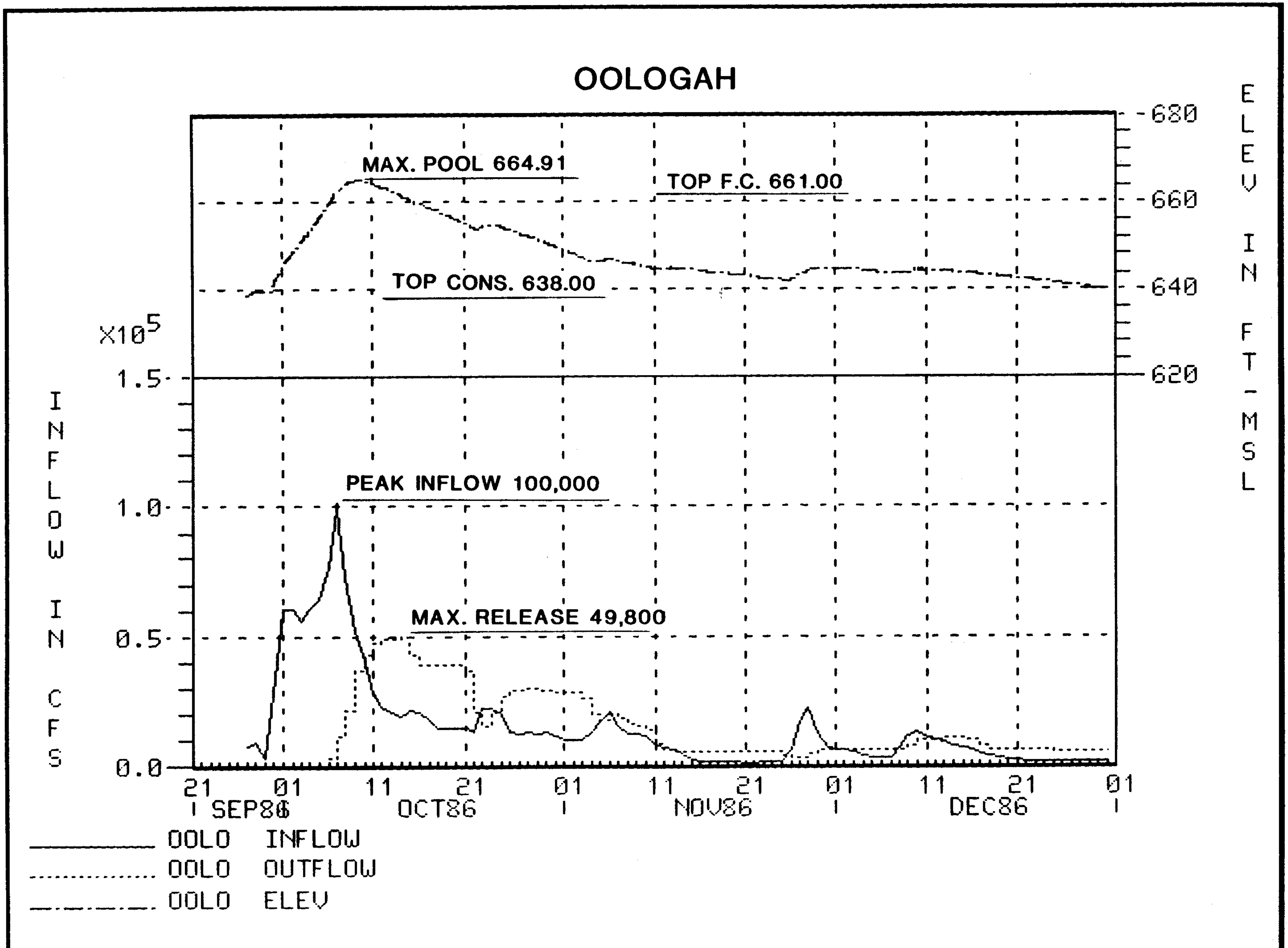
MAX. POOL 981.09
TOP F.C. 987.50
TOP CONS. 948.50
PEAK INFLOW 41,500
MAX. RELEASE 4,625
INFLOW IN CFS
ELEV IN FT-MSL
60000
40000
20000
0
1000
980
960
940
21
01
11
21
01
11
21
01
11
21
01
SEP86
OCT86
NOV86
DEC86
FALL INFLOW
FALL OUTFLOW
FALL ELEV



HULAH
MAX. POOL 769.42
TOP F.C. 765.00
TOP CONS. 733.00
PEAK INFLOW 133,000
MAX. RELEASE 58,000
X10^5
1.5
1.0
0.5
0.0
INFLOW IN CFS
780
760
740
720
ELEV IN FT-MSL
21 SEP86 01 11 OCT86 21 01 11 NOV86 21 01 11 DEC86 21 01
HULA INFLOW
HULA OUTFLOW
HULA ELEV

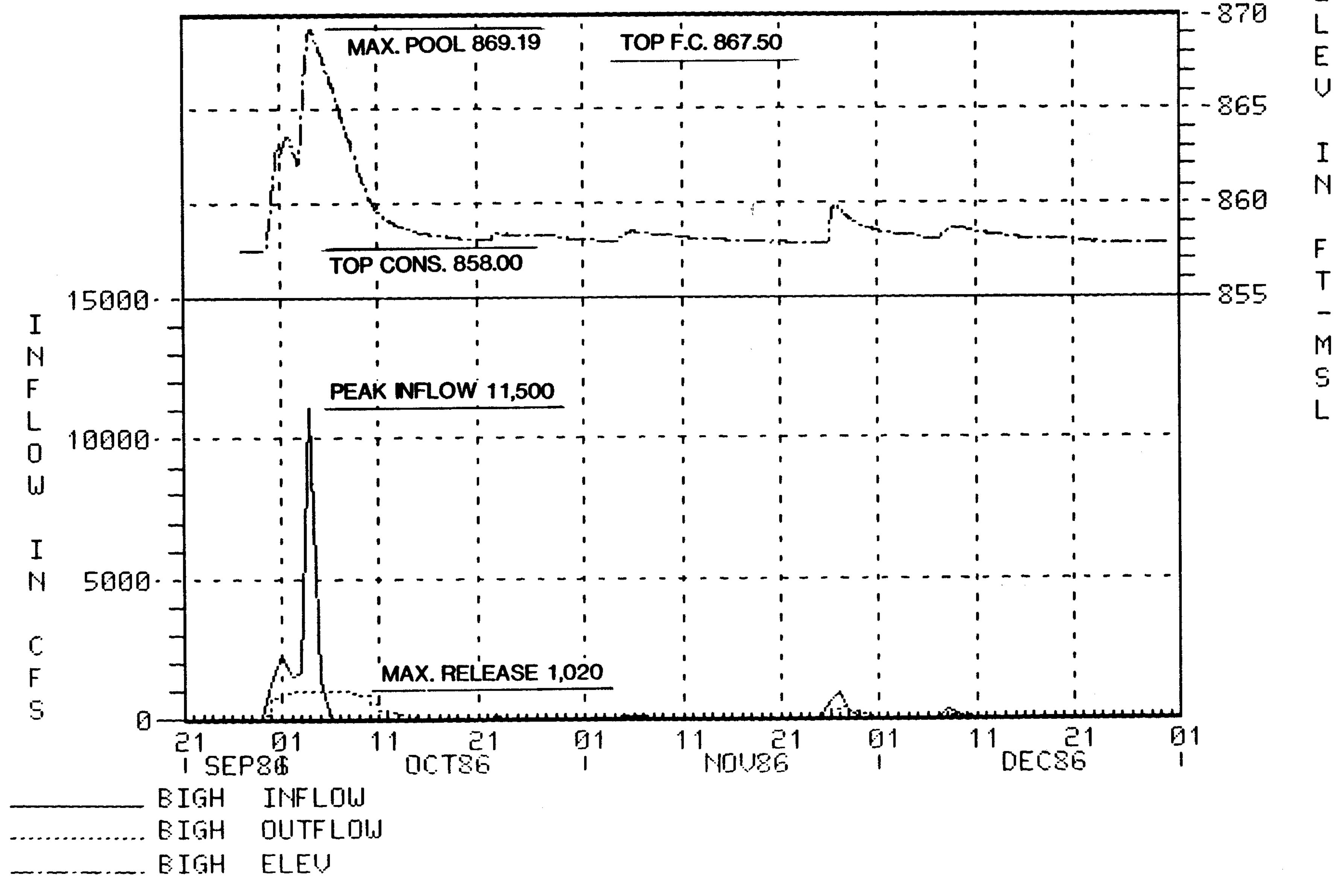


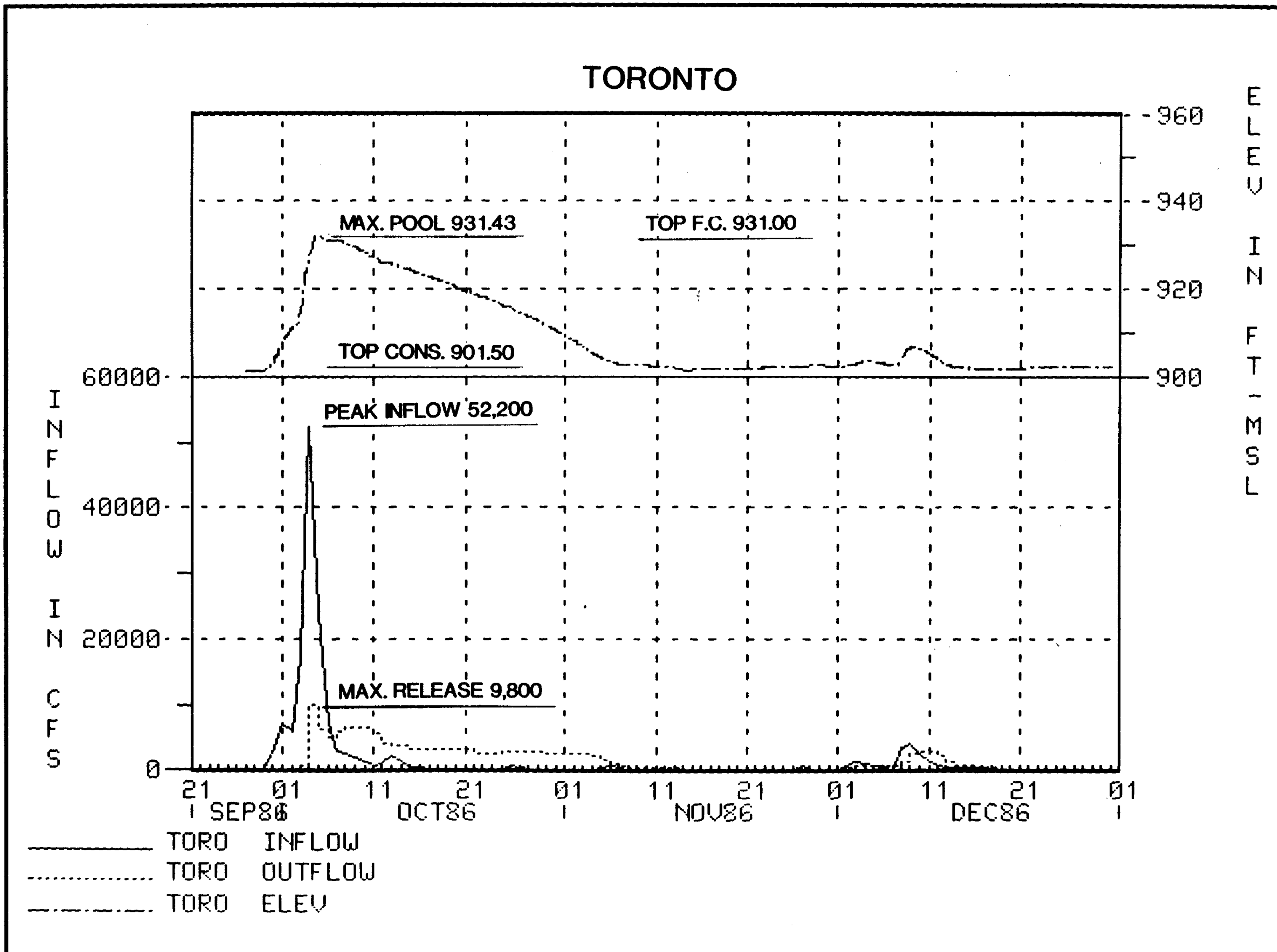
COPAN
MAX. POOL 735.35
TOP F.C. 732.00
TOP CONS. 710.00
PEAK INFLOW 102,200
MAX. RELEASE 50,800
X10^5
1.5
1.0
0.5
0.0
INFLOW IN CFS
740
730
720
710
ELEV IN FT-MSL
21
01
11
21
01
11
21
01
11
21
01
SEP86
OCT86
NOV86
DEC86
COPA INFLOW
COPA OUTFLOW
COPA ELEV

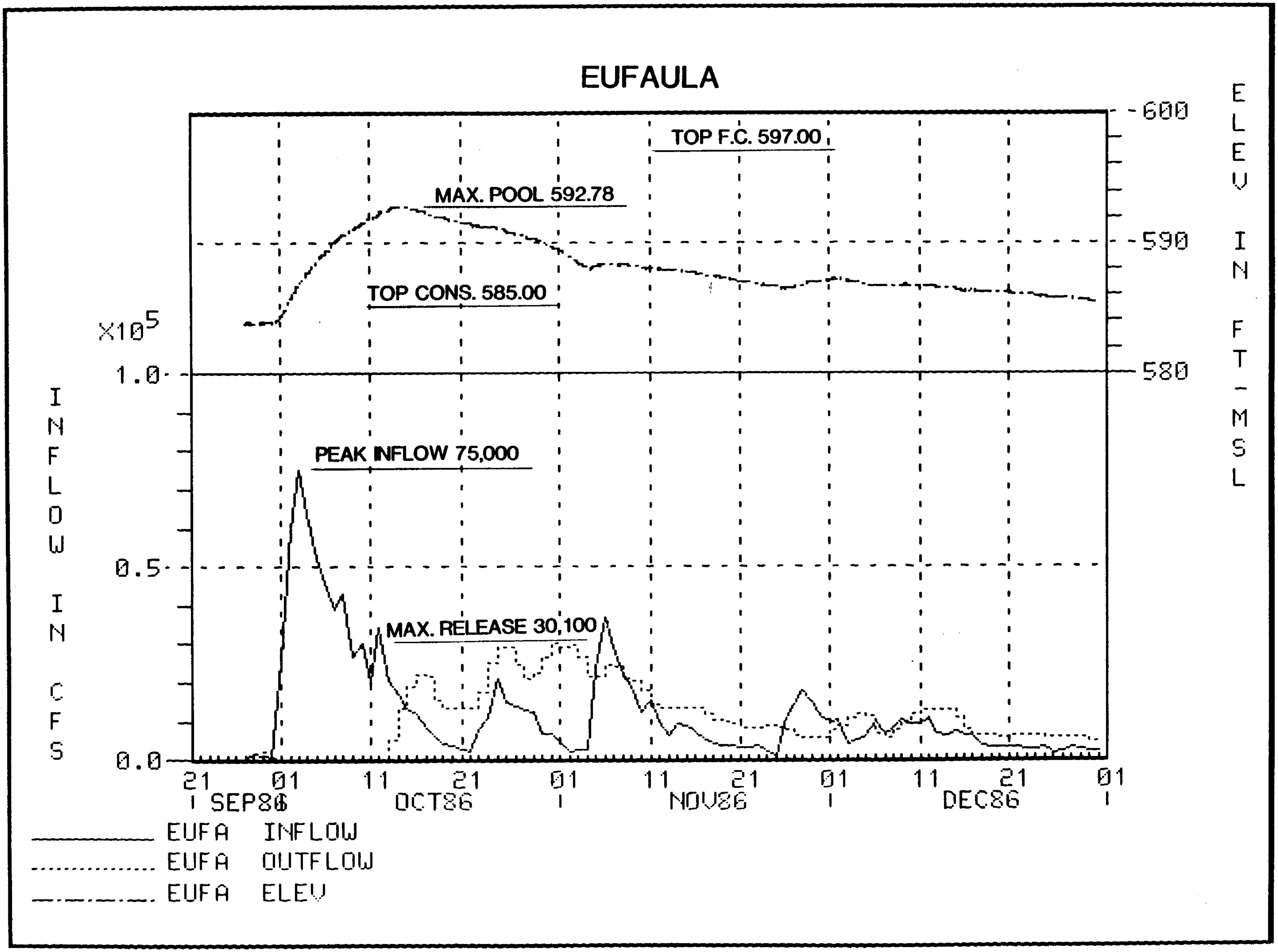


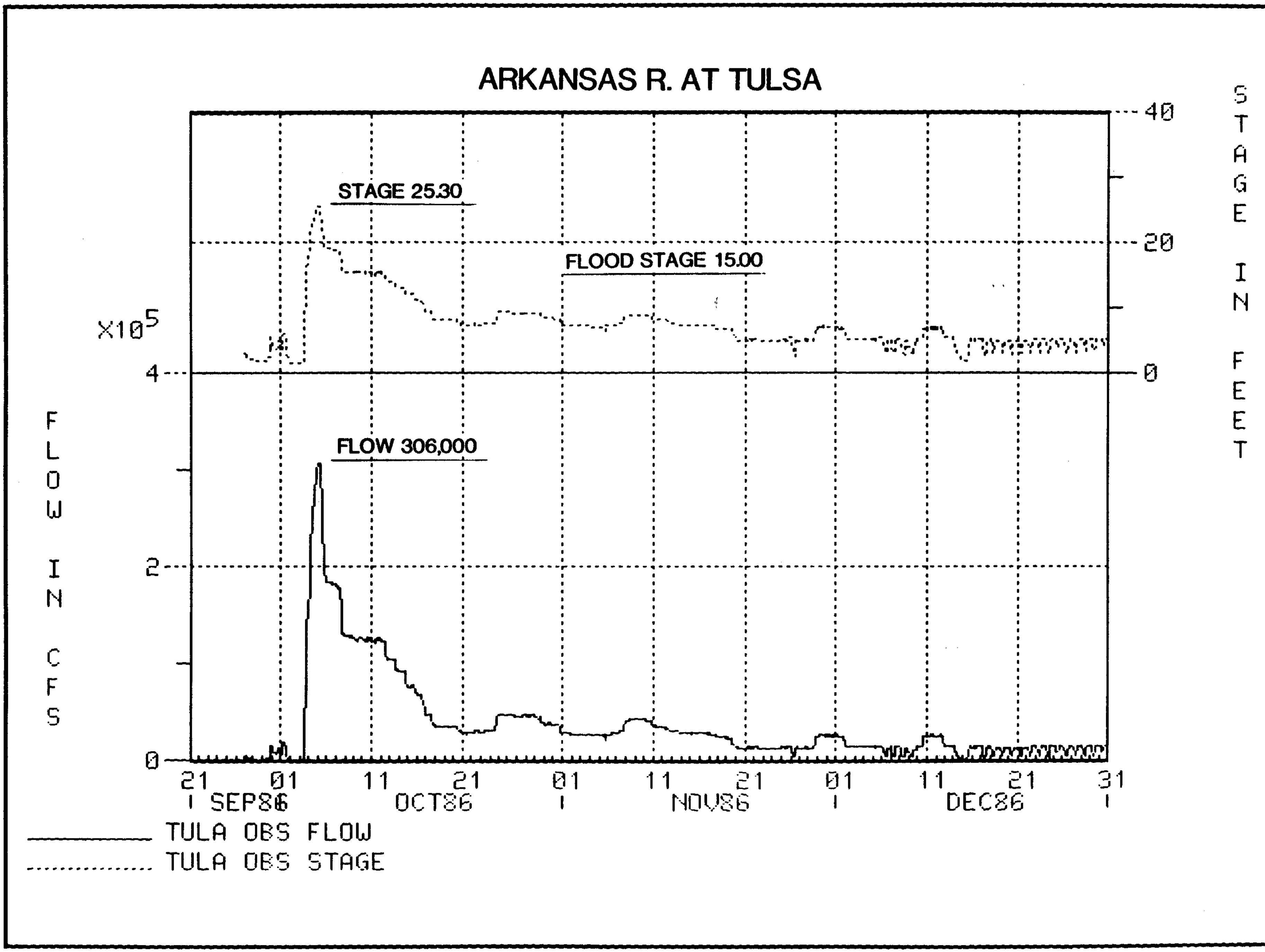
OOLOGAH
MAX. POOL 664.91
TOP F.C. 661.00
TOP CONS. 638.00
PEAK INFLOW 100,000
MAX. RELEASE 49,800
X10^5
1.5
1.0
0.5
0.0
INFLOW IN CFS
680
660
640
620
ELEV IN FT-MSL
21 SEP86 01 11 OCT86 21 01 11 NOV86 21 01 11 DEC86 21 01
OOLO INFLOW
OOLO OUTFLOW
OOLO ELEV

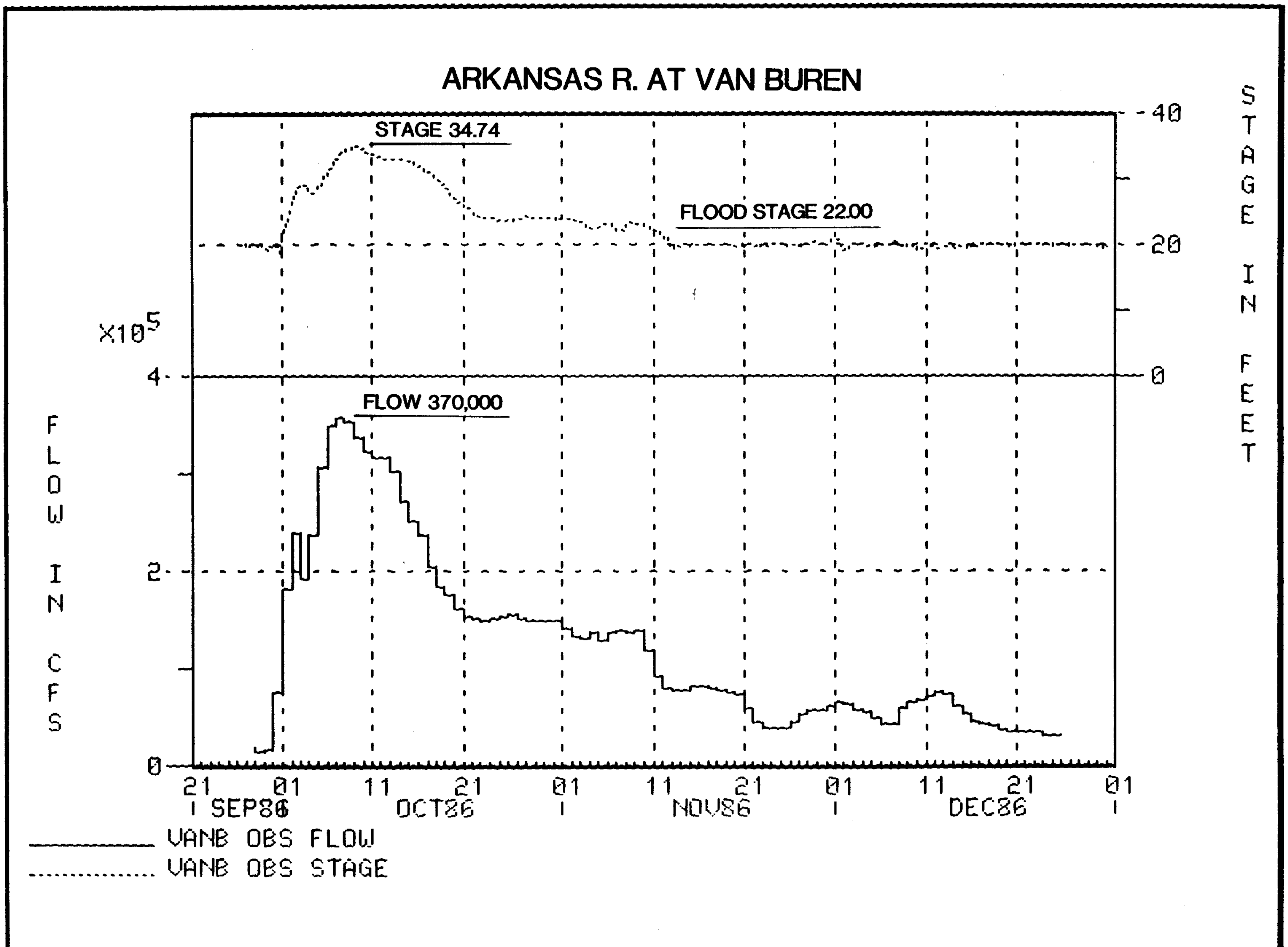
PEARSON-SKUBITZ BIG HILL

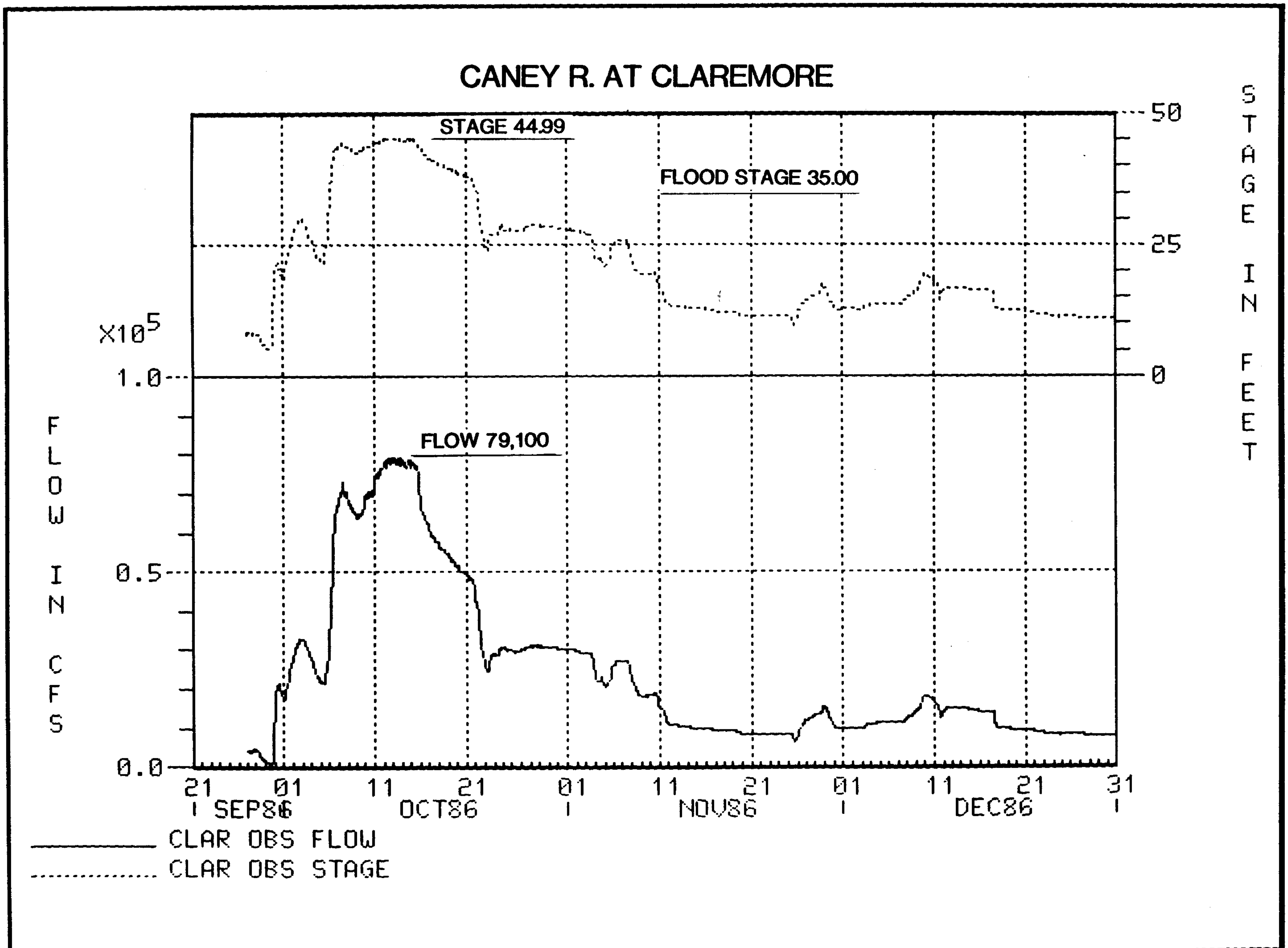


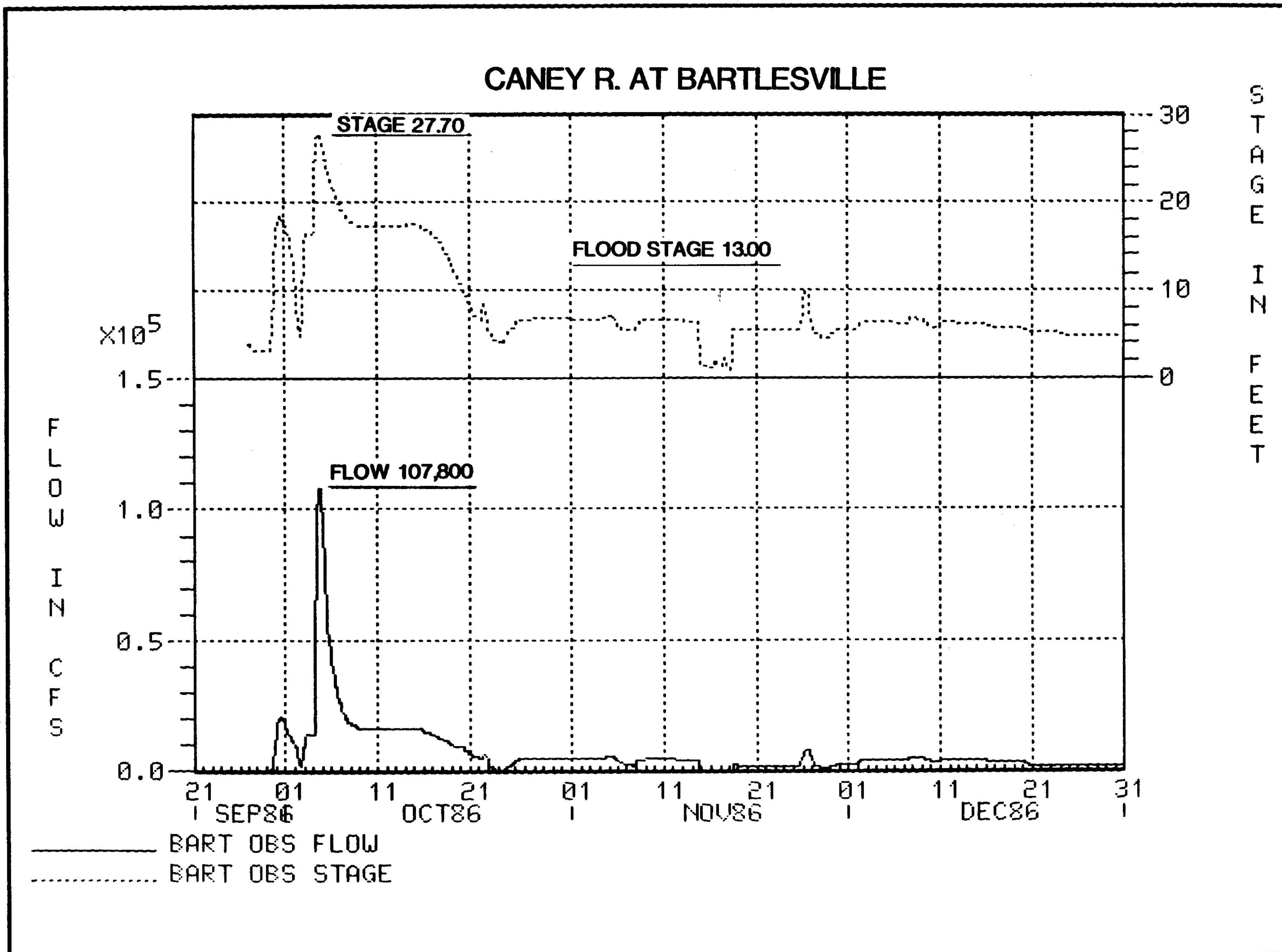

TORONTO
MAX. POOL 931.43
TOP F.C. 931.00
TOP CONS. 901.50
PEAK INFLOW 52,200
MAX. RELEASE 9,800
960
940
920
900
ELEV IN FT-MSL
60000
40000
20000
0
INFLOW IN CFS
21 01 11 21 01 11 21 01 11 21 01
SEP86 OCT86 NOV86 DEC86
TORO INFLOW
TORO OUTFLOW
TORO ELEV


EUFAULA
TOP F.C. 597.00
MAX. POOL 592.78
TOP CONS. 585.00
PEAK INFLOW 75,000
MAX. RELEASE 30,100
X10^5
1.0
0.5
0.0
INFLOW IN CFS
600
590
580
ELEV IN FT-MSL
21 SEP86
01
11 OCT86
21
01
11 NOV86
21
01
11 DEC86
21
01
EUFA INFLOW
EUFA OUTFLOW
EUFA ELEV

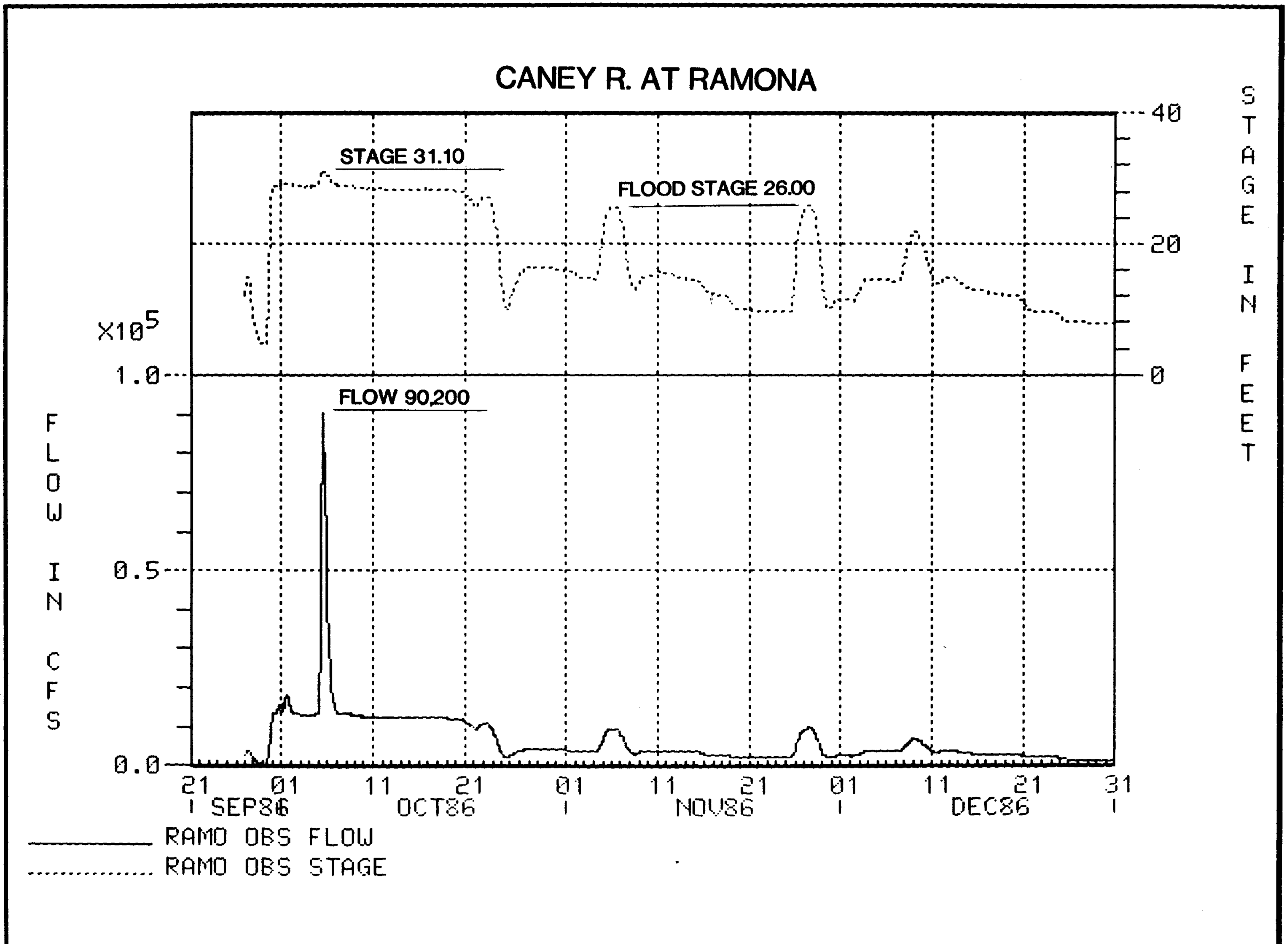

ARKANSAS R. AT TULSA
STAGE 25.30
FLOOD STAGE 15.00
FLOW 306,000
X10^5
FLOW IN CFS
STAGE IN FEET
0
2
4
20
40
21 SEP86
01
11 OCT86
21
01
11 NOV86
21
01
11 DEC86
21
31
TULA OBS FLOW
TULA OBS STAGE

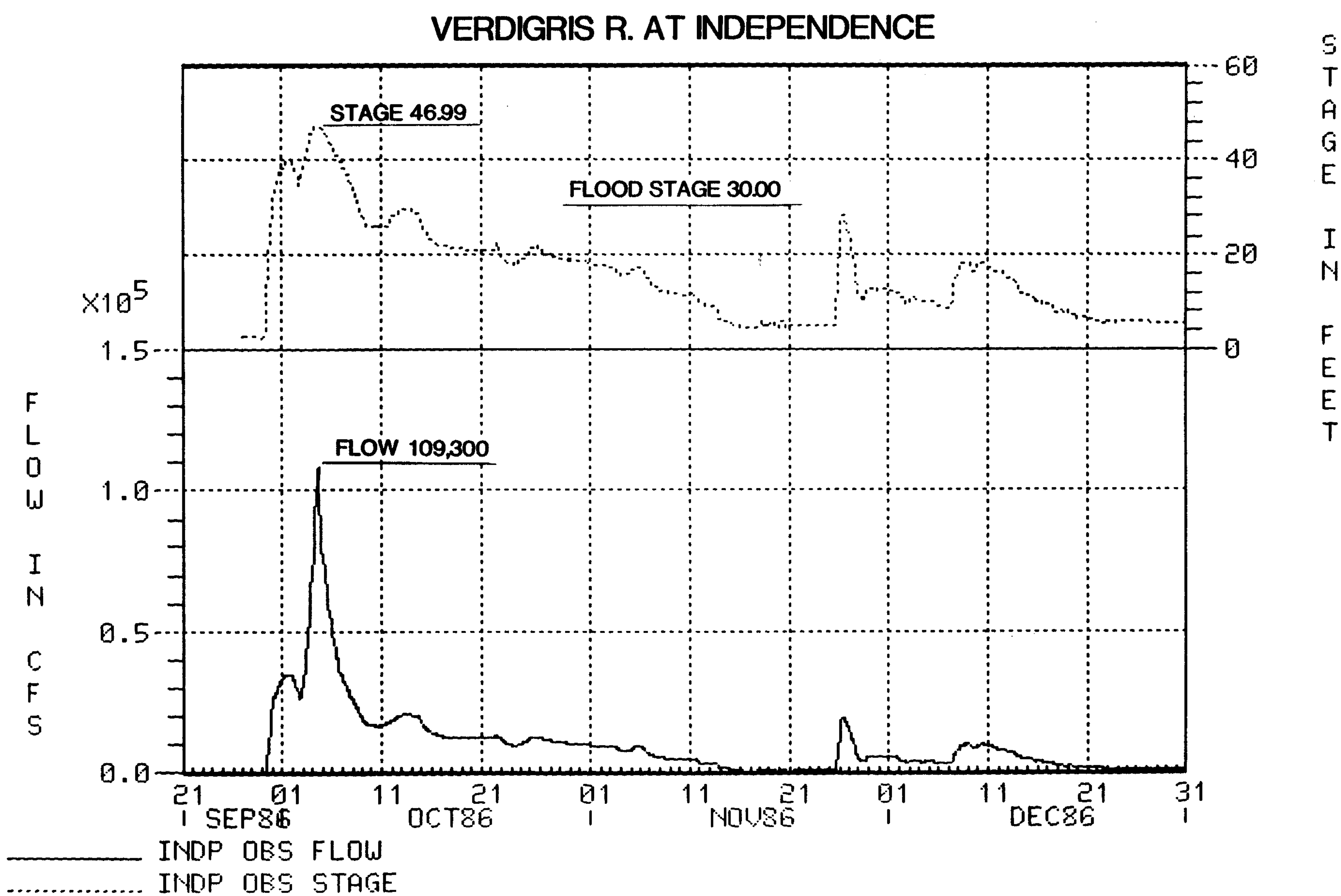

ARKANSAS R. AT VAN BUREN
STAGE 34.74
FLOOD STAGE 22.00
FLOW 370,000
X10^5
4
2
0
40
20
0
FLOW IN CFS
STAGE IN FEET
21 01 11 21 01 11 21 01 11 21 01
SEP86 OCT86 NOV86 DEC86
VANB OBS FLOW
VANB OBS STAGE


CANEY R. AT CLAREMORE
STAGE 44.99
FLOOD STAGE 35.00
FLOW 79,100
X10^5
1.0
0.5
0.0
FLOW IN CFS
STAGE IN FEET
50
25
0
21 SEP86
01
11 OCT86
21
01
11 NOV86
21
01
11 DEC86
21
31
CLAR OBS FLOW
CLAR OBS STAGE



CANEY R. AT BARTLESVILLE
STAGE 27.70
FLOOD STAGE 13.00
FLOW 107,800
FLOW IN CFS
X10^5
1.5
1.0
0.5
0.0
STAGE IN FEET
30
20
10
0
21
01
11
21
01
11
21
01
11
21
31
SEP86
OCT86
NOV86
DEC86
BART OBS FLOW
BART OBS STAGE


CANEY R. AT RAMONA
STAGE 31.10
FLOOD STAGE 26.00
FLOW 90,200
X10^5
1.0
0.5
0.0
FLOW IN CFS
40
20
0
STAGE IN FEET
21 SEP86
01
11 OCT86
21
01
11 NOV86
21
01
11 DEC86
21
31
RAMO OBS FLOW
RAMO OBS STAGE


VERDIGRIS R. AT INDEPENDENCE
STAGE 46.99
FLOOD STAGE 30.00
FLOW 109,300
X10^5
1.5
1.0
0.5
0.0
FLOW IN CFS
60
40
20
0
STAGE IN FEET
21
01
11
21
01
11
21
01
11
21
31
SEP86
OCT86
NOV86
DEC86
INDP OBS FLOW
INDP OBS STAGE

APPENDIX B

AERIAL PHOTOGRAPHS OF

FLOOD AREAS AND FLOOD PROFILES

(Bound Separately)