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.