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Briefing Report to the Chairman, Subcommittee on Environment, Energy, and Natural Resources, Committee on Government Operations, House of Representatives

July 1987

WATER RESOURCES

Corps of Engineers Management of 1986 Flooding in Northeastern Oklahoma

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Resources, Community, and
Economic Development Division

B-221499

July 17, 1987

The Honorable Mike Synar
Chairman, Subcommittee on
Environment, Energy, and
Natural Resources
Committee on Government Operations
House of Representatives

Dear Mr. Chairman:

In response to your October 8, 1986, letter and subsequent discussions with your office, this briefing report provides information on the efforts of the Corps of Engineers to deal with the flooding that occurred in September and October of 1986 in northeastern Oklahoma. Specifically, it addresses (1) whether the Corps released water from its reservoirs in accordance with its operating procedures, (2) whether a July 1, 1986, modification to the Arkansas River Basin Operating Plan adversely affected the flooding, (3) the weather and flooding forecast responsibilities of the Corps and other entities, and the accuracy of predictions of the rate at which water flowed (inflow) into the Keystone Reservoir, (4) the problems with the river gauges used in calculating inflow into Keystone Reservoir, (5) the accuracy of flood warnings for the Brookside area of Tulsa and the town of Bartlesville, (6) the communication of water release information by the Corps to state and local entities, and (7) the post-flood evaluations conducted by Corps management, the Department of the Army, and other agencies.

The record-level rainfall that dumped up to 19 inches of water during 7 days in late September and early October 1986 caused significant flooding, ruined homes and businesses, and devastated agriculture. The area's weather is historically characterized by severe thunderstorms, tornadoes, and flash flooding. To help control flooding, the Corps of Engineers operates 37 projects (11 in and around the Tulsa area) in the Arkansas River Basin, which includes parts of 7 states.

In summary, the Corps followed its operating procedures for releasing floodwaters from the reservoirs, although problems in such areas as forecasting and communications arose during the flooding. The Corps has undertaken initiatives to address these problems. Among our specific observations are the following:

-- The Corps of Engineers' Tulsa District followed its operating procedures for releasing water from the Hulah, Copan, and Keystone reservoirs, which directly affected the amount of flooding in the cities of Bartlesville and Tulsa.

-- The July 1986 modification to the Corps' operating plan regarding releases of water from the flood control storage pools in 11 reservoirs did not adversely affect the flooding because it was not invoked until November 11, 1986.

-- The Corps' prediction of inflow into the Keystone Reservoir above Tulsa was 53 percent below the actual amount. The Corps' low estimate was caused for the most part by inaccuracies in its computer model. However, the Corps did not base its decision to release water from the reservoir on its prediction. Instead, it used a National Weather Service forecast of a much heavier inflow which was very near the actual amount. The Corps is updating its computer model and, in the long term, will use a more advanced weather radar system currently being developed.

-- Many river gauges malfunctioned or were damaged during the flooding, including the two gauges that provide river stage (height) readings for calculating inflow into the Keystone Reservoir. However, this had minimal impact because the U.S. Geological Survey personnel stationed at both gauges took manual measurements, and according to the Corps, provided the information needed to help in regulating the gates at Keystone.

-- Predicted flooding did not materialize for the Brookside area of Tulsa because water released from the Keystone Reservoir flowed with such force that it deepened the river channel, which was then able to hold more water than usual. The flooding forecasted for Bartlesville arrived later than predicted because water released from the Hulah and Copan reservoirs spilled out over river banks and spread out over the land instead of flowing directly to Bartlesville.

-- Both the Corps and the state of Oklahoma are responsible for notifying local entities of impending floods, but their written guidance did not spell out notification procedures when flooding may be caused by the Corps' release of reservoir water. Therefore, there was some confusion about the Corps' notification responsibility. In April 1987, the Corps revised its procedures to require that water release information be provided to state and local entities.

-- The Corps' December 1986 post-flood evaluation report spelled out 22 areas needing improvement and covered engineering, coordination, and personnel matters. The report said that some recommendations have been implemented and that others will be implemented in the future. The Federal Emergency Management Agency and the state of Oklahoma also completed post-flood evaluations. Among the areas they identified as needing corrective action are (1) establishing a central inter-regional, interagency media information center and (2) maintaining sets of floodplain boundary maps. In addition, the Corps inspected the 11 dams after the flood and noted no major structural deficiencies.

To obtain this information, we interviewed Corps officials in Washington, D.C.; Dallas, Texas; and Tulsa. We reviewed various documents relating to the weather forecasts, the operation of the reservoirs, the notification activities of the Corps during the flooding, and the post-flood evaluation reports. As agreed, we did not review the adequacy of the Corps' reservoir operating procedures. We also interviewed U.S. Geological Survey officials in Oklahoma City, National Weather Service officials in Norman and Tulsa, Oklahoma officials, Bartlesville officials, and Tulsa city and county officials concerning their actions during the flooding, and we reviewed documents relating to their activities. We also met with National Weather Service officials in Washington, D.C., to obtain information on a new weather forecasting system under development. As agreed with your office, we did not request official comments from the Corps. We conducted our work between October 1986 and June 1987 in accordance with generally accepted government auditing standards.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. At that time, we will send copies to the Secretary of Defense and other interested parties. If you have any questions regarding the attached information, please call me at (202) 275-7756. Major contributors to this report are listed in appendix I.

Sincerely yours,

James Duffus III

James Duffus III
Associate Director

Contents

SECTION 1
THE SEPTEMBER TO OCTOBER 1986 FLOOD

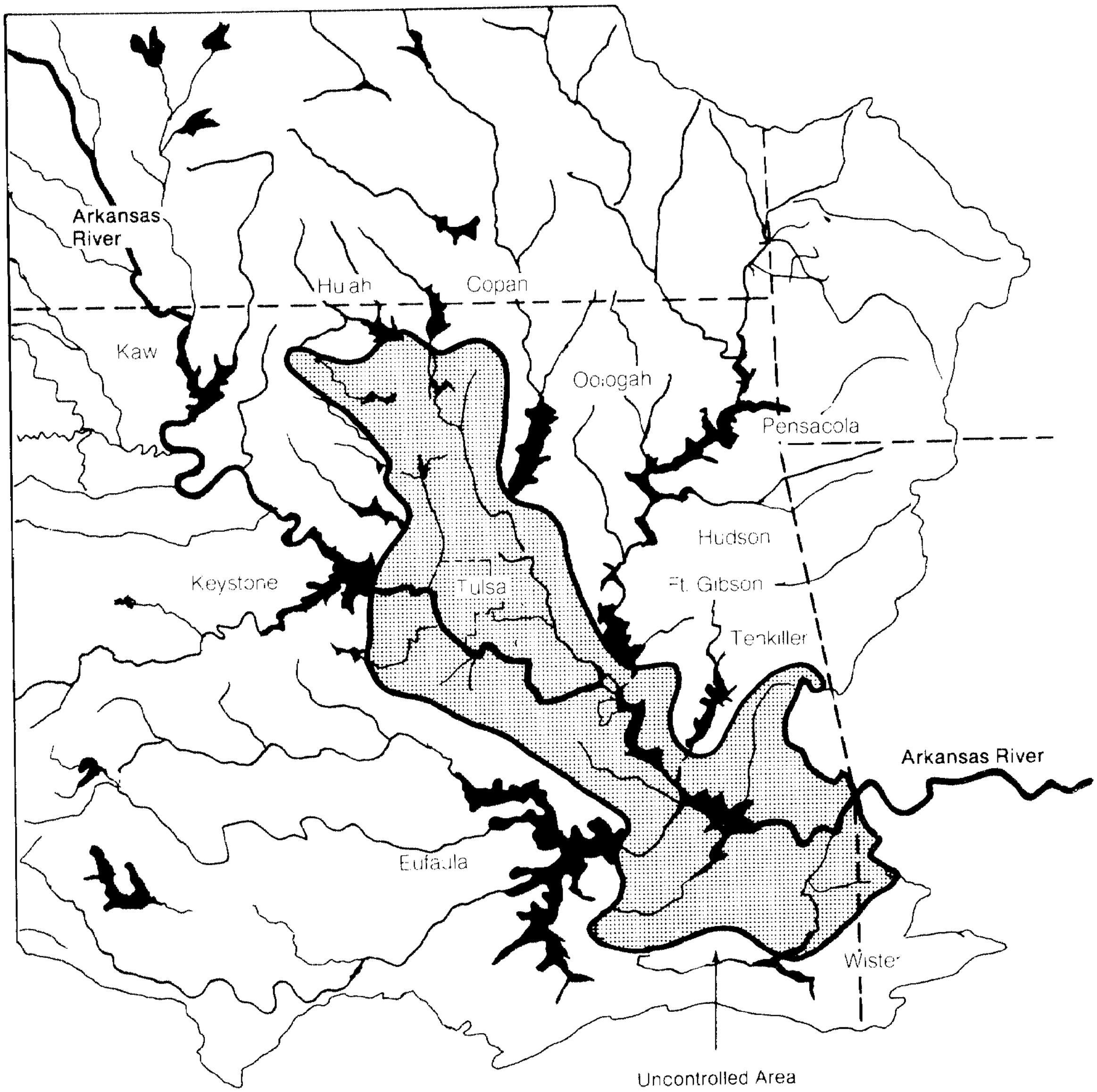
THE ARKANSAS RIVER BASIN

Question. Where is the Arkansas River Basin, and how many flood control projects does the Corps operate within it?

Response. The Arkansas River Basin covers parts of seven states, including most of Oklahoma and Kansas. (See fig. 1.1.) In addition to the main stem of the Arkansas River, basin tributaries include other large rivers such as the Verdigris, Illinois, and Grand. The basin contains 37 projects operated by the Corps' Tulsa district.

Fig. 1.2 shows the location of the 11 major Corps reservoirs in the Arkansas River Basin that are located in the area where most of the severe flooding occurred. The shaded area is the uncontrolled area of the basin--approximately 7,600 square miles. Water in this area does not drain into any of the 11 major reservoirs controlled by the Corps.

Figure 1.2: Corps' Reservoirs in Area of Flooding



Source: U.S. Army Corps of Engineers

RAINFALL

Question. To what extent did the rainfall result in flooding and damages?

Response. Record rainfall resulted in flooding over a large portion of northeastern Oklahoma and southeastern Kansas between September 28 and October 4, 1986.

Record amounts were dumped in local areas. For example, beginning about 7 a.m. on October 2, a 24-hour rainfall of from 7 to 12 inches deluged an area southwest of Enid, Oklahoma, to northeast of Ponca City, Oklahoma. This storm affected the area above the Keystone Reservoir (14 river miles west of Tulsa), the Hulah Reservoir (27 river miles northwest of Bartlesville), and the Copan Reservoir (21 river miles north of Bartlesville), where releases by the Corps triggered criticism by various individuals that the Corps was to blame for aggravating the flooding.

The rainfall also resulted in record or near-record flooding along the Arkansas River, as well as along streams and tributaries in the Arkansas River Basin. Seven of the 11 major Corps reservoirs were filled to the top of or above their flood storage capacity, requiring releases of water that aggravated the flooding.

Damages from the flooding in a 13-county area were extensive, according to an October 1986 Federal Emergency Management Agency's (FEMA) report. A total of 199 housing units were destroyed and 2,227 other units had major or minor damage. Agricultural losses were estimated at about $14.5 million. Two fatalities and 44 injuries were attributed to the flood.

CHRONOLOGY OF THE RAINFALL AND FLOODING

Question. How much rain fell each day, and what rivers and reservoirs were flooded?

Response. Rainfall amounts varied over the 11 major reservoirs, ranging from 9.8 inches in an area above Keystone to 18.5 inches in an area above Hulah. As of October 6, all major rivers and six reservoirs were flooded.

The following information details the day-to-day rainfall and flooding situation at the 11 reservoirs in the Arkansas River Basin between September 29 and October 6, 1986. We obtained these data from the Corps' Tulsa District.

September 29

At noon, rainfall that had begun the day before was reported. The rivers above Hulah and Copan were above flood stage, and rainfall amounts recorded at various rainfall gauges ranged from 2.5 to 4.0 inches in the Arkansas Drainage System. (See fig. 1.3.)

September 30

Rainfall continued, accumulating from 5.0 to 9.3 inches in the drainage system. The town of Bixby, below Tulsa, was flooding because of uncontrolled runoff.

October 1

Rains continued to fall. Nine of the 11 Corps reservoirs were filling their flood control storage, and the system's flood control storage level was filled to 29 percent of capacity. (See fig. 1.4.) Two reservoirs--Eufaula and Wister--had not filled their flood control storage.

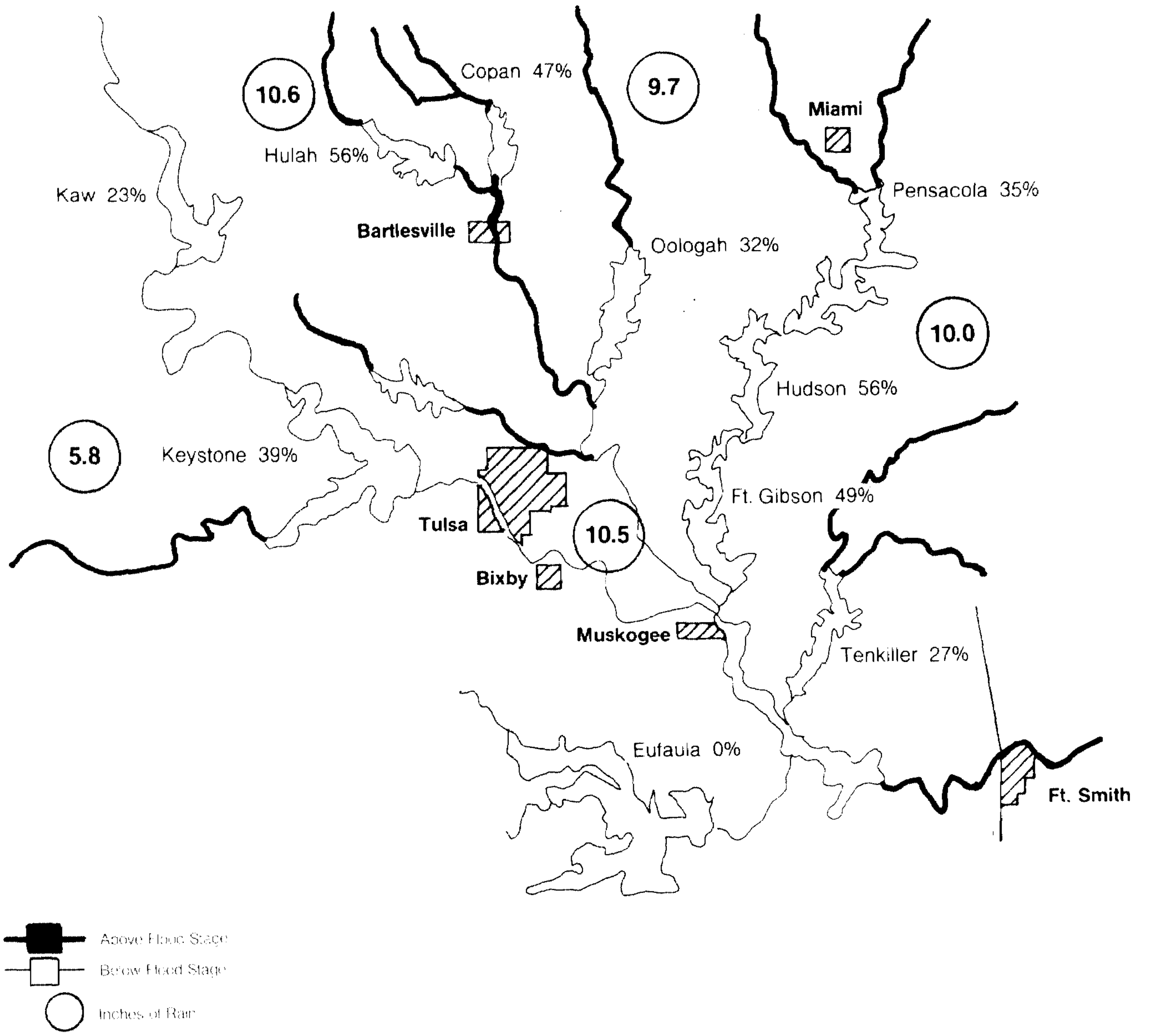
October 2

Eufaula was beginning to fill its flood control storage. The Corps had not made any releases from its reservoirs because flooding downstream from the reservoirs was occurring. Cumulative rainfall amounts ranged from 6.1 to 11.6 inches in the system. At midnight, the flood storage in the system was filled to over 55 percent of capacity.

October 3

Heavy rainfall during the night of October 2 increased the flood storage level to 65 percent of capacity. Accumulated rainfall in the system ranged from 9.4 to 17.8 inches.

Figure 1.4: Arkansas Drainage System, Noon October 1, 1986, System Flood Storage Filled: 29%



Note: The Wister Reservoir, located southwest of Fort Smith, Arkansas, is not shown on this map because water never exceeded the top of the reservoir's conservation storage during the flooding.

Source: U.S. Army Corps of Engineers

October 4

An additional inch of rain fell above the Hulah and Copan reservoirs, and Bartlesville experienced severe flooding. Keystone Reservoir was filled to 96 percent of flood control capacity. Overall, the system was filled to 74 percent of flood storage capacity. (See fig. 1.5.)

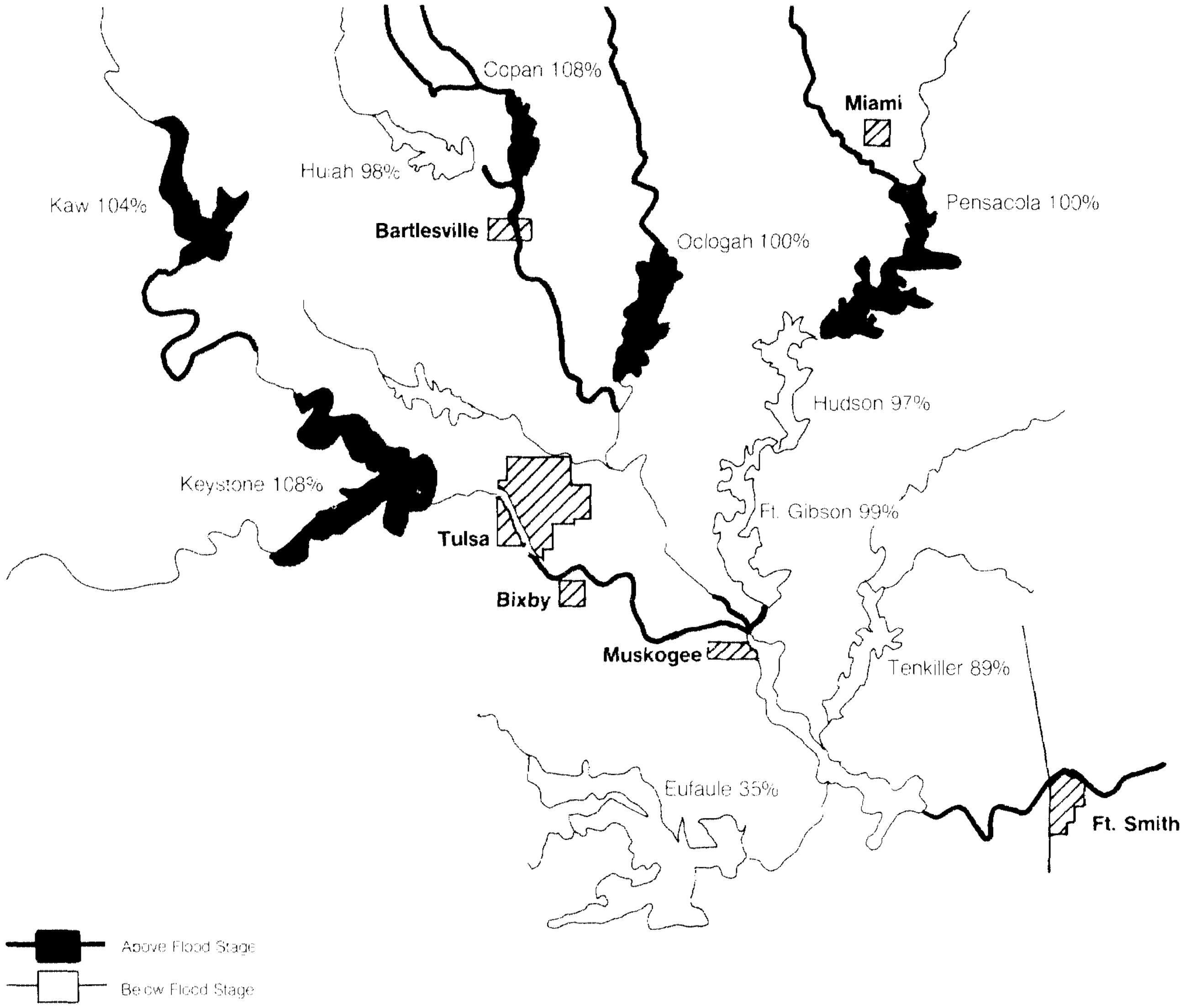
October 5

The water level in Hulah receded into its flood control storage. The water levels in Kaw, Keystone, Copan, and Fort Gibson equaled or exceeded the top of their flood control storage. The system was filled to 79 percent of flood storage capacity.

October 6

Oolagah and Pensacola reached the top of their flood control storage. The system was filled to 85 percent of storage capacity, the highest level it attained. (See fig. 1.6.) As of October 13, flood waters had receded and only Oolagah was above its flood control storage.

Figure 1.6: Arkansas Drainage System, Noon October 6, 1986, System Flood Storage Filled: 85%



Source: U.S. Army Corps of Engineers

RESERVOIR OPERATING PROCEDURES

Question. What is the general purpose of the Corps' reservoir operating procedures?

Response. The Corps operates its dam and reservoir system to help control a heavy influx of rain into a basin. Under normal operating conditions, the water behind the 11 dam structures is maintained at a low level (conservation storage level). This situation allows maximum use of the flood control storage during periods of heavy rainfall. The capacity of the reservoirs is large enough to store water runoff during most rainfall events. It allows the Corps to release any water accumulated in the flood control storage after the rain stops falling and inflow into the reservoir diminishes. (See fig. 1.7.)

Corps' operating procedures require that, as a general rule, no releases are to be made if flooding downstream from the dam is occurring, unless predicted inflow indicates that the flood control storage will be exceeded. As a general rule, when the flood control storage level is exceeded, releases of less than the inflow rate are made regardless of downstream flooding. Once the water level exceeds the safety zone, releases are made at the inflow rate or the maximum discharge capacity, whichever is less, in order to protect the structural integrity of the dam.

When a record rainfall occurs, such as the 1986 flood, and the rain continues to fall after the conservation storage and the flood control storage levels are filled, water enters the safety zone level, and releases are made in accordance with Corps' operating procedures.

Regarding the Keystone Reservoir, the Corps began releasing 57,000 cfs on October 3 when the flood control pool was at 87 percent of its capacity. This release was based on the predicted inflows into Keystone. The releases gradually increased, and at 5:00 p.m. on October 4, releases had been increased to 300,000 cfs. From this point, inflows declined, and releases were decreased. At its highest level, water reached 756 feet (at mean sea level) at Keystone. The top of the safety zone is 757 feet.

SECTION 3
FORECASTING

RESPONSIBILITIES

Question. Does the Corps duplicate other organizations' forecasting responsibilities?

Response. We did not identify duplication of forecasting responsibilities among the two organizations of the National Weather Service--the National Weather Service Forecast Office (NWS) in Norman, Oklahoma, and the River Forecast Center (RFC) in Tulsa, Oklahoma, the Corps of Engineers' Tulsa District, and the U.S. Geological Survey (USGS) in Oklahoma City. The NWS, RFC, and the Corps each have different forecasting responsibilities, summarized as follows:

- -- The NWS forecasts weather conditions and severity of rainfall, tornadoes, hailstorms, and flash flooding. It disseminates this information to the general public through the National Oceanic and Atmospheric Administration (NOAA) weather wire and weather radio stations.

- -- The RFC forecasts river stages and crests and disseminates this information to the general public in the same way as NWS.

- -- The Corps forecasts reservoir inflows, i.e., the amount of water that will flow into its reservoirs. Its forecasts are based on rainfall data provided by the NWS, and other data. The Corps may request assistance from the RFC in forecasting reservoir inflows, as it did during the recent flood.

- -- The USGS has no forecasting responsibilities. It maintains and operates stream gauges and collects historical river stage data. During critical flood stages, the USGS will, on request, measure river stages and water velocity and plot these data on a rating curve to produce a cfs measurement at a particular point. It prepared such data for the Corps during the flood.

ACCURACY

Question. How accurate were the Corps' Keystone Reservoir inflow predictions, and what impact did they have on flooding?

Response. On October 3, 1986, the Corps' Tulsa District forecast the maximum inflow into the Keystone Reservoir at a rate of 225,000 cfs after three severe storms had occurred between September 29 and October 3. This inflow forecast was not accurate because peak inflow was 344,000 cfs, or about 53 percent higher than the Corps' forecast. Fig. 3.1 compares the Corps' inflow forecasts with actual inflow between September 30 and October 7, 1986.

The Corps attributed its low forecast to the following:

-- Inadequate data were reported by cooperative weather observers (CWOs). CWOs are citizens who observe and report rainfall amounts to the NWS for a monthly fee of about $15. CWOs are spaced about 30 miles apart and report by telephone any rainfall of one-half inch or more during a 24-hour period. The Corps' Tulsa District hydrologist told us that he believes the one-half inch criteria is too high, and that some CWOs failed to report rainfall. He believes, therefore, that the Corps was basing its forecasts on flawed data.

-- One of the computer modules (HEC-1) that the Corps used to calculate the inflow could not handle the three-storm situation that occurred in such a short time frame. It was designed to cover a single short-term event.

-- Another Corps' computer module (Precip Program) that helps calculate inflows incorrectly projected, because of inadequate rainfall data, the average amount of precipitation that fell over certain Arkansas River Basin areas during the second of the three storms. This inaccurate projection led to lower water runoff estimates than actually occurred and thus to lower inflow forecasts.

The Corps' understated forecast had no impact on downstream flooding caused by the gate releases because the Corps did not use its forecast to regulate gate releases. Instead, the Corps asked the RFC to predict the peak inflow into the Keystone Reservoir, immediately after an October 3, 1986, news conference at which the RFC predicted that the storms that had already occurred would cause record flooding along the Cimarron River, which flows into the Keystone Reservoir. The RFC predicted a peak inflow of 350,000 cfs

ACCURACY OF RIVER STAGE PREDICTIONS

Question. How accurate were the river stage predictions by the RFC?

Response. Table 3.1 compares the RFC forecast with the actual river stage crest for 9 river stations, which we selected for illustrative purposes. Except at the Perkins river station, the actual crests were less than the forecast crests.

The hydrologist-in-charge at the Tulsa RFC told us that the RFC does not have specific criteria to measure the acceptable level of accuracy of river stage crest forecasts during flood periods. However, the RFC considers any forecast within 12 inches of the actual river stage crest to be "acceptable." During the 1986 flood, the RFC made 95 forecasts of river stage crests, and 80 were within 12 inches of the actual crests. Ten of the forecasts were between 12 and 18 inches of actual crests, and the other 5 forecasts were in excess of 18 inches of the actual crests.

-- Better quantitative measurement of hail and rainfall intensity.

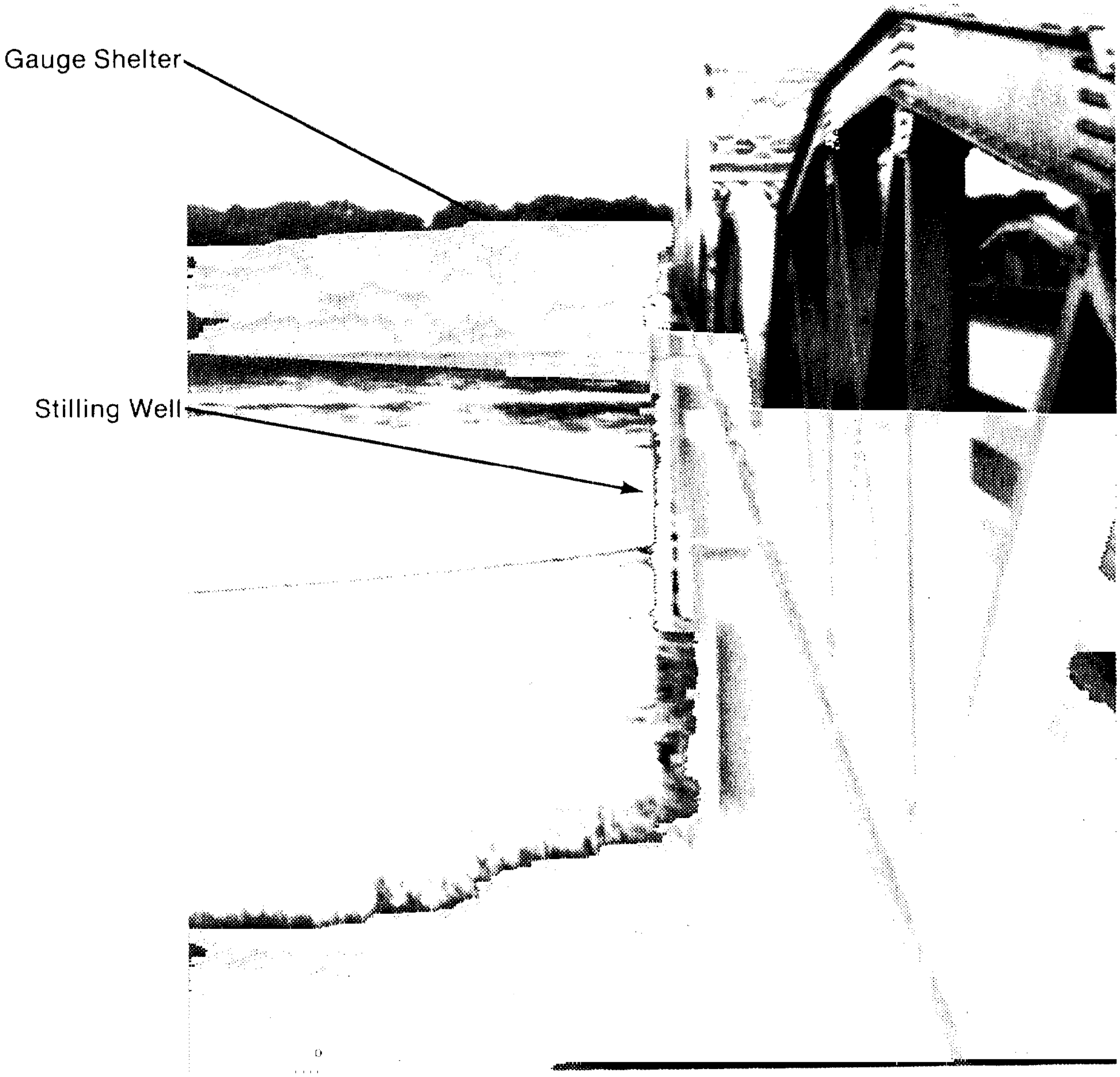
The first NEXRAD production unit is scheduled to be delivered to the NWS at Norman, Oklahoma, in late summer of 1989.

SECTION 4
RIVER GAUGES

DESCRIPTION OF RIVER GAUGES

Most gauging stations used by the Tulsa Corps, Tulsa RFC, and Oklahoma USGS, are equipped with battery-operated radios called DCPs. The DCP transmits river stage (river height) and rainfall data to a NOAA orbiting satellite, which relays the data to a central receiving station in Suitland, Maryland, where the data are processed. The Tulsa Corps can access these data to help it regulate water releases from its reservoirs. Figures 4.1 and 4.2 show two different types of river gauges at Perkins and Ralston.

Figure 4.2: Gauge Shelter at Ralston, Oklahoma, on a Bridge Over the Arkansas River



The Ralston stream gauge shelter is located on a bridge abutment in the Arkansas River. The long tube below the station is a stilling well. The well houses the sensor that reads the river stage.

Ralston Gauge

The Ralston stream gauge, located on the Arkansas River, was damaged around 6:30 p.m. on October 4, 1986. According to the USGS, this gauge was damaged by high velocity water that ripped off the stilling well's clean-out door. Large quantities of water entered the stilling well and caused inaccurate fluctuations of the sensor gauge. According to the USGS, the door could not be repaired or replaced until the flood water receded, nearly 3 months after the door was damaged.

As in the Perkins situation, the USGS conducted flow measurements and river stage readings at Ralston using the VADA device and provided the information to the Corps.

A USGS team was positioned at Ralston taking measurements before the gauge was damaged. According to the USGS supervisory hydrologist, the Corps requested that the USGS make river stage readings at Ralston and at other gauge stations where gauges were operating so that the Corps could verify the accuracy of the computer-generated readings received via the NOAA satellite. Thus, USGS personnel were already on site at Ralston and available as a back-up source when that gauge was damaged.

In addition, according to the USGS, there are auxiliary gauges at all recording gauge stations, i.e., those stations equipped with instruments that automatically sense and continuously record the river's stage. An auxiliary gauge permits the river stage to be read by a local observer in the event that the recording gauge becomes inoperable. During the flood, Corps employees read the auxiliary gauges at both Ralston and Perkins.

According to the Corps, the temporarily inoperable gauges at Perkins and Ralston did not prevent the Tulsa District from acquiring essential information needed to regulate the flood gates at the Keystone Reservoir. The Corps and USGS used alternative means (the auxiliary gauges and VADA) to produce the river flow and river stage readings needed by the Corps.

PROTECTION AGAINST DAMAGE

Question. Can physical security of gauges be improved?

Response. The river gauges and related equipment used during the flood are state-of-the-art equipment, according to the USGS's District Chief and to the Supervisory Hydrologist, Water Resources Division. They told us that gauges malfunctioned because of intense water flow and damage caused by debris, not because equipment was old or obsolete. According to the USGS, the gauges in use and the protective measures employed are the best available at this time. Both USGS officials told us there was no way to prevent the damage that occurred during the flood.

The Supervisory Hydrologist also told us that vandals sometimes cause damage to gauge equipment. They may use gauge equipment for target practice or they may fill rain gauges with dirt. The USGS has installed bulletproof jackets on some gauge houses in order to protect equipment inside the house, but such preventive measures do not protect rain gauges or other equipment located on the roof of the house. According to the Supervisory Hydrologist, USGS has no cost data on repairing damages caused by acts of vandalism.

Both Corps and USGS personnel mentioned power-operated cableways constructed across rivers as an alternative means of obtaining river readings during flood situations. According to the USGS, these cableways allow field personnel to span the river rapidly and take readings from above the river as an alternative to taking readings from bridges or boats during emergencies, thus reducing the danger to field personnel. However, the USGS said cableways are costly and not feasible for every location. Cableway equipment is primarily used at wide rivers that flood frequently, and it can only be installed at locations where river banks can support a concrete foundation. As of June 1987, USGS was studying the feasibility of installing cableways at Perkins and Ralston and USGS told us the study will require several months to complete.

SECTION 5
FLOOD WARNINGS

POLICIES AND PROCEDURES

Question. Who makes the warnings and what do the warnings cover?

Response. Figure 5.1 shows the flood warning sequence and the entities involved.

The Tulsa District Corps notifies the Tulsa RFC of scheduled reservoir water releases. According to the hydrologist-in-charge at the Tulsa RFC, the RFC updates its river stage forecasts on the basis of this information, along with estimates of water run-off, current rainfall data, historical data, and stream gauge data, and provides flood stage forecasts to NWS.

The NWS uses RFC river stage forecasts as a basis for developing and issuing flood watches and warnings to the public via the NOAA weather wire and NOAA weather radio network. This information is directed to the media, Corps, and state and local civil defense agencies. The flood warnings include the expected degree of flooding, the affected river, when and where flooding will begin, and the expected maximum river level at specific forecast points during the flood.

According to the 1976 Oklahoma Disaster Assistance Relief Plan, which is currently in use, when a disaster such as a flood threatens or occurs, local government authorities have primary responsibility to warn and evacuate citizens, minimize suffering, and protect life and property. When additional help is needed and requested by local communities, the governor activates the disaster plan, which directs state agencies and volunteer relief agencies to provide the resources and services needed to minimize the effects of the disaster. The state civil defense agency is responsible for coordinating all disaster preparedness plans, actions, and activities of state agencies prior to, during, and after the occurrence of a natural disaster such as a flood. The state civil defense agency is responsible for notifying city and county civil defense agencies of disaster conditions, and the latter agencies are responsible for warning the public.

SECTION 6
COMMUNICATION/COOPERATION DURING THE FLOOD

COMMUNICATING WATER RELEASE INFORMATION

Questions. (1) Who is responsible for notifying affected communities? (2) Did Corps notification guidance conflict with the state's disaster plan?

Response. The guidance provided in the applicable Corps' manual and the Oklahoma state disaster plan indicates that both organizations were responsible for notifying local entities of impending floods. Media reports indicated confusion concerning the Corps' and state civil defense (CD) agency's responsibilities for notifying local CD organizations of reservoir water releases that could cause flooding.

The Tulsa Corps District's guidance for dealing with flood situations is contained in its August 1985 manual, Natural Disaster Procedures Under PL 84-99. The manual states that the Tulsa Corps District Commander should institute measures to keep informed of potential disasters and advise federal and nonfederal interests as appropriate. Furthermore, the Corps' area engineer is responsible for using "current notification lists to alert, provide warning of high water, and effect liaison with levee and district drainage boards, local officials, and local concerns." A supplement to the manual spells out the state and local organizations that are to be notified, including state and local CD agencies. Although the manual directs the Corps to notify state and local CD agencies of flooding in general terms, it does not specifically address flooding caused by reservoir water releases.

The state CD agency guidance for dealing with natural disasters, including floods, is contained in the May 1976 Oklahoma Disaster Assistance Relief Plan. Under the plan, the state, when a weather watch is issued by the NWS, must notify local CD directors and/or local officials in the threatened area of an alert condition. As in the case of the Corps' manual, the Oklahoma plan does not specifically address flooding caused by water releases from Corps' reservoirs.

In our opinion, both the Corps' manual and the Oklahoma plan require notification of state and/or local CD agencies of impending flooding during such emergency conditions as the 1986 flooding. Neither document spells out notification procedures when flooding may be caused by release of reservoir water. However, the Corps' January 1982 Operation and Maintenance Manual for Keystone Dam contains specific notification procedures to be used when the Corps must make uncontrolled releases of water because of failure of or severe damage to the Keystone Dam or appurtenant works. According to the Chief of the Corps' Emergency Operations Center, this type

LOGS DOCUMENTING COMMUNICATION

Question. Did the Corps maintain logs that reflect notification to state and local CD organizations of increased water discharges from the Keystone, Hulah, and Copan reservoirs?

Response. Logs maintained by the Corps' Emergency Operations Center in Tulsa show that the Corps notified state and local CD agencies of increased discharges from the Keystone, Copan, and Hulah reservoirs. The logs contain information concerning flood-related activities occurring from October 1 through October 10, including gate change notifications, sandbag distribution efforts, weather and flood conditions, equipment and personnel requests, evacuations, and activities at flood control structures. The Center chief also told us that the Tulsa District received calls from local CD authorities about gate changes, and the Corps responded with the best information available at the time.

A state CD duty officer told us that overall, the Corps did a good job, but he did not receive information concerning reservoir discharge increases from the Corps. We could not verify this statement because state CD logs appear incomplete, containing no entries concerning notifications to or from the state CD of increased discharges from Keystone, Copan, or Hulah. However, Corps' logs indicate that the Corps contacted the state CD about discharge increases from these reservoirs.

The city of Tulsa CD Director told us that he could not obtain timely information relating to reservoir gate changes from the Tulsa District Corps. We found, however, that Tulsa's CD log contained five entries between October 3 and 4, 1986, indicating that the Corps did notify the city of increased discharges from Keystone. The Corps' log showed that it notified the Tulsa CD of seven gate changes during this 2-day period. Tulsa CD logs also showed that the NWS and/or the state CD notified the Tulsa CD of discharges from Keystone, Copan, and Hulah on eight occasions between October 2 and 4, 1986.

IMPROVEMENTS

Question. Do working relations and communications need to be improved?

Response. Overall, CD officials reported positive relationships with the Corps. The Corps is improving its communications procedures.

Working Relations

The Oklahoma State CD Director was not aware of any communication/coordination problems between the Corps and his office. He found the Corps extremely cooperative, and communications between the agencies were good.

The Bartlesville CD Director said the Corps' efforts during the flood were exceptional. The Corps' area office in Bartlesville and district office in Tulsa worked closely with his office in order to provide flood information as soon as it was known. The assistance provided by the Corps was invaluable, according to the Director, and beyond what is normally required.

The Tulsa CD Director also told us that, despite the liaison problem, the Corps did a good job. As previously noted, the Corps plans to station a hydrology representative in the Corps' Emergency Operations Center to provide reservoir gate change information to Corps' liaisons.

Improving Communications

According to the Corps' public affairs officer, the news media and the public made numerous telephone calls to the hydrology section to find out about the flood. She said these calls tied up the lines needed to coordinate Corps' business. The Corps has dedicated eight separate telephone lines with unlisted numbers for the news media, civil defense personnel, and key Corps project and other agency personnel. The public can now call listed numbers at the Corps' public information center.

DEPARTMENT OF THE ARMY EVALUATION

Question. What was the result of the Department of the Army evaluation?

Response. The Assistant Secretary of the Army--Civil Works directed a special assistant to determine, among other matters, whether revised operating procedures for releasing water from Arkansas River Basin reservoirs, (commonly referred to as the Corps' "Fine Tuning Plan"), implemented by the Corps in July 1986, caused more flood damage than would have otherwise occurred. The special assistant concluded in his November 1986 report that the plan had no effect on the flooding. The basis for his conclusion generally parallels the explanation we provide in Section 2.

CORPS' DAM SAFETY EVALUATIONS

Question. What was the result of the Corps' dam safety evaluations?

Response. Since the flood, the Corps has inspected the 11 major dams in the Arkansas River Basin, as part of its ongoing safety of dams inspection program, according to the Chief of the Dam Safety Section of the Tulsa district. The inspections were performed by representatives of the Corps' northern and eastern area offices, project personnel, contract representatives, and/or other Corps' personnel from the southwest division offices in Tulsa and in Dallas. According to a civil engineer who participated in the inspections, they included examinations of the dam, the spillway and outlet works, embankments, and operating equipment. The inspection reports for 5 of the 11 major dams involved in the flood--Keystone, Hulah, Copan, Kaw, and Oologah indicated that there was no major structural damage to the dams or their appurtenances.

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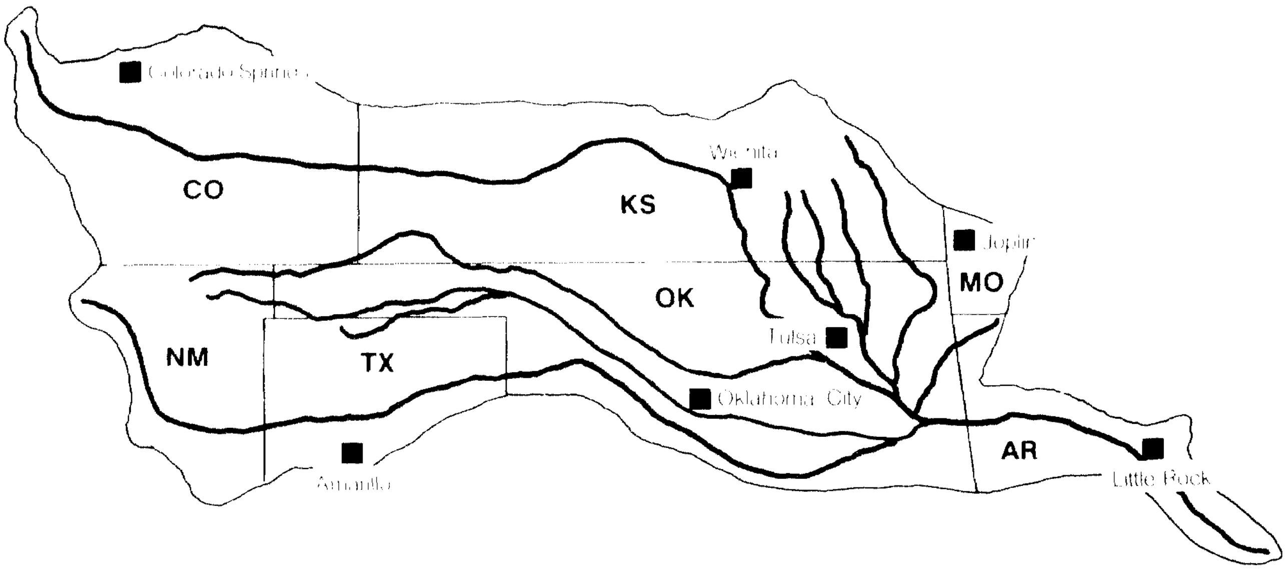
FIGURES

ABBREVIATIONS

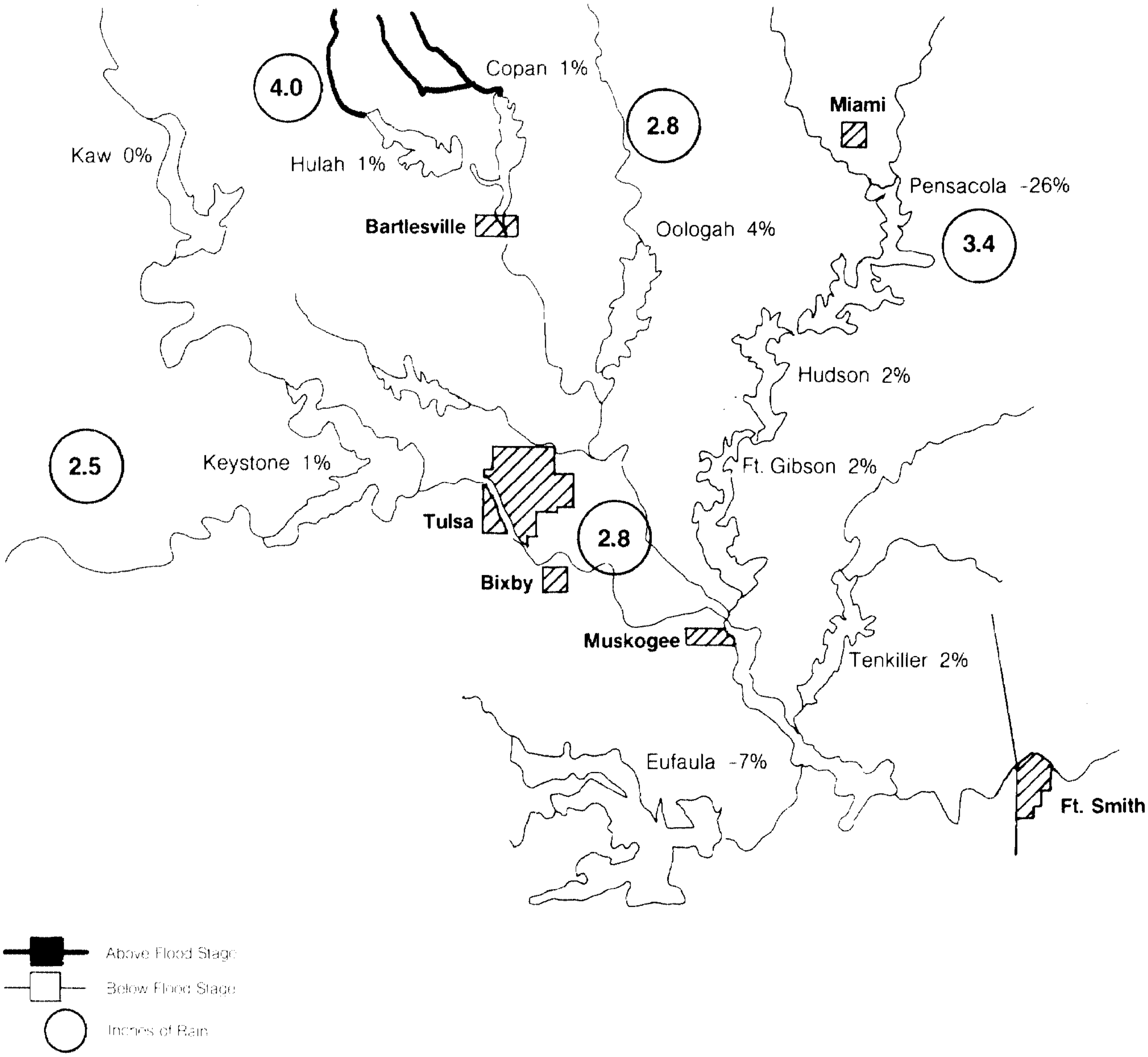
CD	Civil Defense
cfs	cubic feet per second
CWO	cooperative weather observer
DCP	data collection platforms
FEMA	Federal Emergency Management Agency
NEXRAD	Next Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service Forecast Office
RFC	River Forecast Center
USGS	U.S. Geological Survey
VADA	Velocity-Azimuth Depth Assembly

Figure 1.1: The Arkansas River Basin



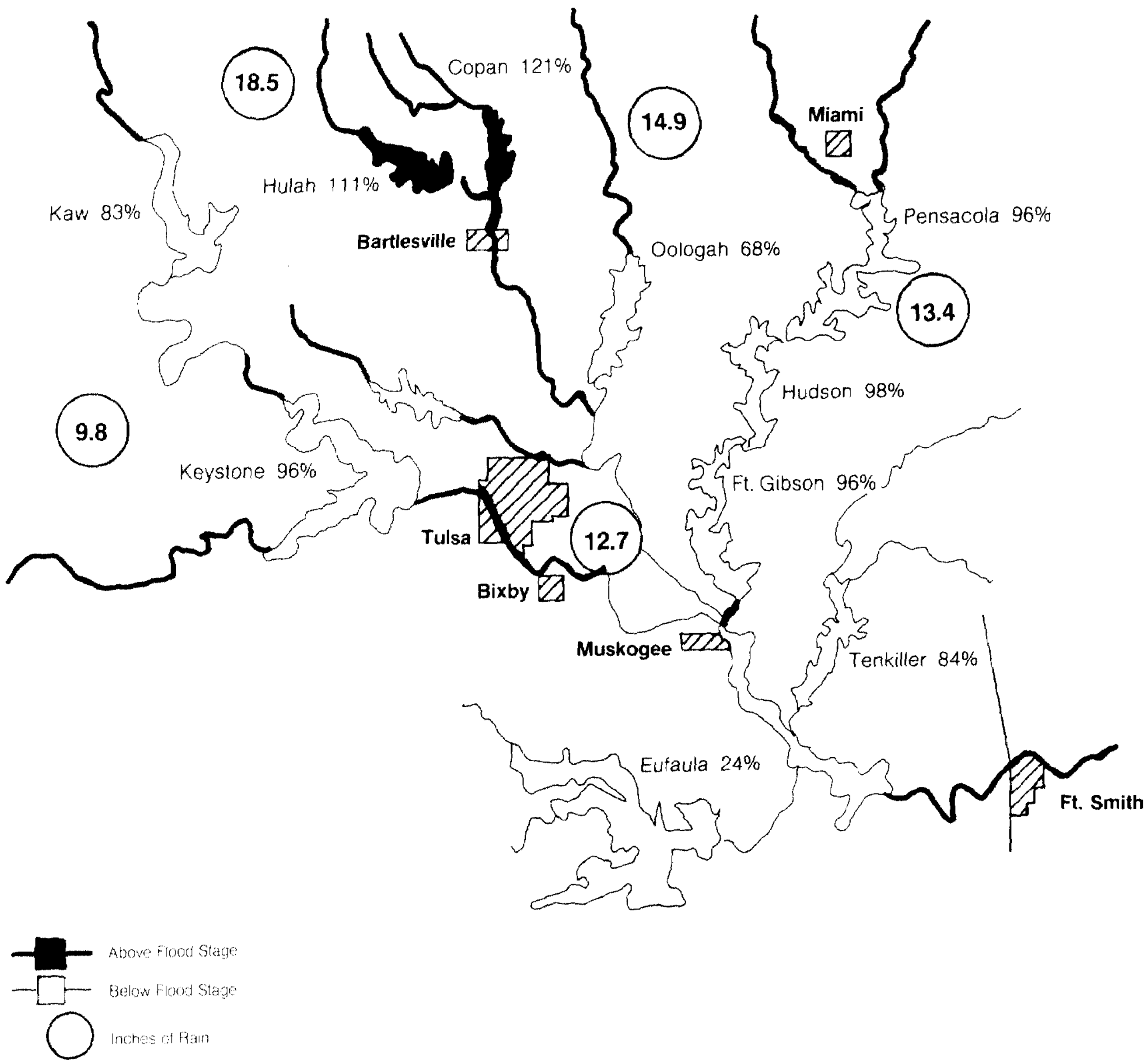
Source: U.S. Army Corps of Engineers

Figure 1.3: Arkansas Drainage System, Noon September 29, 1986, System Flood Storage Filled: 2%



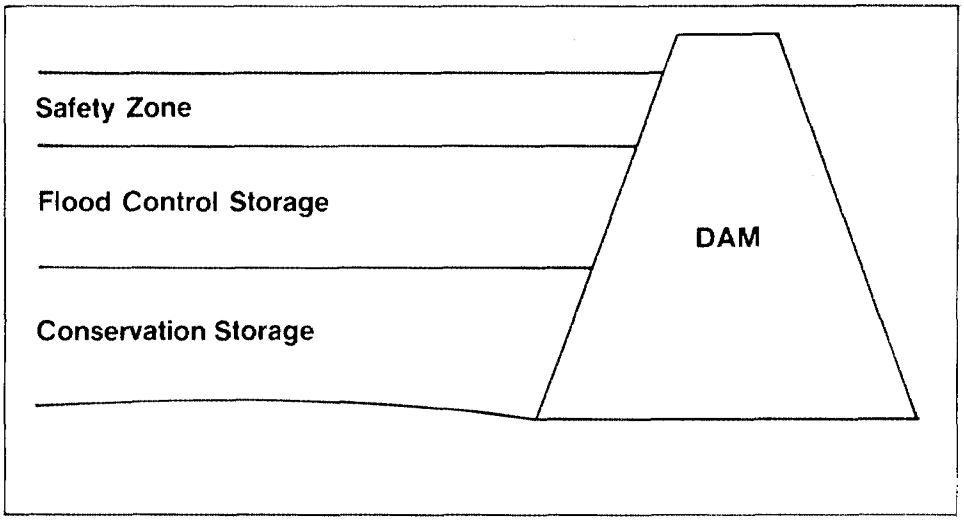
Source: U.S. Army Corps of Engineers

Figure 1.5: Arkansas Drainage System, Noon October 4, 1986, System Flood Storage Filled: 74%



Source: U.S. Army Corps of Engineers

Figure 1.7: Diagram of a Flood Control Structure



Source: U.S. Army Corps of Engineers

Question. Did the Corps release water from the Hulah, Copan, and Keystone reservoirs in accordance with its operating procedures?

Response. The Corps released water from these three reservoirs in accordance with its procedures.

Media reports indicated that residents of Bartlesville and Tulsa believed that the Corps contributed to the flooding in these cities because they allowed Hulah, Copan, and Keystone reservoirs to fill, necessitating releases of large amounts of water in a short time. They contended that the Corps could have kept these reservoirs at lower levels by releasing lesser amounts of water over a longer time period, rather than allowing the water to accumulate in the reservoirs. However, Corps procedures did not allow releases from the reservoirs because flooding was occurring downstream. Compounding the problem was the uncertainty of the exact track that an oncoming hurricane would take; forecasts were showing that the path of the hurricane might be either above or below the Hulah, Copan, and Keystone reservoirs. The Corps district engineer told us that if the hurricane tracked below the reservoirs and if the Corps had been releasing water, the flooding in the two cities would have been more severe than it was.

At noon on October 3, 1986, the Hulah Reservoir was filled to the top of its safety zone (110 percent full), and the Corps was releasing water at the rate of 26,150 cubic feet per second (cfs). The inflow to the reservoir at this time was 133,000 cfs. Corps' procedures require releases equal to the inflow amount, or the maximum discharge rate, which would have resulted in an increased release to 133,000 cfs, and would have sent a large volume of water toward Bartlesville with little warning. The Corps then made an engineering determination that the structure would remain sound if the pool were allowed to rise an additional 3 feet above the safety zone. Corps' operating procedures allow water to rise above the safety zone but only with Corps' division approval, which was granted in this case. By 10:00 p.m. on October 3, the inflow had decreased to 58,000 cfs, and the Corps began releasing that amount. From that point on, the releases matched or exceeded the inflow amounts, which were declining, and the water in the reservoir then began dropping into the flood control storage at 6:00 a.m. on October 5.

On October 3, 1986, the Copan flood control pool was 86 percent filled, and the Corps determined that the capacity of the flood control pool would be exceeded. The Corps began releasing 650 cfs on October 3, and gradually increased the releases to a maximum of 50,800 cfs on October 4 at 8:05 a.m. At this point, 2 feet of the 6 feet of the safety zone were being utilized. Thereafter, water releases were gradually decreased.

SECTION 2
OPERATING PLAN MODIFICATION

Question. Did the July 1, 1986, modification to the Arkansas River Basin Operating Plan adversely affect the September-October 1986 flood?

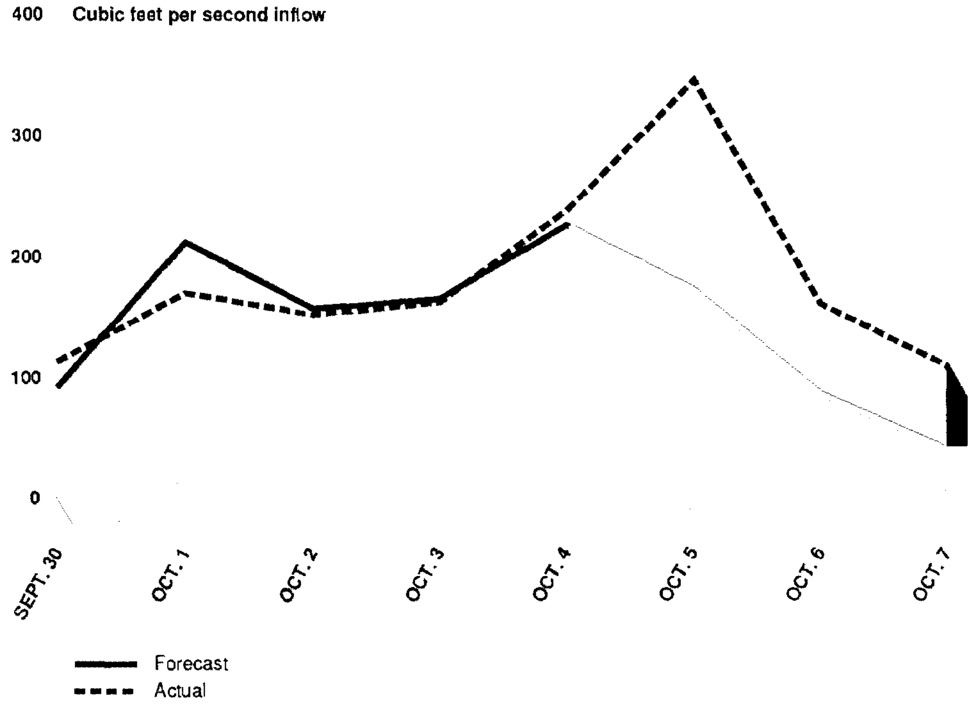
Response. Some concern has been expressed that a July 1, 1986, modification to the plan may have exacerbated the flooding. The modification requires a more tapered release over a short time frame of waters from flood control storage, when the average flood storage control level for the 11 reservoirs recedes to 18 percent of storage (see fig. 1.7). It is designed to allow navigation to operate more efficiently on the Arkansas River by slowing the increase in the current that would be caused by a more rapid release of the waters.

The modification could have caused a problem if a tapered release of waters in storage before the September flooding had resulted in more water being in the reservoirs when the September 29 flooding began. With higher water levels in the storage areas caused by such a tapered release, there would be less room to accommodate the higher water levels caused by the flood. However, flood water storage levels were essentially empty on September 29. Therefore, no release of flood water--tapered or otherwise--was required.

The modification did also not affect water levels during the flooding because it provides that the tapered release can only occur after the waters recede to the 18 percent level, not when the waters are still rising. Flood waters did not recede to this level until November 11, 1986--well after the September 29 to October 6 flooding.

Thus, the modification was not invoked until after the flood and therefore had no adverse impact.

Figure 3.1: Comparison of Corps' Predicted and Actual Inflows for Keystone Reservoir



and a "worst case scenario" of 409,000 cfs. The Corps discarded its estimate of 225,000 cfs and instead used the RFC's 350,000 cfs estimate in making decisions for releasing water from the Keystone Reservoir. The actual peak inflow was 344,000 cfs. The Corps' Hydraulics and Hydrology Branch Chief told us that the Corps used the RFC estimate because (1) the Corps lacked forecasting experience with its HEC-1 computer module and (2) the RFC hydrologist who made the 350,000 cfs forecast had 20 years of forecasting experience.

Table 3.1: Comparison of RFC River Stage Forecasts and Actual Crests (in feet)

River station	Forecast	Actual
Bartlesville	28.0	27.7
Claremore	44.5	44.4
Commerce	26.5	26.2
Muskogee	40.0	39.6
Pawnee	28.0	27.2
Perkins	24.0	26.5
Ralston	24.0	23.5
Tahlequah	24.0	22.5
Tulsa	25.5	25.3

IMPROVEMENTS

Question. How can forecasting be improved?

Response. A Corps official told us that having the CWOs measure all rainfall would be prohibitively expensive. Two technological improvements for forecasting rainfall and detecting hazardous weather are underway.

Cooperative Weather Observers

The Corps believes that more precise rainfall reporting by CWOs could improve the forecasting of river stages and reservoir inflow. Currently, if a CWO detects rainfall of one-half inch or more during a 24-hour period, the data must be reported by telephone to the NWS at 7:00 a.m., 1:00 p.m., and 7:00 p.m. The Corps would prefer to have CWOs report all measurable rainfall to the NWS. The Tulsa RFC hydrologist-in-charge told us that he believes rainfall of less than one-half inch accounts for about 80 percent of the total rainfall. He said this amount is significant because small amounts of rain soak into the ground and affect runoff. The Hydraulics and Hydrology Branch Chief told us, however, that the cost of having the CWOs report all rainfall to the NWS would be prohibitive.

Precip Program

During the 1986 flood, the Corps' precip program module incorrectly distributed the average Arkansas River Basin rainfall. This error led to inaccurate runoff estimates. The Corps' Hydrology Engineering Center in Davis, California, is developing a new program to perform the desired precip program calculations, and according to the Corps hydrologist in Tulsa, an official from the Center said that the program was essentially complete and would be released soon.

NEXRAD

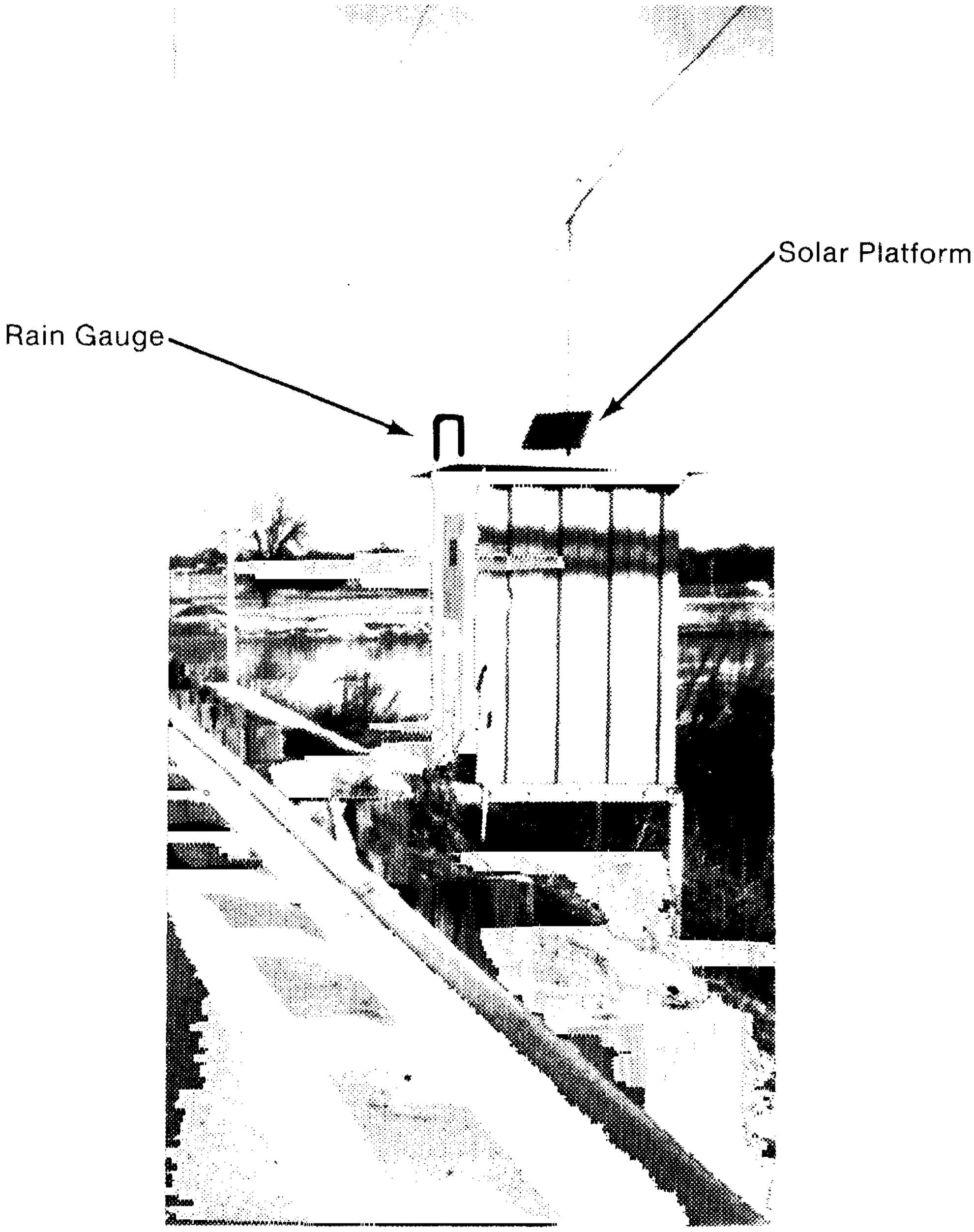
The Next Generation Weather Radar (NEXRAD) is being developed jointly by the Departments of Commerce, Defense, and Transportation. NEXRAD will provide enhanced capability to detect and issue hazardous weather warnings. Some of the anticipated improvements include:

- Better storm identification. (Current radar picks up only one storm; NEXRAD will penetrate one storm and pick up a second storm.)

- More timely access of automatic rain gauges in each Doppler radar area.

- More accurate and timely rainfall estimates.

Figure 4.1: Gauge Shelter at Perkins, Oklahoma, on the Cimarron River Bank



The stream gauge shelter at Perkins measures 5 by 6 by 8 feet and houses data-recording equipment. The data are obtained through a sensor located in the river. The data collection platforms (DCP) in the gauge shelter transmits river stage data to the NOAA satellite via a solar platform located on the roof. A rain gauge on the roof is also linked to the DCP.

PROBLEMS

Questions. (1) Which gauges malfunctioned and for how long? (2) Are back-up resources available when gauges malfunction? (3) What was the effect of the malfunctions on inflow forecasts, and on reservoir gate operations?

Response. Seventeen of the 115 river gauges in the basin either malfunctioned or were damaged between September 29 through October 4, 1986. The malfunctions generally resulted in inaccurate river stage readings by river gauge sensors, and in problems in transmitting river stage information to the NOAA satellite from the DCPs.

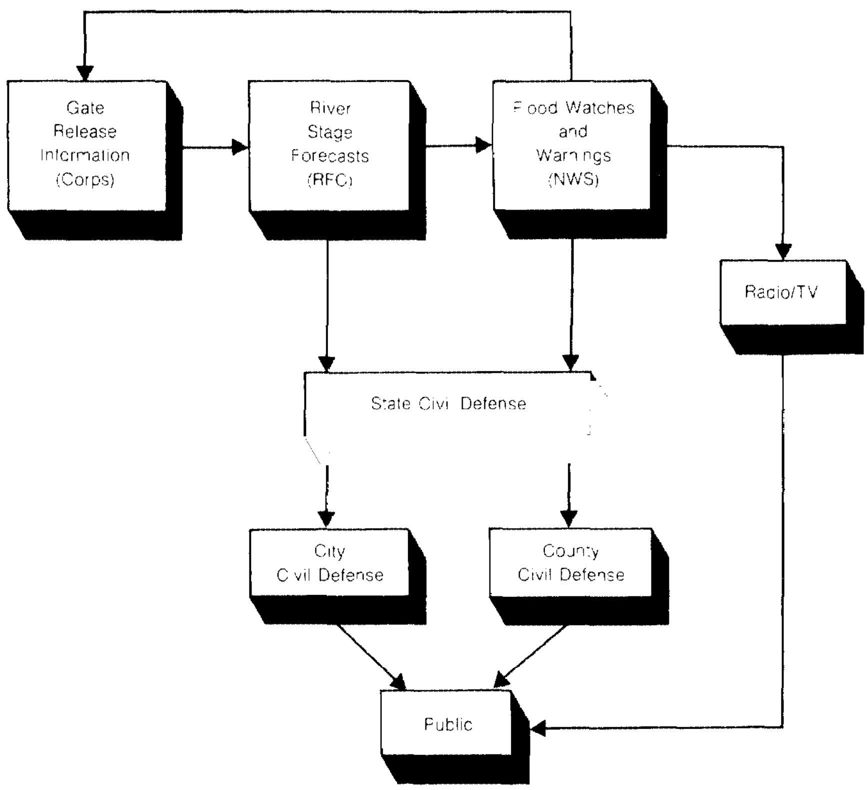
At Perkins, USGS personnel were on site to provide readings 11 hours after the gauge malfunctioned. At Ralston, USGS personnel were at the site when the gauge malfunctioned and were able to provide back-up support immediately. There was minimal impact on gate operations because the Corps obtained needed data through on-site observers. The problems associated with the gauges at Perkins and Ralston are discussed below.

Perkins Gauge

The gauge at Perkins, Oklahoma, located on the Cimarron River, was damaged at about 11:00 p.m. on September 29. According to the USGS, this gauge was damaged by debris that washed along the river bed, shearing off the sensor. The USGS temporarily repaired the gauge around midnight on October 3, but the gauge was damaged again at about 8:00 a.m. on October 4 and temporarily repaired the same day. USGS officials told us that because of the high water the damage could not be permanently repaired until December 22, 1986.

According to the USGS, the Corps reported the inoperable gauge to the USGS as soon as the problem was discovered on September 30. The USGS sent personnel to Perkins to take manual measurements of river flow and river stages using a portable device called a Velocity-Azimuth Depth Assembly (VADA). The USGS provided the Corps with periodic VADA readings during the flood period. We determined that there was an 11-hour delay from the time the Perkins gauge was damaged on September 29 until the USGS provided the Corps with its first reading around 10:00 a.m. on September 30. The Hydraulics and Hydrology Branch Chief told us that the delay did not impact gate operations at Keystone because the flood control storage was just beginning to fill at that time.

Figure 5.1: Flood Warning Sequence and the Entities Involved



Note: Effective April 1987, the Corps will notify federal, state, and local officials of forecast and current reservoir release data.

FLOOD PREDICTIONS FOR BROOKSIDE AND BARTLESVILLE

Questions. (1) Why didn't the flood predicted for Brookside materialize? (2) Why did the flood forecast for Bartlesville arrive 12 hours later than predicted?

Brookside

Brookside, an area in downtown Tulsa, did not flood, according to the Tulsa RFC Hydrologist-in-Charge, because water released from the Keystone Reservoir flowed with such force that it cleaned out and deepened the Arkansas River channel as it progressed downstream toward Tulsa. Therefore, the river channel was able to hold more water than usual. Such scouring action, according to the hydrologist-in-charge, is not unusual during major flood events. He said that scouring at a specific location cannot be verified, however, because as reservoir releases are slowed and the flooding recedes, silt and debris are redeposited in the river channel.

The Norman NWS Meteorologist-in-Charge told us that the NWS should not have attempted to forecast flooding for a specific residential area, such as Brookside. Such a pinpoint forecast was out of the ordinary, but this was an extraordinary flood event, and the NWS tried to respond to requests for specific information in as much detail as possible.

Bartlesville

The RFC erred in predicting the arrival time of floodwater in Bartlesville because it based its prediction on the normal course of water in the channel, according to the RFC Hydrologist-in-Charge. However, as water was released from the Hulah and Copan reservoirs, the respective channels could not contain the volume of water released. The water spilled over the banks and went in lateral directions, and this change delayed the floodwaters reaching Bartlesville.

The hydrologist-in-charge told us that, although the RFC had never before dealt with a flood of this magnitude, it should have realized the water would take a lateral direction. He said the RFC's computer model for forecasting floods would be reprogrammed to incorporate the lessons learned from this flood.

of situation did not occur during the flood because the releases were not caused by dam or equipment failure. Therefore, guidance in the manual did not apply. We determined that the Tulsa CD Director was operating under the incorrect assumption that the Corps was using the Keystone Dam manual as guidance.

On April 9, 1987, the Tulsa Corps District revised its procedures concerning public information during emergency flood operations. The procedures require that both forecast and current reservoir release information will be provided by the reservoir control section of the Corps' Hydraulics and Hydrology Branch to all federal, state, and local officials by telephone during major flood events. This change clearly pinpoints notification responsibilities, and it should eliminate confusion that may have existed during the 1986 flood.

CORPS' LIAISON

Question. Was the Corps' liaison stationed at the Tulsa Emergency Operations Center kept informed of Corps' decisions?

Response. The Corps' operating procedures require that the Corps work with state and local organizations during a flood, but they do not define what such liaison should entail. The Corps' Chief of the Emergency Operations Management Branch told us that the Corps placed a liaison at the Tulsa Emergency Operations Center from October 3 to October 5, 1986, and his primary responsibility was to coordinate sandbag distribution efforts.

The liaison was at the Tulsa center to provide gate change information to the city and to be a decisionmaker or a spokesperson for the Corps, according to the Tulsa CD Director. The Corps' liaison told us, however, that he was not provided Keystone gate change information on a routine basis; the Corps' logs show that such information was provided to him on five occasions at the Tulsa center.

The chief of the center told us that in the future, the Corps will have a representative from the hydrology section located in the Corps' Emergency Operations Center to transmit gate change information to Corps' liaisons in the field.

SECTION 7
POST-FLOOD EVALUATIONS

CORPS' MANAGEMENT EVALUATIONS

Question. What post-flood management evaluations have been made by the Corps?

Response. Both the Corps' Tulsa district office structural engineer and the Chief of the Hydraulics and Hydrology Branch prepared reports in late October 1986 that identified problems resulting from the flood. Neither report was required by Corps' procedures, but each reflected a concern by each individual to report his views as quickly as possible after the flood. The October 28, 1986, report of the structural engineer, which was sent to the Chief of the Corps' Tulsa Dam Safety Branch, spelled out electrical equipment, power house, and operating machinery problems generally related to the Keystone, Kaw, Oologah, Hulah, and Copan reservoirs. The report suggested raising or relocating transformers, raising an operating machinery deck, replacing an emergency generator, and adding pumping capacity for emergency use.

The October 30, 1986, "Lessons Learned" report of the branch chief addressed 13 issues, such as problems with stream gauges, reliability of radar information, and manpower shortages. The report was sent to the Corps' district engineer in Tulsa, and included several suggestions for improvement.

Seven of the 13 issues were restated along with 15 other issues in the December 1986 After Action Report, which was required by a Corps' regulation. This report, prepared by the Tulsa District's Emergency Operations Branch, made specific recommendations for each of the 22 issues and identified the action agency. The report indicated that some recommendations had already been implemented, and others would be implemented in the future.

To follow up on problems identified in the After Action Report and to analyze other policy issues, the Corps is preparing a comprehensive post-flood water management analysis report. It is scheduled to be issued by July 31, 1987.

OTHER AGENCY EVALUATIONS

Question. What other evaluations have been made?

Response. Pursuant to federal law, FEMA has completed two post-flood evaluations: the Interagency Hazard Mitigation Report, issued in October 1986; and the Interagency Post-Flood Recovery Progress Report, issued in February 1987, which follows up on the October report.

The October report was prepared by FEMA with the help of 18 federal, state, and local government agencies. It discusses 20 issues, such as establishing a central inter-regional, interagency media information center; developing a flood hazard awareness program; meeting with various agencies to critique methods and procedures used in forecasting, regulating, or monitoring flood flows; maintaining sets of floodplain boundary maps; and initiating perpetual maintenance programs for all existing storm water drainage systems and features. The report identifies the corrective action needed and the agency or agencies that should implement the action. FEMA's February follow-up report described the status and impact of the action suggested and the work in process to carry out the action.

A state report, the Oklahoma Flood Hazard Mitigation Plan of 1987, issued in May 1987, identified 15 flood hazard problems and measures to be implemented or continued in the state effort to alleviate the suffering and damage caused by flooding. The plan discusses the problems, solutions, and the lead agency responsible for the measures. For example, the master drainage plan measure calls for the Indian Nation Council of Governments to develop a Tulsa metropolitan area hazard mitigation program that will include a model storm drainage ordinance for adoption by local governments in the metropolitan area. This proposal is in response to 1 of the 20 issues raised in the FEMA reports.

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