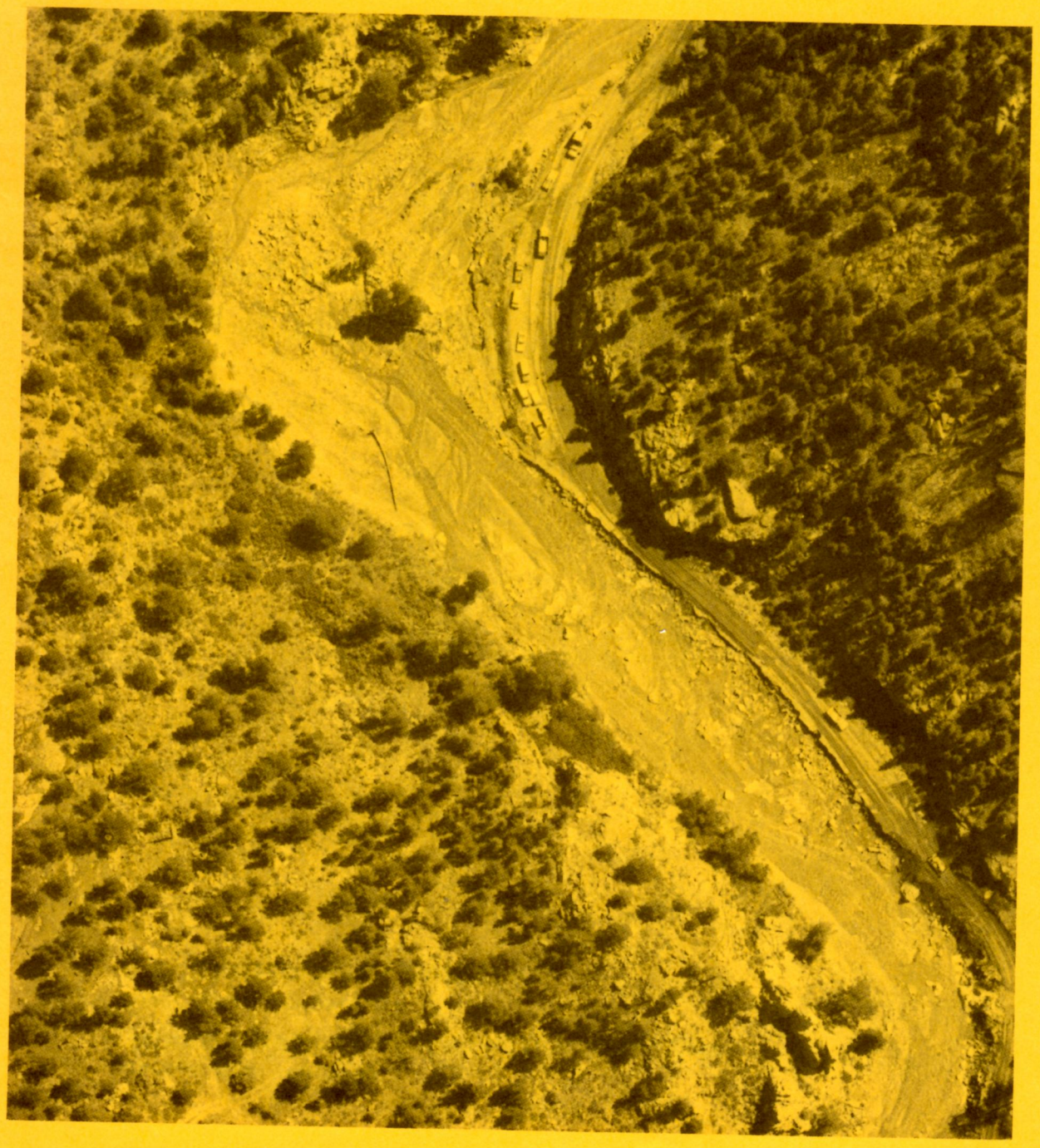
NATURAL DISASTER SURVEY REPORT 76-1

Big Thompson Canyon Flash Flood of July 31-August 1, 1976

A REPORT TO THE ADMINISTRATOR



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

Rockville, Maryland
October 1976

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U.S. DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary

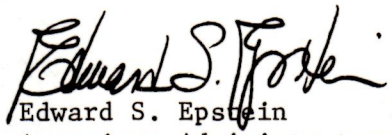
National Oceanic and Atmospheric Administration
Robert M. White, Administrator

BEFORE

AFTER

FOREWORD

While rescue efforts were still underway following the disastrous flash flood which devastated the Big Thompson Canyon, a NOAA survey team was formed and dispatched to Colorado to assess the effectiveness of the warning system and to make recommendations for improvements. This report presents the findings and recommendations of the survey team.



Edward S. Epstein
Associate Administrator for
Environmental Monitoring and
Prediction

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PREFACE

A NOAA survey team reviewed the National Weather Service and National Environmental Satellite Service system performance related to the flash flood which struck Colorado's Big Thompson Canyon the night of July 31-August 1, 1976. The team was composed of Robert E. Beck, Deputy Associate Administrator for Environmental Monitoring and Prediction; Walter D. Castle, Office of Program Integration; John C. Davies, Office of Meteorological and Hydrological Services; Herbert Lieb, Chief, NWS Disaster Preparedness Staff; Laurence G. Shaffer, Assistant Chief, NWS Central Region Meteorological Services Division; Lawrence L. Longsdorf, NWS Central Region Flash Flood Coordinator; H. Michael Mogil, Severe Storms Meteorologist, NWS Public Weather Branch; James F. W. Purdom, NESS Applications Group; and Carl A. Posey, Office of Public Affairs (ERL-Boulder).

Members of the team were in the flood area as early as August 1 and fact-finding began on Monday, August 2. The field portion of the survey, which included trips into and over the damage area, visits to officials and media representatives in Fort Collins, Loveland, and Denver, and to NOAA offices in Denver and Kansas City, was essentially completed by August 6. However, the rainfall survey, which relied on extensive cooperation of other agencies and numerous citizens, required more time, as did visits by team members to NWS and NESS facilities in Camp Springs, Maryland.

The survey team wishes to thank the numerous individuals who cooperated by giving of their time and assistance. These included personnel of NOAA and other Federal agencies, officials of the State of Colorado, Larimer County, various city officials, and the representatives of the news media. Their help made this report possible and will contribute to improvements in the warning system.

CHAPTER 1

THE BIG THOMPSON FLOOD

Flash floods are merciless destroyers. The incredible destructive power and speed with which large volumes of water rush down mountain slopes and across canyon floors make them killers. The Big Thompson flash flood which struck on the evening of July 31, 1976, was no exception. A few short hours separated the onset of heavy rain from the flood crest passing the canyon mouth to quickly subside on the plains below. The heroic efforts of law enforcement officers, who were in the canyon prior to 8:00 p.m.*, and rescue workers kept the loss of lives from being higher but at least 135 persons were killed and the search for the missing continues at the time of this report.

Big Thompson Canyon was an outdoorsman's paradise. One of many such scenic spots in Colorado, it winds torturously down through the Front Range of the Rocky Mountains a distance of some 25 miles (40 km). Estes Park marks the western end of the canyon and it ends near Loveland where the mountains meet the great plains. Dotted with several small communities, many year-round homes, and mountain cabins, it had a permanent population of about 600 people and attracted hundreds of overnight visitors each weekend to the cabins, motels, campgrounds, and camper/trailer sites scattered along its entire length. The total number of people in the canyon on the night of July 31 can only be estimated. Larimer County officials place the number of people in Big Thompson Canyon on that evening between 2,500 and 3,500. A great majority of these were tourists, campers, climbers and others enjoying the rugged beauty of the canyon. The canyon was easily accessible by good highways from both ends. Its eastern end at Loveland is 70 miles (113 km) from Denver and 40 miles (64 km) from Boulder. Many out-of-state visitors as well as Colorado residents were attracted to the canyon. U.S. Highway 34 followed the river through the narrow canyon. The small river, usually a clear, cold, rapidly flowing mountain stream 1 to 2 feet deep, descends some 2,500 feet (760 m) through the 25-mile (40 km) long canyon.

The Big Thompson River is a tributary of the South Platte River. Its source is in Rocky Mountain National Park in north-central Colorado. Its drainage basin covers more than 800 square miles (2,070 sq. km). On the evening of July 31, 1976, during the period 6:30 p.m. to about 11:00 p.m., very heavy rain fell over a 70-square mile (180 sq. km) area in the central portion of the watershed. The most intense rainfall, more than 12 inches (304 mm), occurred over the slopes of the western third of the Big Thompson Canyon. More than four inches of rain fell over the entire canyon area from near Estes Park to Drake (see figure 1). The resulting runoff exceeded the highest previously recorded by almost an order of magnitude, reaching an estimated 31,200 cubic feet (880 cu. m) per second at the mouth of the

*Unless otherwise stated, all times given in this report are Mountain Daylight Time.

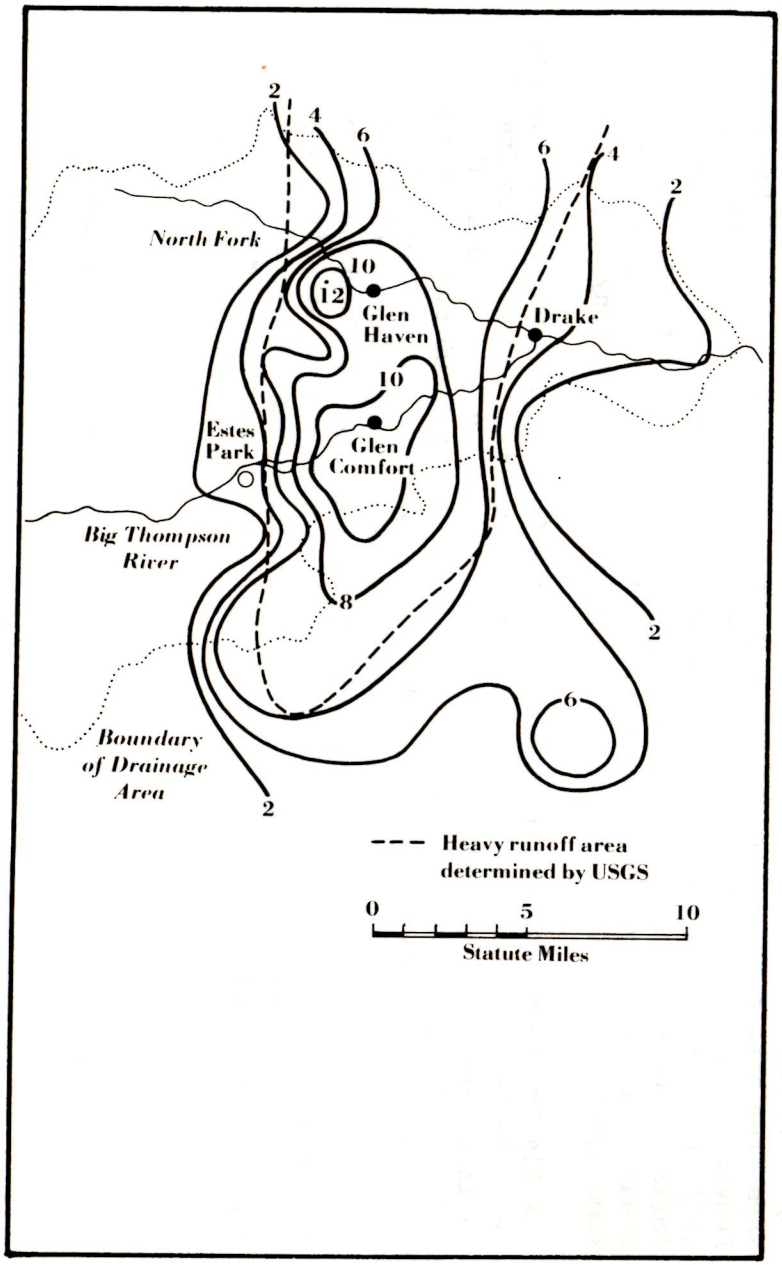


Figure 1. Total Precipitation (Inches) July 31 - August 2, 1976
Based on climatologic network and supplemented by unofficial precipitation reports

TIME SEQUENCE (MDT) FROM FIELD SURVEY

Time	Location	Comments/Source
6:30 - 7:00	Estes Park	Light rain started/news media
6:30	Glen Haven	Rain started/Gordon Leonard
6:00+	Glen Comfort	Heavy rain started/Oscar Hirickstad
7:00 - 8:30 9:00 - 11:00	Estes Park Power Plant	Rain/operator
7:00	Drake	Rain started/Littlejohn report
7:30 - 8:30	Glen Haven	Heavy rain/Gordon Leonard
7:00 - 8:00	Glen Haven vicinity	Heavy rain/Frank Faiella
7:30	Glen Comfort	Very heavy rain/Oscar Hirickstad
7:40	2 mi. upstream from Drake	Heavy, blinding rain/news media
8:00	Glen Comfort	Height of storm/Oscar Hirickstad
8:30 - 9:30	Glen Haven	Light rain/Gordon Leonard
9:30 - 11:00	Glen Haven	Heavy rain/Gordon Leonard
11:00+	Glen Haven	Light rain remainder of night/ Gordon Leonard
	Glen Comfort	Light rain all night/Oscar Hirickstad
1:30 AM	Drake	Able to go down to Drake/ Littlejohn report

canyon. According to reliable witnesses, there were no surging walls of water marking the head of the flood crest, but rather a very rapidly rising river. The waves of debris typical of flash floods such as this often give the appearance of a 'wall of water.'

A question always asked in unusual natural events is: "How rare was this rainfall and flood?" It is very difficult to answer in precise terms, but the survey team has been able to establish some facts that relate to that question. First, the flood level exceeded the 100-year flood expectations. This means that the flood was in the less than 1% probability of occurrence in any year. Second, the rainfall amount of 12+ inches in about 4 hours is not really unusual when viewed with other events. For example, in 1969, 32+ inches (over 810 mm) of rain fell in less than 8 hours in southwestern Virginia and rainfall amounts of 10-12 inches (250-300 mm) in a 3 to 4 hour period occur in several locations each year. Third, there are flash floods similar to this one occurring frequently during the summer in the Rocky Mountains. However, most of these flash floods go unnoticed because the canyons are devoid of people and roads. The Big Thompson flash flood effect was greatly amplified by the constriction due to the narrow channeled flood plain in the canyon.

Meteorological conditions that produced the 4 1/2-hour deluge of rain were somewhat abnormal. On Friday and Saturday a surface cold front had moved slowly southward through the Central Plains states. By 6:00 p.m. Saturday, July 31, the now almost stationary front lay east-west through Missouri and Kansas into central Colorado where it curved northward along the eastern slopes of the Front Range of the Rocky Mountains from about Denver into central Wyoming. The air on both sides of the front was conditionally unstable with abnormally high amounts of moisture in lower levels concentrated on the north side of the front. The Denver radiosonde observation taken at 6:00 p.m. Saturday, July 31, showed mixing ratios of 8-9 gms/kg to 600 millibars (60 kPa) and the observation made 12 hours earlier showed slightly higher moisture values. Convective activity that had persisted along the frontal zone into Saturday morning as light scattered showers began to intensify by early afternoon in eastern and south-central Colorado. Thunderstorms had reached severe intensities by 3:00 p.m. when severe thunderstorm warnings were issued for Kit Carson and Cheyenne counties in eastern Colorado. Also, active thunderstorms were scattered along the Front Range in a generally north-south line or zone from northern New Mexico into southern Wyoming. About 6:00 p.m., Limon weather radar first detected convective cells beginning to develop over the Big Thompson drainage basin. During the brief period from 6:30 to 7:00 p.m. the organization and intensity of the thunderstorm activity began very significant and rapid changes. The new convective cells along the Front Range began to intensify, with explosive development in north-central Colorado. Storms along the remainder of the frontal zone began a rapid decay. By 8:00 p.m. only the band of storms along the Front Range remained active. Slow northerly movement coupled with rapid development of new cells to the south combined to produce a seemingly stationary intense storm and very heavy precipitation over the Big Thompson drainage basin from about 6:30 p.m. to 11:00 p.m. A more detailed description of the synoptic situation is contained in Chapter 3.

CHAPTER 2

DATA ACQUISITION

Meteorological data and information from surface, upper air, radar and satellite observations are available at WSFO Denver. These data arrive over several communications channels. This chapter will discuss these data sources and channels of communication as they existed on the day of the flood.

Surface Observations

WSFO Denver receives four types of surface observations for its forecast and warning programs: (1) aviation observations from first and second order stations and supplementary aviation weather reporting stations (SAWRS); (2) reports from cooperative or paid observers in the hydrologic, fire weather, and public service networks; (3) reports from automated reporting equipment; and (4) reports from the public, spotter networks, and law enforcement agencies.

Communication channels used to deliver data to WSFO Denver are listed in the following table. Commercial telephone service into the flood area was disrupted by the flood. The radar remote display from WSMO Limon was inoperative on July 31, 1976, and there were long-standing problems with some automated observations. These will be discussed under the section dealing with the particular type of observation. There were no problems reported with other channels of communication.

Teletype	Facsimile	Telephone
Service A	FOFAX	Commercial
Service C	NAFAX	FTS
Fire Weather Circuit		Hot-line
RAWARC	WBRR	NAWAS
NOAA Weather Wire		AHOS/T
AHOS/S		
Computer Terminal		

Aviation Observations--Aviation weather observations are taken by NWS or FAA personnel on a 24-hour basis at 9 Colorado locations. The NWS WSMO at Limon takes three-hourly surface observations. Surface weather observations are made at Alamosa from 4:00 a.m. to midnight on weekdays and from 4:00 a.m. to 7:00 p.m. on weekends. With the exception of Alamosa, where no provision is made for evening precipitation reports on the weekends, all these stations report 6-hourly precipitation amounts. Observers at second-order (contract) stations and Supplementary Aviation Weather

Reporting Stations (SAWRS) provide a widely varying schedule of observations from Rifle, Durango, Aspen, Gunnison, Montrose, Lamar, Leadville, Hayden, Cortez, Salida, Craig, and Fort Collins. With the exception of Hayden and Cortez, some precipitation amounts are available from these stations. The Fort Collins observations, taken every two hours, are phoned to WSFO Denver. None of these surface observation points are in the Big Thompson Canyon. Figure 2 shows the aviation observing points in Colorado.

Cooperative and Paid Observers--A large part of the observations needed in the NWS hydrologic, fire weather, and public service programs are provided by cooperative and paid observers.

The Colorado Amateur Weather Net has 48 weather observing sites. These stations report local weather conditions only once each morning and were of no benefit in the warning situation. Fifteen of the 48 stations are in the Platte drainage basin and the one at Estes Park is in the Big Thompson watershed. None of the stations were in the area of heaviest rainfall.

There are 37 fire weather observing stations in Colorado. The observations, which include 24-hour precipitation amounts, are made at 1:00 p.m. daily during the fire season. The observations are distributed on the fire weather teletype circuit serving Colorado, Wyoming, and western South Dakota. These reports also were of no benefit in warnings of the flash flood since the storm developed and the flood passed between observing times.

Cooperative or paid observers provide the 28 rainfall reports which make up the bulk of the precipitation input used by WSFO Denver and the Kansas City River Forecast Center in forecasting for the Platte drainage area in Colorado. As shown in figure 3, none of these reports are in the Big Thompson or Cache la Poudre basins.

Reports from automated data sources--Figure 4 shows the locations of the 19 river stage reporting points in the Platte drainage area. Ten of these are automated; nine must be read manually. None of these regular reporting points are in the Big Thompson or Cache la Poudre basins. There is a state-owned gage on the lower portion of the Cache la Poudre River that is telemetered into the home of a resident of Ft. Collins. This gage was used as a source of information by WSFO Denver on the night of the flood, but did not contribute information about the Big Thompson River.

A start toward more complete automation of the Colorado hydrologic network has been made by installing 16 Automatic Hydrologic Observing Stations (AHOS). Two of the installations, river gages at Orodell and Julesburg, are interrogated by telephone. These two reporting gages are used routinely by WSFO Denver. Fourteen installations use radio to send the data through the GOES satellite and then ground relay to WSFO Denver. Figure 5 shows the AHOS locations. These 14 installations, termed AHOS/S,

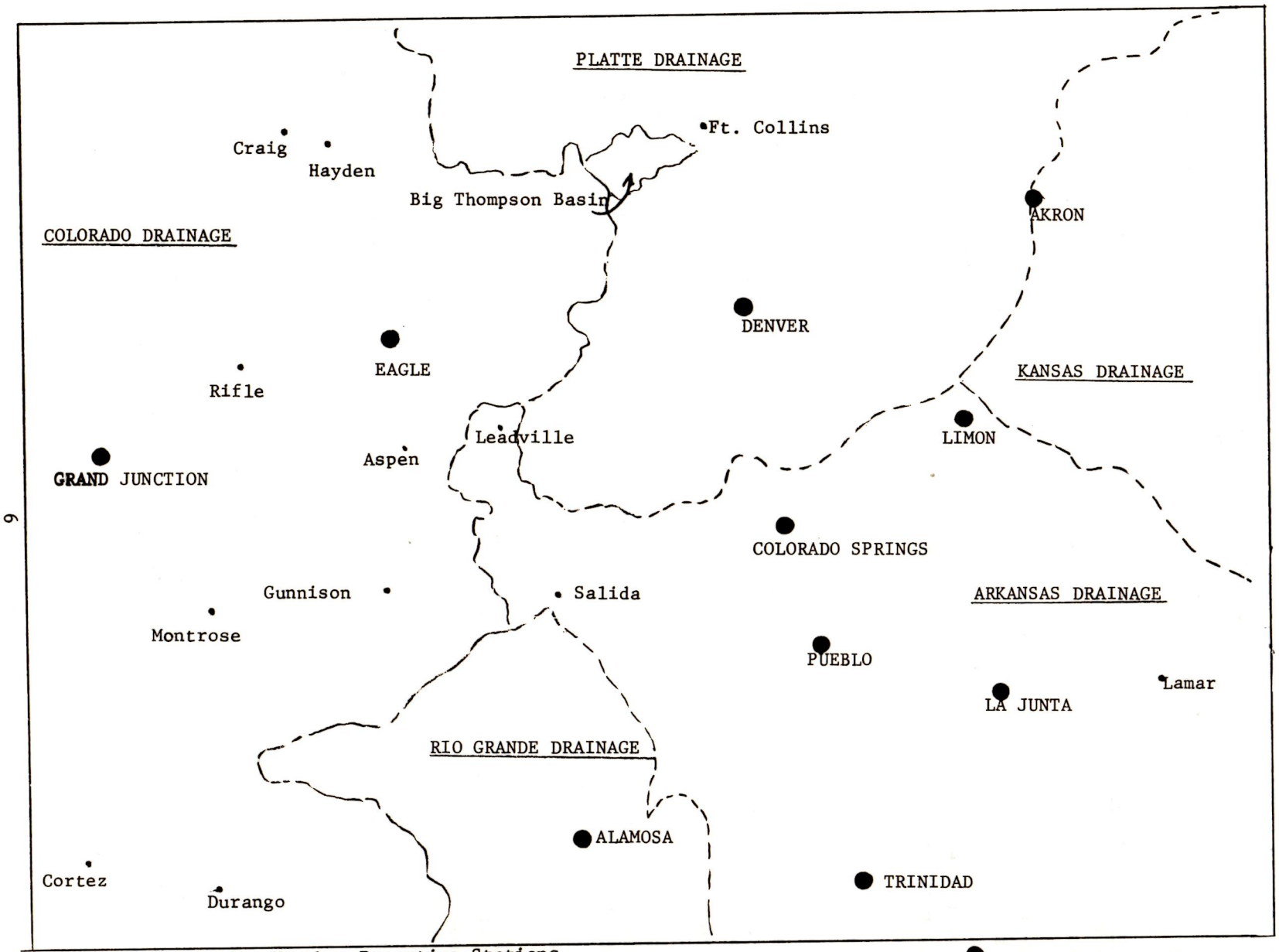


Figure 2. Aviation Weather Reporting Stations.
(River Drainage Basins are outlined by dashed lines.)

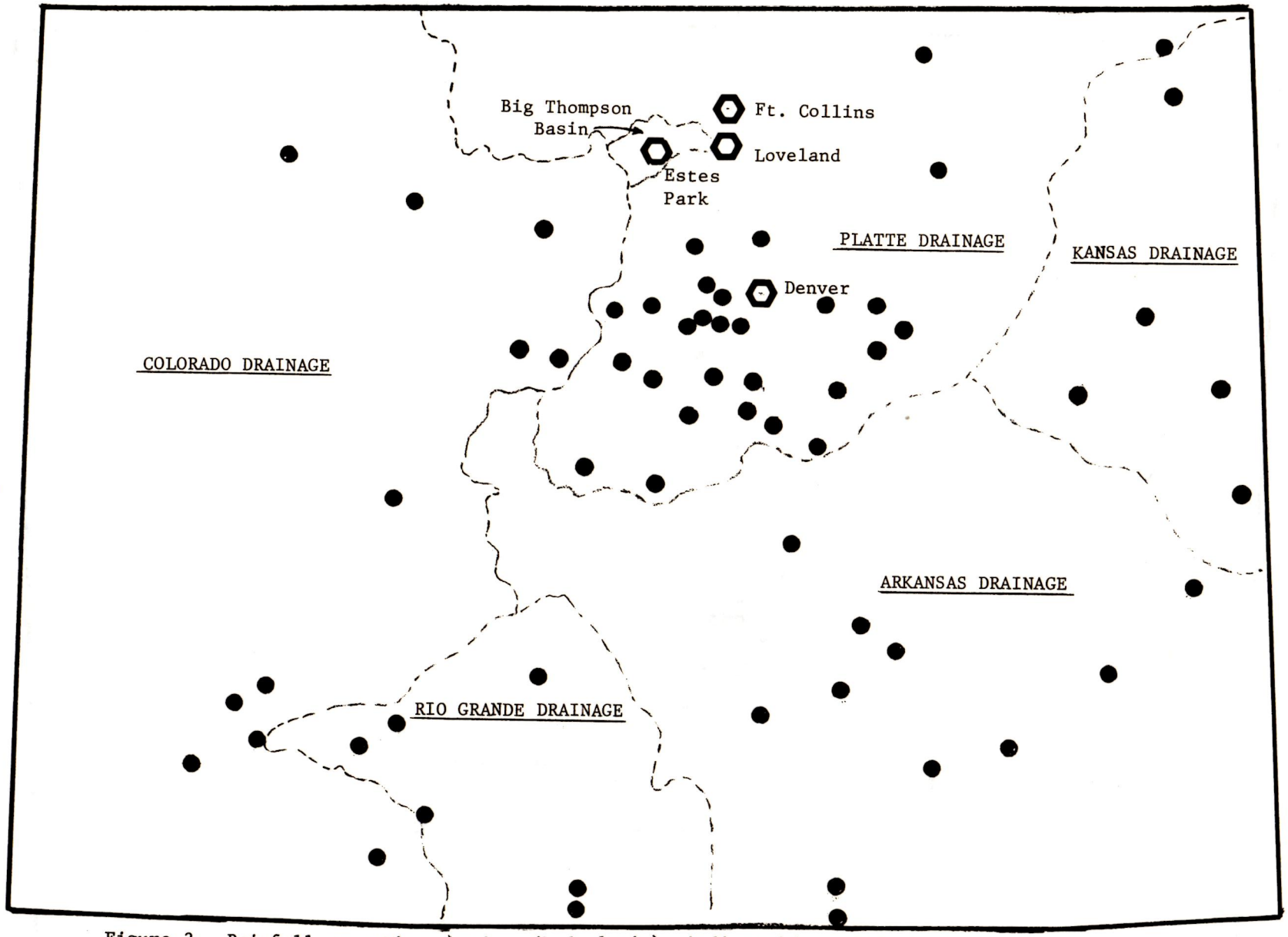


Figure 3. Rainfall reporting stations (hydrologic), indicated by solid circles.

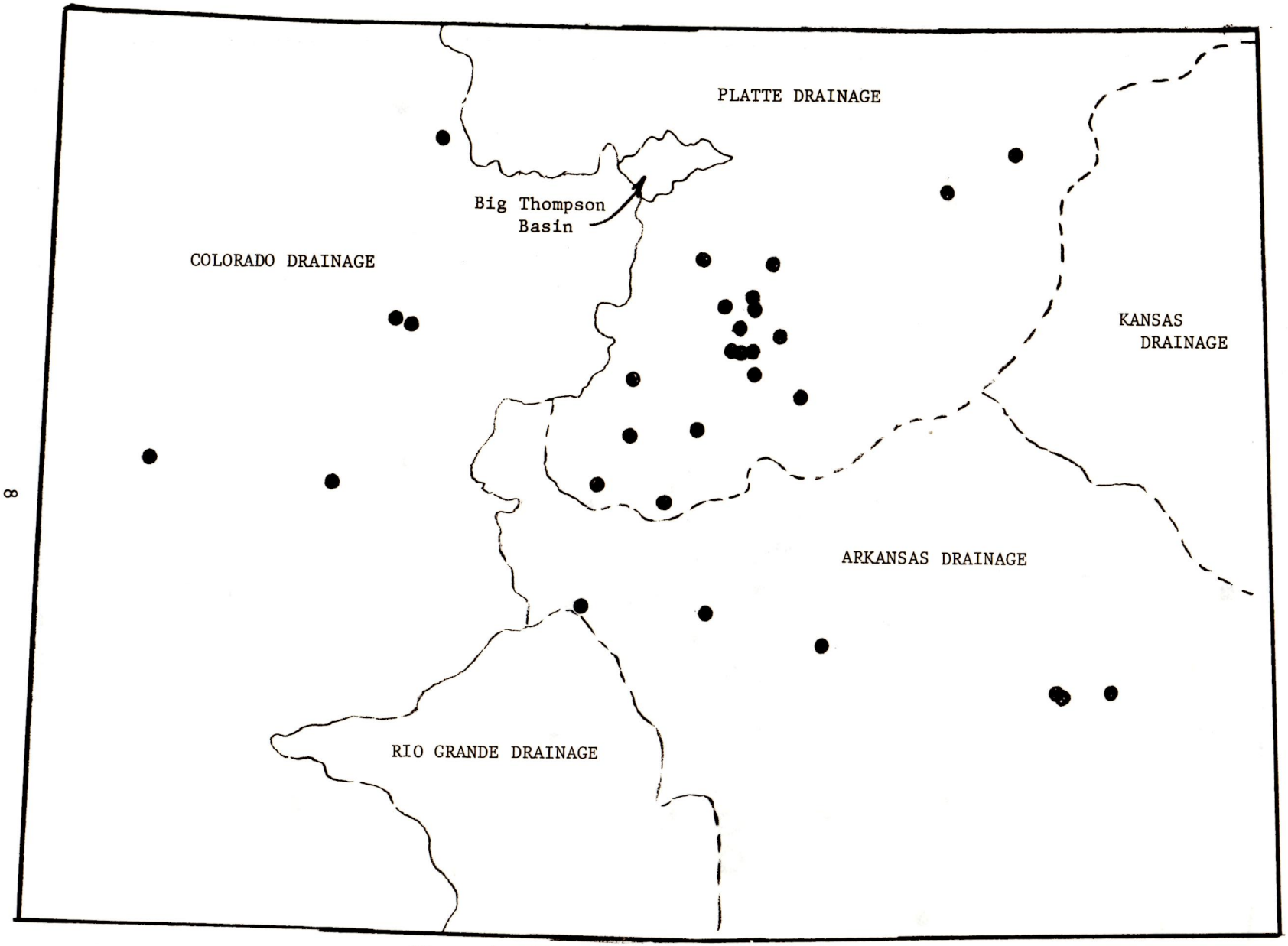


Figure 4. River Stage Reporting Points.

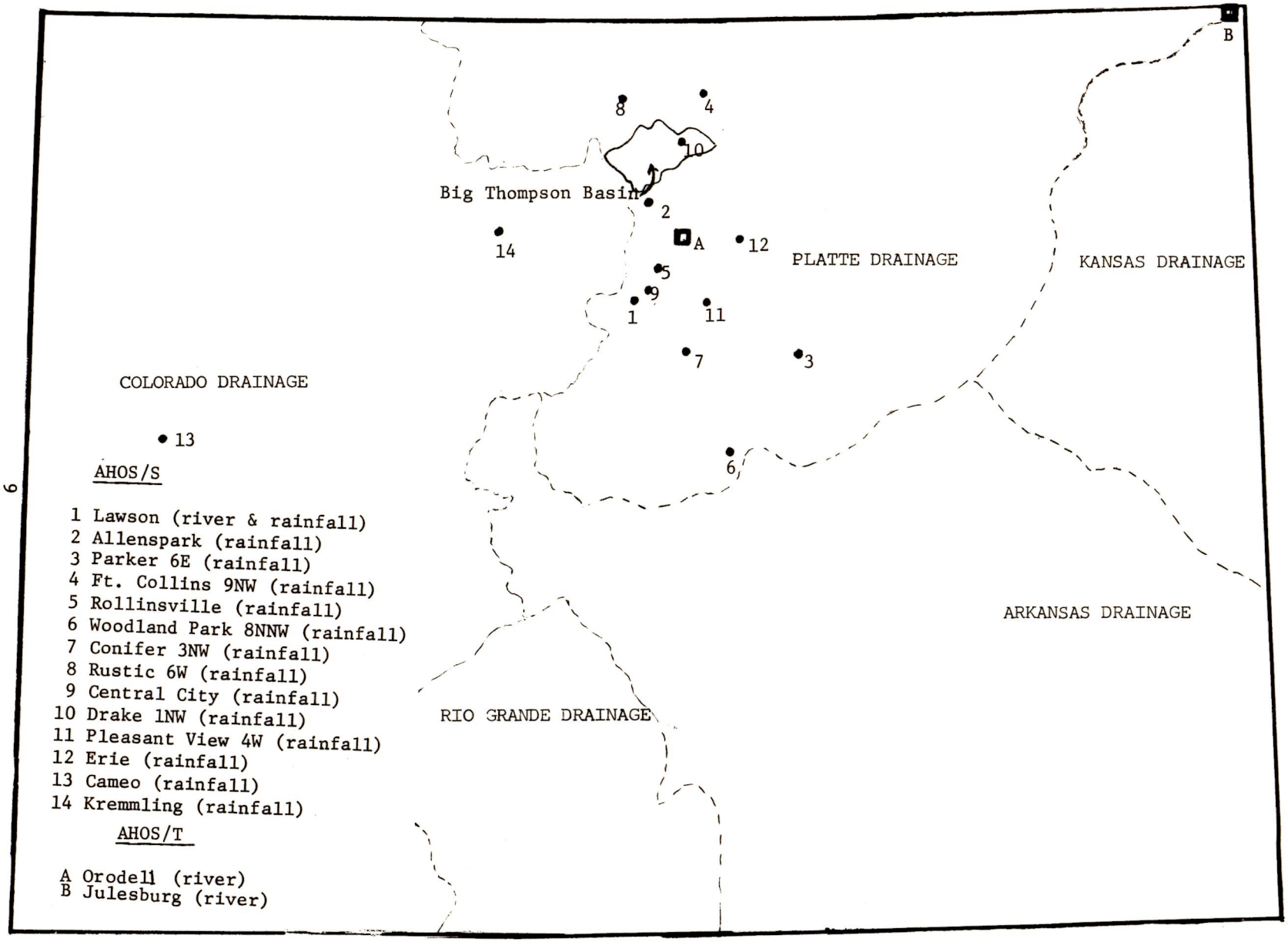


Figure 5. AHOS Sites.

have presented significant maintenance and reliability problems according to the forecast and maintenance staffs at WSFO Denver and the Central Region Headquarters. Termed "experimentally operational," these 14 installations, which were activated in 1975, were not yet commissioned. No use of the data from them was being made by WSFO Denver prior to or during the flood. They had concluded that the maintenance and reliability problems with these test systems made them unusable. The electronic technicians at Denver have continued to monitor the read-outs daily, for maintenance purposes.

There were initial problems with the SMS-1 satellite data relay systems. Since transmission through SMS-2 began in March, 1975, the primary problem with these systems, according to the Equipment Program Officer at Denver, was in the Data Collection Platform Radio Sets (DCPRS). The maintenance problems with the 14 sets were recognized by NWS in 1975 and new sets will replace these test sets by the end of 1976.

One of the AHOS/S units was installed at Drake in the Big Thompson Canyon. The reports from this rain gage indicate that it was operating and reporting on schedule until Thursday, July 29. On that date, the reading dropped from the previous reported accumulation of 5.00 inches to 1.00-inch, indicating that either the equipment had malfunctioned or the gage had been partially emptied. The 1.00-inch reading continued to be reported until the gage was destroyed by the flood shortly after its last scheduled report was made at 7:00 p.m. on July 31.

Three of the AHOS/S rain gage sites (Drake, Rustic, and Fort Collins) have people under contract to periodically empty the rain gages and mail in the recorder charts. The Meteorologist-in-Charge at WSFO Denver indicated they were going on the assumption that the test system would work and did not ask these people to act as back-up observers for a test system.

Reports from public, spotter networks, local and state officials--These reports are vital to an effective warning program. Radar and satellite systems give indications, but do not tell exactly, what weather is occurring. Most severe local storms are too small in horizontal extent to be picked up by the standard surface observing networks. Therefore, surface observing networks, satellites, and radars must be reinforced by on-the-spot cooperative observers if we are to give the precision and accuracy to warnings needed to make them useful and credible to the public.

There were many such potential observers in the Big Thompson Canyon early in the evening of July 31. Numerous eyewitness accounts of downpours and flooding were later reported in newspapers. Not one of these reports reached the forecaster in WSFO Denver in time to refine his warning and reflect the disastrous events in the canyon. Shortly after 8:00 p.m., law enforcement dispatchers had indications of rocks blocking a section of U.S. Highway 34, but this information was not given to WSFO Denver until about 9:30 p.m. At about 10:00 p.m. similar information was put on NOAA Weather Wire by

a State Highway Patrol office in Denver.

The last face-to-face contact that personnel at WSFO Denver had with local officials in Larimer County occurred in April 1974. The April 1975 annual visit to recruit and train storm spotters for the upcoming severe thunderstorm season did not take place due to a severe travel fund restriction then in effect. A telephone call from WSFO Denver was made to the Larimer County Sheriff's office, eliciting a map of county storm spotters. There was no contact with county officials in 1976. The reasons for this situation given by the Meteorologist-in-Charge at WSFO Denver was a lack of travel funds and a personnel shortage. The survey team found that there were fiscal year 1976 travel funds available which were not spent as of August 1, 1976, and that there were extra scheduled shifts available in WSFO Denver which could have been used for the purpose of travel for disaster preparedness and recruiting of cooperative observers.

The survey team found that the cooperative observer and spotter networks in the disaster area had not received adequate attention over the past two years and that potential sources of rainfall and river conditions which had been in existence for long periods of time had not been contacted by WSFO Denver or other NWS personnel to obtain cooperative reports.

Upper Air Reports

Denver is a rawinsonde station in the national network. Observations are made routinely at Denver at 6:00 a.m. and 6:00 p.m. Data from the national network are utilized in synoptic-scale analyses and prognoses by the National Meteorological Center. The National Severe Storms Forecast Center uses the data in its smaller scale analyses and severe thunderstorm watches. At WSFO Denver, the local rawinsonde observation is plotted and displayed for forecaster use. During the summer months, observations are also plotted for Amarillo, Albuquerque, Winslow, Salt Lake City, Grand Junction, and Lander. Upper air observations were taken and disseminated without problems on July 31, 1976. Figure 6 is a plot of the Denver soundings made on July 31. They are characterized by conditionally unstable lapse rates and much higher than normal water vapor content. Light winds aloft were reported.

Weather Radar

Weather radar coverage of eastern Colorado is provided by the WSR-57 radar at Limon. WSMO Limon is an independent office operating directly under the Central Region Headquarters. WSFO Denver has no formal administrative or operational responsibility for or control over WSMO Limon. The Limon radar, which is located about 65 miles (105 km) southeast of Denver, was activated in June 1970. Limon was chosen as the site for the radar to provide support for the public forecasts and warnings to population centers in eastern Colorado.

The Big Thompson Canyon is within range of this radar. Estes Park is located at 310°/111 nautical miles (206 km) and Drake at 315°/106 nautical miles (196 km) from Limon. (See figure 7 for copy of radar overlay.) The radar

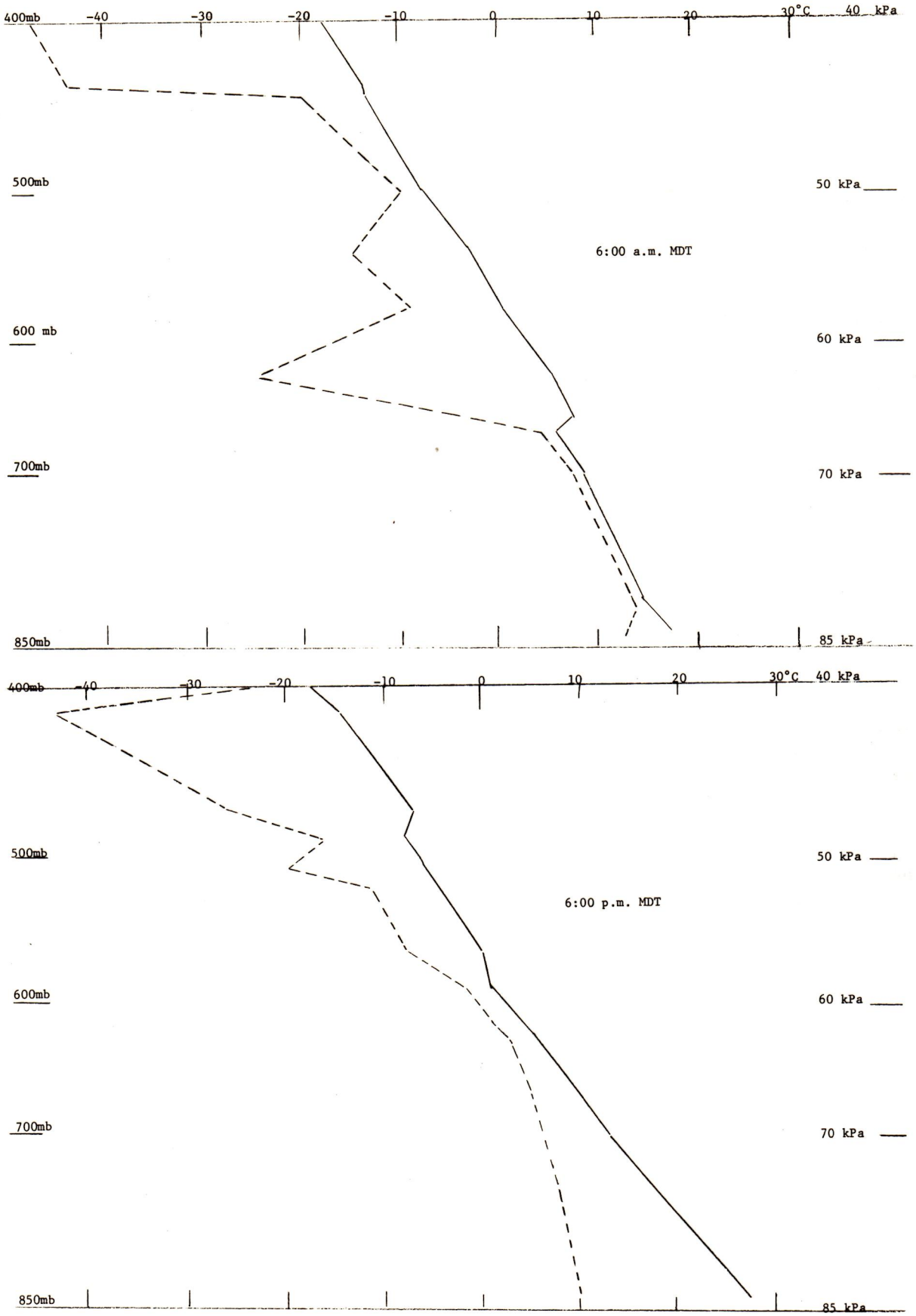


Figure 6. Temperature (solid line) and dew point temperature (dashed line) from Denver soundings taken on July 31, 1976.

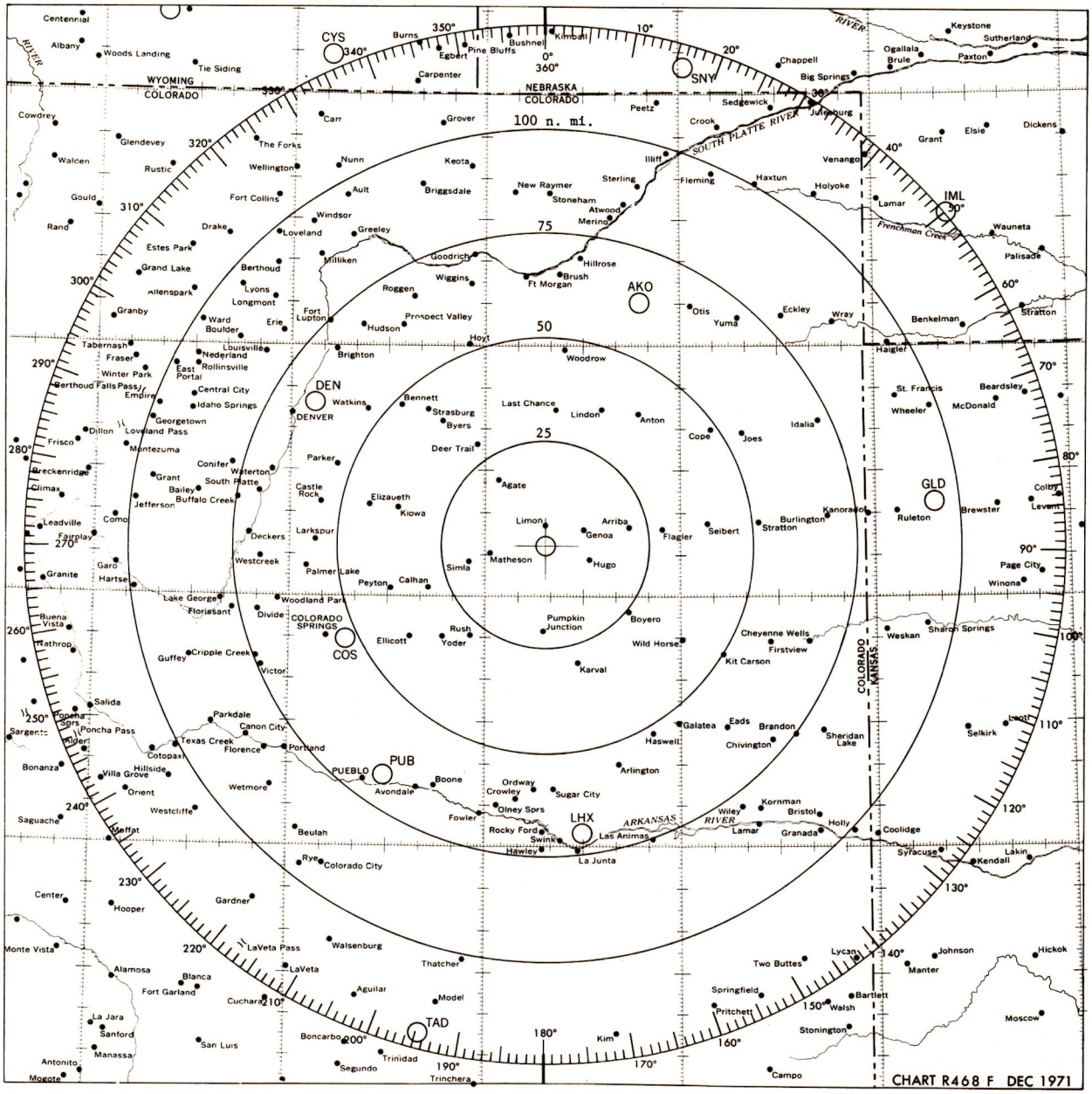


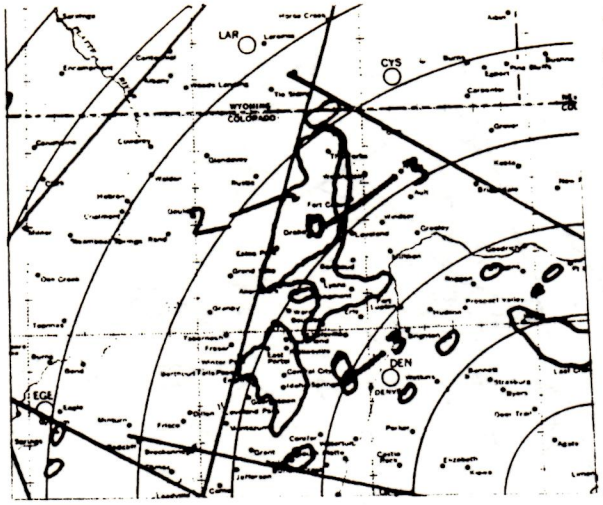
Figure 7. Copy of 125 nautical mile overlay for Limon radar.

was operating through the afternoon and night of July 31-August 1, although at 7:30 p.m., the radar operator became concerned that the Video Integrator Processor (VIP) might be reading low and had begun obtaining storm intensities in the LIN mode.* The VIP, which automatically provides contouring of various levels of echo intensity, relies on relatively complex circuitry. The LIN mode of operation relies on simpler circuits to obtain these intensities. The radar operator informed the lead forecaster at WSFO Denver of this action between 9:30 and 10:30 p.m. Based on a review of photographs of the PPI scope made during the time in question, the team concluded that the WSR-57, including the VIP, was operating satisfactorily on the evening of July 31, 1976.

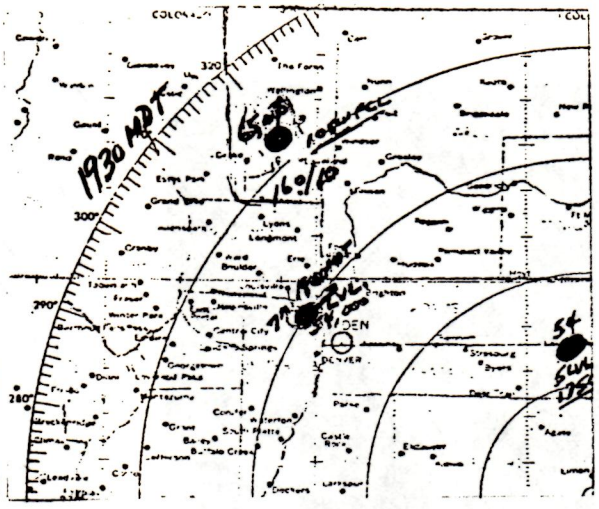
Reproduction of the WSR-57 radar's PPI scope presentation, plus operator annotations, are provided to WSFO Denver by means of a facsimile system known as WBRR (Weather Bureau Radar Remote). The WBRR system was not operating on July 31, 1976. This equipment was logged out of operation at 3:30 p.m. on Friday, July 30, and was restored to service at 1:00 p.m. on Sunday, August 1.

Without the WBRR picture, the lead forecaster at WSFO Denver was dependent for his radar information upon a verbal description of radar echoes as given by the radar operator at Limon over the direct telephone circuit connecting the two offices. This circuit was used frequently during the evening of the flood, and the lead forecaster plotted what he considered significant information on blank radar overlays at approximately 7:30, 8:20, and 11:00 p.m. Comparing these sketches with copies of the applicable portion of the PPI scope tracings (figure 8) made by the radar operator at about the same times supports the team's conclusion that the outage of the WBRR detracted from the capability of the lead forecaster at WSFO Denver. This outage had little effect on the issue time or content of the initial warning released at 7:35 p.m., but the forecaster was subsequently unable to fully grasp the situation as the radar was viewing it. The lead forecaster initially stated to the team that he didn't believe that the WBRR outage had any significant impact on his warning capabilities. After looking at the radar operator's sketches, he revised his views on this point. He became aware of important information on radar echo location and intensity he had not assimilated by telephone. Figure 9 shows the PPI scope photographs and the radar operator's tracings; persistence of the precipitation echoes over the Big Thompson Canyon is evident in both.

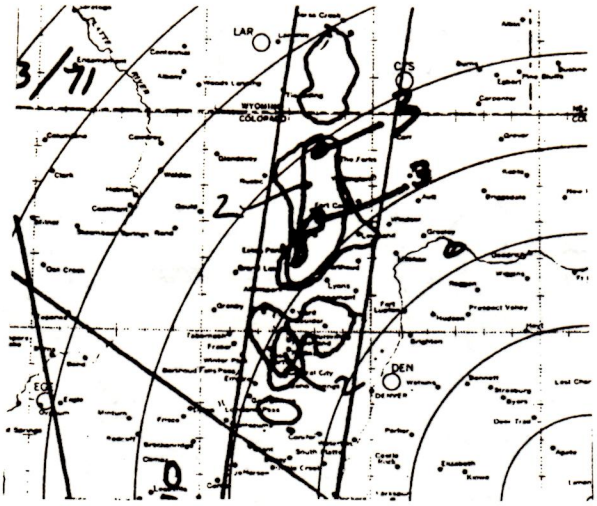
*A check of the radar after the flood indicated that the VIP was operating within acceptable tolerance. The reason the operator believed the VIP might be reading low was the apparent discrepancy between the extremely high radar echo tops (62,000 feet or about 18.9 km) and the relatively low reflectivity (level 3) for the storm centered 10 miles southwest of Fort Collins at 7:30 p.m.



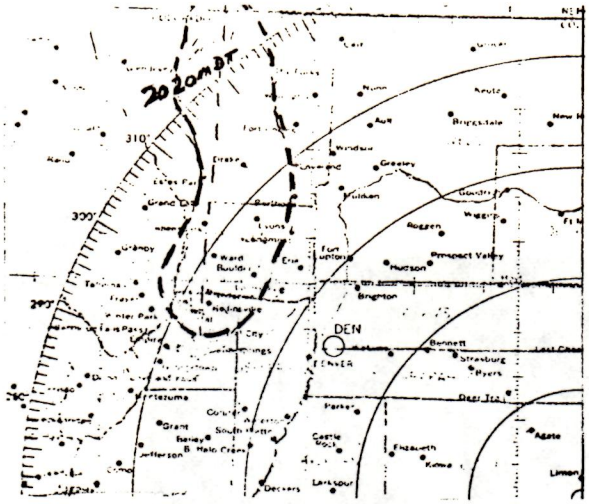
Scope tracing made for 7:30 p.m. observation



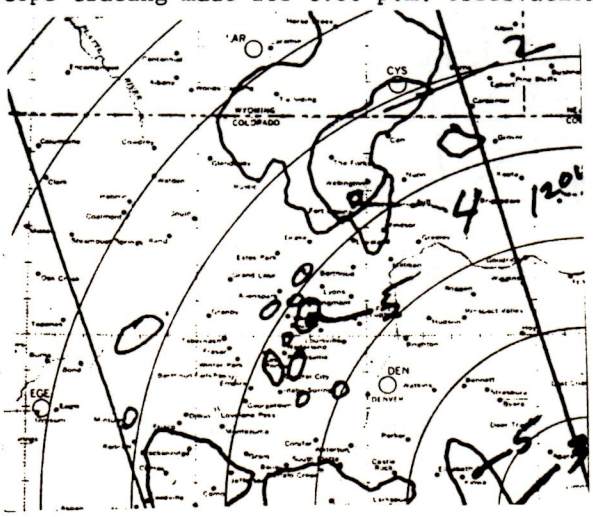
7:30 p.m. Cells to east and immediately northwest of Denver are earlier times.



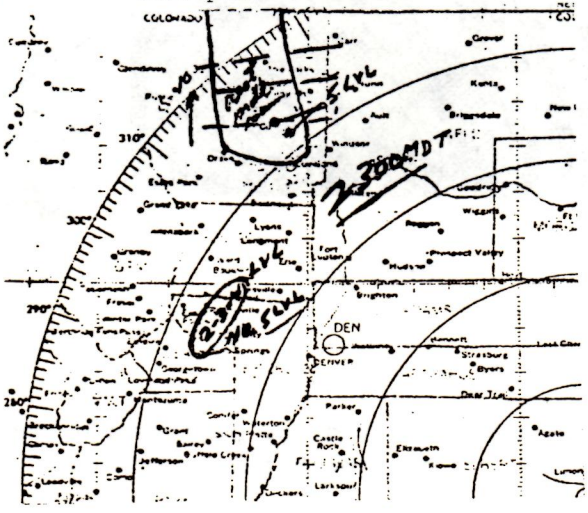
Scope tracing made for 8:30 p.m. observation



8:20 p.m.

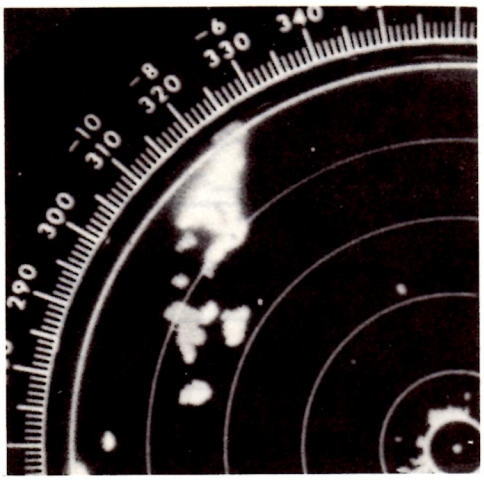


Scope tracing made for 11:30 p.m. observation

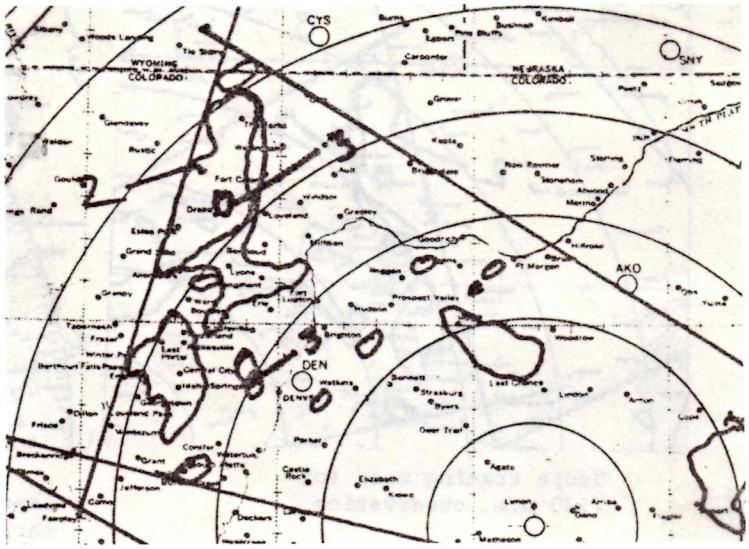


11:00 p.m.

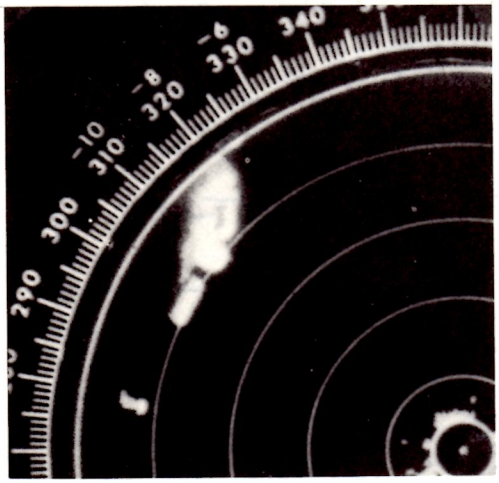
Figure 8. Comparison of radar scope tracings and sketches made by forecaster.



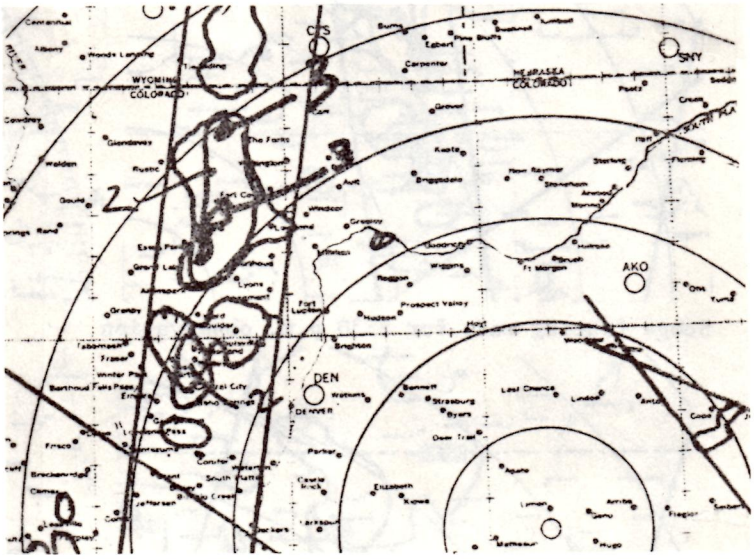
7:28 p.m.



Radar scope tracing made for
7:30 p.m. observation



8:32 p.m.



Radar scope tracing made for
8:30 p.m. observation

Figure 9. Radar scope photographs and tracings indicating persistence of precipitation echoes.

The intensity (reflectivity) of weather radar echoes is used operationally to estimate rainfall rates. The accuracy of this technique decreases with increasing distance of the precipitating cloud from the radar. This is due largely to earth curvature causing the radar beam to intersect increasingly higher levels in precipitating clouds as ranges increase. For this reason, no quantitative estimates of rainfall rates are made for ranges beyond 125 miles (230 km) from WSR-57 radars. Thus, the distance of the Big Thompson Canyon from Limon (100-115 miles) approaches the effective limits for estimating rainfall from WSR-57 radars, particularly in the absence of "ground truth" rainfall observation to calibrate or verify the radar estimates. It should also be noted that other factors, such as the structure of the cloud (liquid water versus water-covered hail) affect reflectivity and the accuracy of rainfall estimates. In practice, the following table, which was available to both the radar operator and the lead forecaster, is used to convert reflectivity levels to estimated rainfall rates:

Level 1 - less than 0.1 inch (2.5 mm) per hour
Level 2 - 0.1 to 0.5 inch (2.5 to 12.7 mm) per hour
Level 3 - 0.5 to 1 inch (12.7 to 25.4 mm) per hour
Level 4 - 1 to 2 inches (25.4 to 50.8 mm) per hour
Level 5 - 2 to 5 inches (50.8 to 127 mm) per hour
Level 6 - greater than 5 inches (127 mm) per hour

Both the lead forecaster and the radar operator have stated that they were puzzled by an apparent discrepancy between the very high radar echo tops (62,000 feet) and relatively low reflectivity (level 3) of the storm centered 10 miles southwest of Fort Collins about 7:30 p.m. Storms with tops this high normally have reflectivity values greater than level 3. The radar operator stated that he concluded from the high tops and vertical structure of the storm cells that the area was receiving large amounts of rain and so notified the forecaster about 7:15 p.m., when he also suggested a severe thunderstorm warning with a mention of flooding. This was the basis for the severe thunderstorm warning issued by WSFO Denver at 7:35 p.m.

The radar operator was maintaining a log of Manually Digitized Radar (MDR) values indicative of cumulative rainfall shown by the radar. The MDR total for the four hourly observations from 6:30 to 9:30 p.m. was 18, slightly below the NWS standard flash flood alerting threshold of 20.

Experience gathered at the National Severe Storms Laboratory and from the Digitized Radar Experiment (D/Radex) indicates that these standard values are not always valid. A recent study* of cool season precipitation (generally stratiform clouds) and MDR values in the southern Appalachians shows widely differing radar/rain gage relationships for mountainous and flat terrain.

*NOAA Technical Memorandum SR-84 "A Comparison of Manually Digitized Radar Data and Observed Cool Season Precipitation over the Southern Appalachians." January 1976.

The survey team was favorably impressed with the attitude and skill of the radar operator on duty at Limon the evening of the flood. He was called in early that afternoon and assisted the day shift operator from 1:00 p.m. until he took over operator duties at his scheduled duty time of 4:00 p.m. He remained on duty for an additional 12 hours.

Several of the Denver forecasters indicated that the radar at Limon began giving problems "about two years ago." An examination of the outage sheets prepared by the electronics technicians at Limon indicates outages in 1975 were relatively few and for short periods. There was perhaps a slight increase in March and April of 1976 and a very large increase in outages and hours of outage in July, as seen on the following table.

Month	Number of outages	Hours of outage	Repair Time
Feb. 1975	1	7	7
Mar.	1	1	1
Apr.			
May			
June			
July			
Aug.	3	4	4
Sept.			
Oct.			
Nov.	2	7	6
Dec.	2	6	6
Jan. 1976			
Feb.			
Mar.	3	9	8
Apr.	4	6	5
May			
June			
July	8	188	45

In an attempt to find a reason for the recent increase in outage in 1976, the survey team examined electronics technician manning at Limon. Prior to January 1976, two technicians were assigned. One was then transferred to Huron and the vacant position was transferred to WSFO Cheyenne. In June 1976, the remaining technician assumed the role of acting official-in-charge and performed the added administrative and supervisory duties while continuing his maintenance responsibilities. Some of the outage time in July 1976 is attributable to bringing a technician from Garden City, Kansas during a period the Limon technician was on leave. The WBRR outage during the flood was caused by failure of a part in the video transmitter circuits. It was difficult to trouble-shoot and was repaired by the Limon technician as expeditiously as could be expected.

The Meteorologist-in-Charge at WSFO Denver was asked for his appraisal of the reliability of the Limon radar. He indicated, in his judgement, the problems were more with inexperienced operators rather than the equipment.

Although not directly related to this event, it is true that WSMO Limon had experienced a very high rate of staff turn-over which has had an adverse impact on operator experience level. Based on discussions with staff members at Limon and with the Central Region Director, the team concluded that this was due to two factors. First, the grade structure at Limon places operator grades one level lower than operators for a WSR-57 collocated with a WSO or WSFO where they participate in non-radar functions. The second factor is the scarcity and high price of family housing in or near Limon. Operators stay at Limon only until they can bid successfully on another job. There have been a total of 18 different people assigned to the 5-man operator staff since 1970 with the greatest turnover beginning in 1974.

In spite of these problems, a qualified radar operator was on duty during the storm. The survey team also noted first-hand that the forecasters at WSFO Denver rely very heavily on the Limon WSR-57 in carrying out their warning functions.

Satellite Data

A large amount of satellite imagery is available to the forecaster at WSFO Denver and he may also call on the Satellite Field Service Station (SFSS) in Kansas City for assistance in interpretation of satellite information.

On the day and evening of the flood, all satellite data were received at WSFO Denver and SFSS Kansas City as scheduled at half-hourly intervals. Grids are implanted on the pictures by computer prior to receipt at both offices. Gridding accuracy was within the 20 miles which has been established as a requirement. All imagery received at WSFO Denver was of high photographic quality and was posted for the forecaster to see, with each picture available to the forecaster about 20 minutes after it was taken. This delay is inherent in the system. Images are ready for interpretation by the meteorologist at SFSS Kansas City 30 to 35 minutes after the satellite has viewed an area. The additional lag-time, as compared with availability at WSFO Denver, is due to photographic dark room processing of the imagery and its ingestion into the SFSS image analyzer equipment.

Use of Satellite Data at WSFO Denver. The main uses of satellite imagery at WSFO Denver are: (a) determination of thunderstorm location and behavior west of the Continental Divide where WSFO Denver has no real-time radar coverage; (b) location of fronts and squall lines; and, (c) extent of nighttime cloud cover. During the day shift on July 31, the fire weather forecaster used satellite data to monitor thunderstorm development in the southwest part of the state and the lead forecaster increased rainfall probabilities in his forecast based on the abundant moisture evident in the satellite pictures. The lead forecaster on the evening shift began his work at 4:00 p.m. He noticed from satellite pictures that thunderstorms were forming along a line from central Kansas into eastern Colorado, as seen in figure 10. He took note of this line again at 7:30 p.m., as he was issuing a severe thunderstorm warning (figure 11). He again looked at the satellite data between 9:00 and 9:30 p.m. when he used the imagery to again confirm the Limon radar information that the thunderstorms were moving northward out of the Estes Park area.

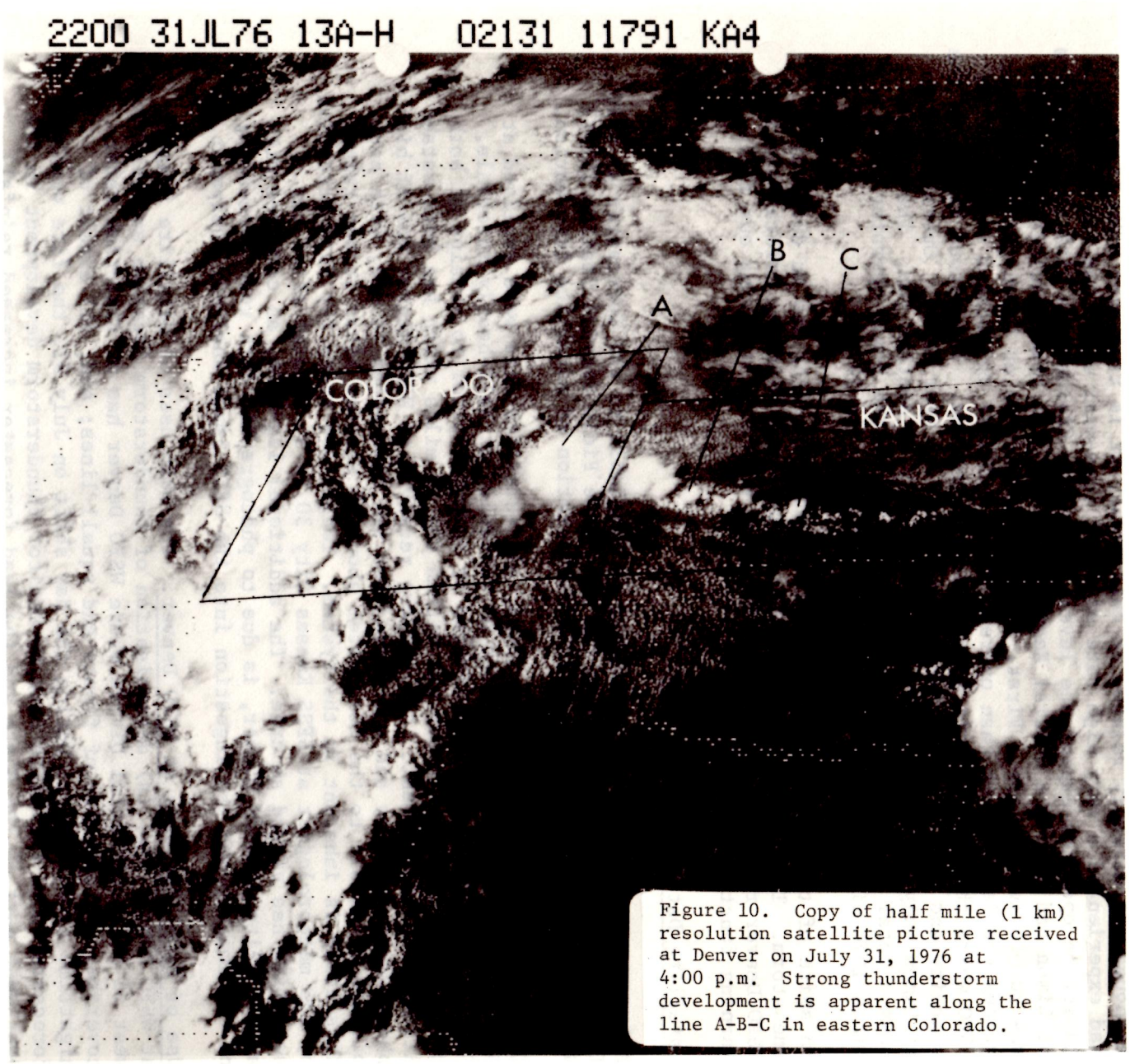


Figure 10. Copy of half mile (1 km) resolution satellite picture received at Denver on July 31, 1976 at 4:00 p.m. Strong thunderstorm development is apparent along the line A-B-C in eastern Colorado.

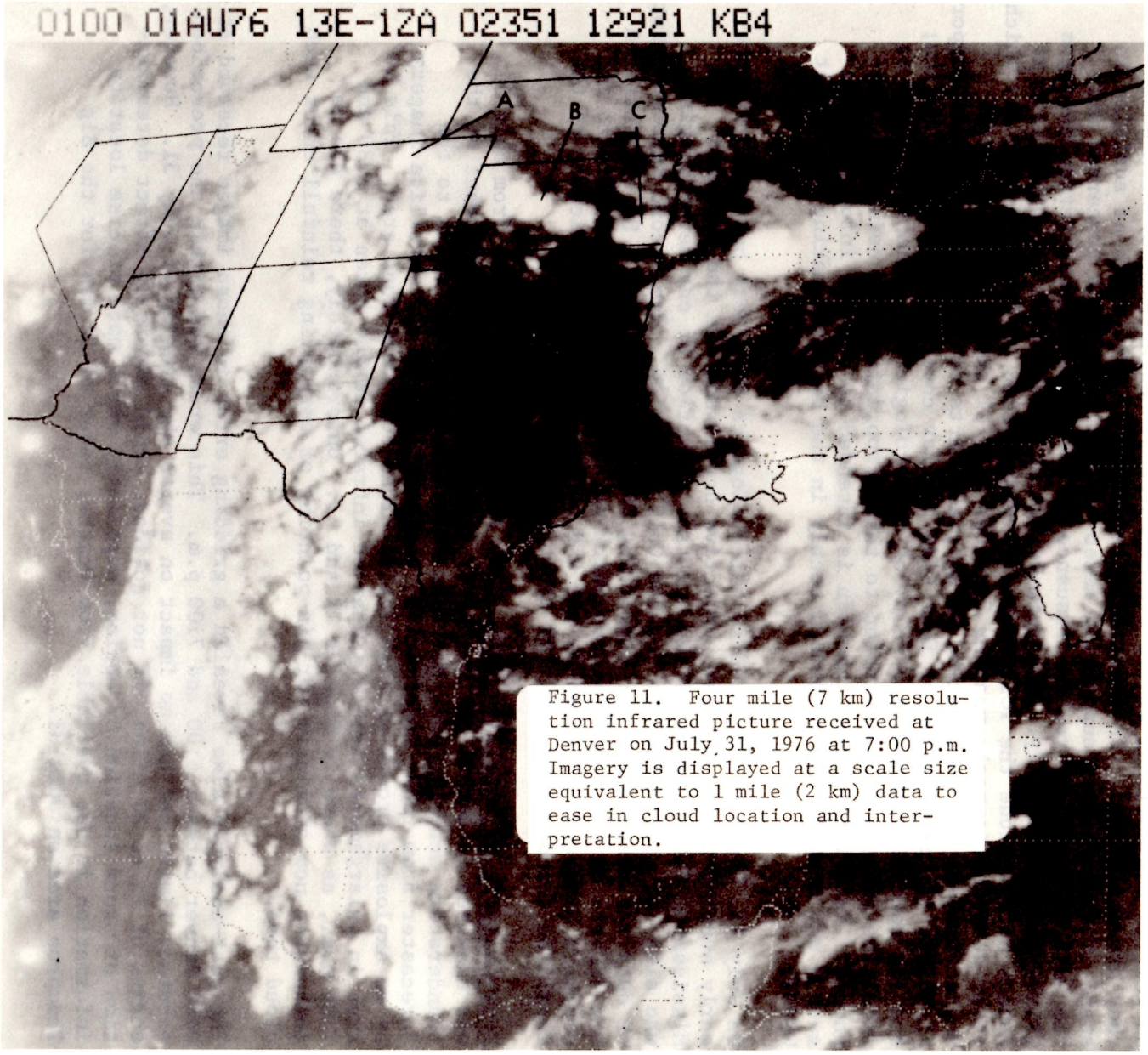


Figure 11. Four mile (7 km) resolution infrared picture received at Denver on July 31, 1976 at 7:00 p.m. Imagery is displayed at a scale size equivalent to 1 mile (2 km) data to ease in cloud location and interpretation.

Use of Satellite Data at SFSS Kansas City. The SFSS located at Kansas City has two meteorologists on duty three shifts per day, providing round-the-clock service. They support 23 WSFOs in NWS's Central and Southern Regions, as well as the National Severe Storms Forecast Center (NSSFC) with which they are collocated. In addition, since July 6, 1976, with no addition in staff, they have been supporting meteorological interests concerned with the Gulf of Mexico by routine issuance of Satellite Interpretation Messages (SIMs) four times daily. The primary duties of the SFSS meteorologists at Kansas City include the following: (a) preparation of four SIMs per day which cover subsynoptic scale weather features over 21 states in the central United States; (b) preparation of special charts four times per day in support of NSSFC; (c) preparation of four SIMs per day covering the Gulf of Mexico; and (d) special, unscheduled relay of meteorological information, based on satellite imagery interpretation to the appropriate WSFOs using FTS telephones. This latter SFSS function is intended to provide information in such a way that it can be used directly in the decision making process at WSFOs.

On July 31, the SFSS Kansas City meteorologists were very busy. During the early evening hours, intense convective development in the southern Mississippi Valley required the constant attention of one meteorologist who also had responsibility for the Gulf of Mexico. The second meteorologist on duty was responsible for supporting NSSFC and 23 WSFOs. He concentrated his efforts on the thunderstorms which were approaching severe limits in southern Missouri and Arkansas and did not detect the significance of the localized thunderstorm activity in north-central Colorado.

Post-Analysis of Satellite Data. The satellite information from July 31 was examined in detail by the survey team. The rapid development of the thunderstorm activity over northern Colorado, which was known to the forecaster from radar information, was signalled in the satellite imagery by an explosive growth in high (cold) cloud tops over that area. This is seen in enlargements made of enhanced infrared images taken at 6:30 and 7:00 p.m., as shown in figures 12 and 13. Unfortunately, there are no techniques now available for pin-pointing or estimating rainfall under such cloud tops.

The post-analysis also revealed a gridding error in those images received at WSFO Denver between 6:00 and 7:00 p.m. This error was within the prescribed accuracy limits and had no impact on events the evening of July 31. However, errors of 15 to 20 miles, if not noticed, could adversely affect determination of storm location or motion, especially where more precise location information is not available from weather radar as it was for the Big Thompson area on July 31.

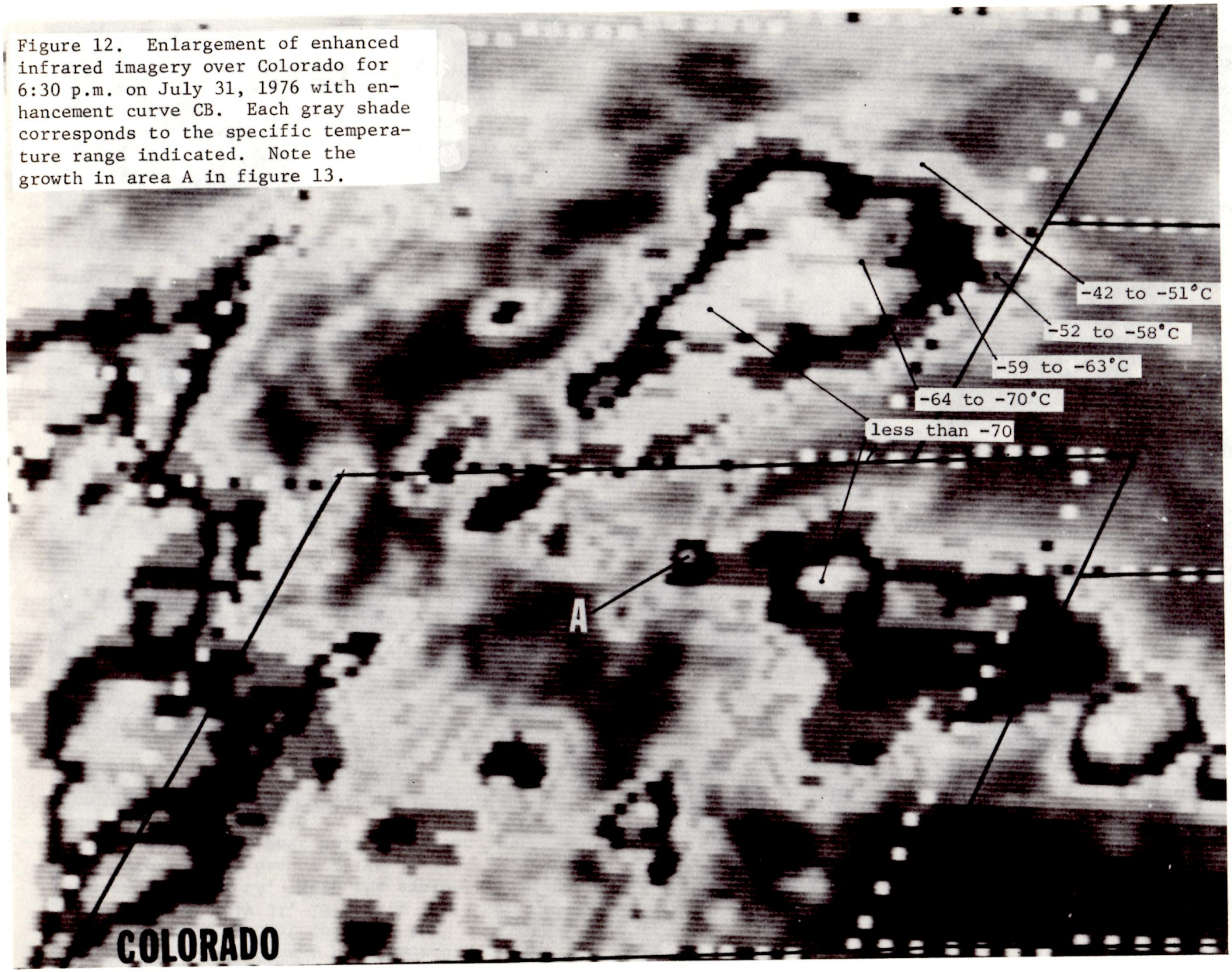


Figure 12. Enlargement of enhanced infrared imagery over Colorado for 6:30 p.m. on July 31, 1976 with enhancement curve CB. Each gray shade corresponds to the specific temperature range indicated. Note the growth in area A in figure 13.

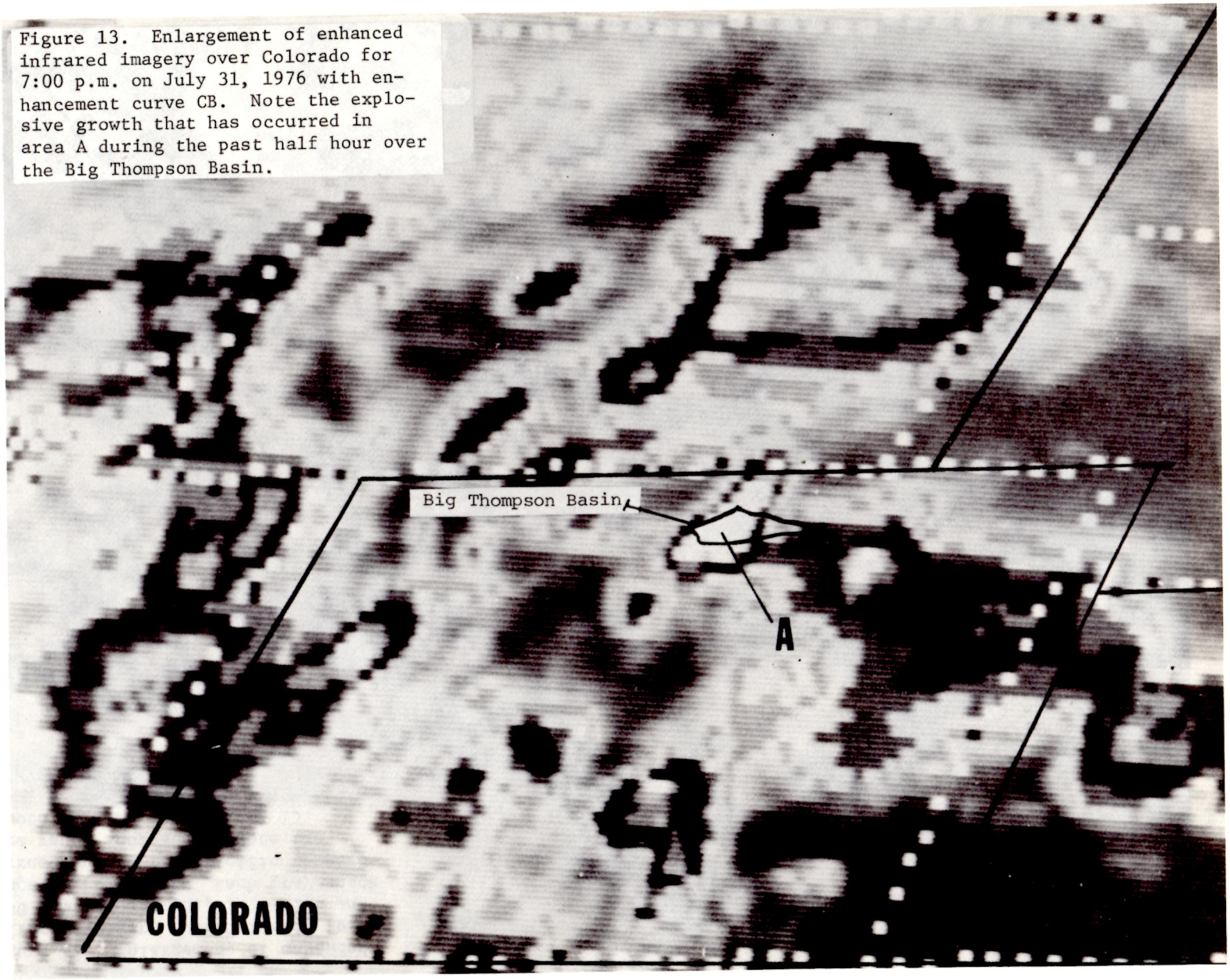


Figure 13. Enlargement of enhanced infrared imagery over Colorado for 7:00 p.m. on July 31, 1976 with enhancement curve CB. Note the explosive growth that has occurred in area A during the past half hour over the Big Thompson Basin.

FINDINGS AND RECOMMENDATIONS

Finding 1: The initial severe thunderstorm warning issued by WSFO Denver at 7:35 p.m. was largely attributable to the performance of the radar operator at WSMO Limon and the information he supplied to the forecaster.

Recommendation: The radar operator should be commended for his actions the evening of July 31, 1976.

Finding 2: The outage of the WBRR hampered the lead forecaster in performing his duties. This equipment had been out of service for more than 24 hours prior to the flood.

Recommendation: NWS should examine the existing maintenance schedule and procedures for this equipment to insure that outages are kept to a minimum.

Finding 3: One of the uncertainties facing the lead forecaster early in the evening of July 31 was an apparent discrepancy between the very high radar echo tops and relatively low reflectivity values reported by WSMO Limon. The NWS standard procedure available to him indicated a rainfall rate between one-half inch and one inch per hour for the reported radar reflectivity values. This indicated rate of rainfall was much lower than that which was actually occurring in the canyon. Furthermore, cumulative totals of radar-estimated rainfall did not meet the alerting limits considered necessary for flash flooding.

Recommendation: NOAA should, as a matter of high priority, initiate a project to review the scientific basis for estimating rainfall rates from radar returns and revalidate or revise the present standard relationships.

Finding 4: The Denver forecaster received no feedback information or surface reports from the affected area in time to allow him to refine his original warning by adding the precise location and a better estimate of the magnitude of the threat.

Recommendation: Actions should be taken by NWS to establish and maintain, consistent with available resources, cooperative river and rainfall reporting points in flash-flood prone areas. Special emphasis should be given to populated areas and favorite recreation spots. The cooperative networks should be exercised periodically to assure that both NWS personnel and the cooperating individuals or offices are aware of the system.

Finding 5: The test network of AHOS/S sites had not been commissioned. It had maintenance problems, primarily with the radio sets. The one AHOS/S rain gage of this test network in the Big Thompson Canyon was inoperative and was washed out by the flood.

Recommendation: NWS should site gages to assure survival and arrange for back-up observations for operational gages wherever possible. Special emphasis needs to be placed on frequently exercising of interrogation features to obtain special reports. Consideration should be given to modifying AHOS/S gages to report on an event basis to automatically alert NWS personnel to heavy rainfall or rapidly rising streams.

Finding 6: A picture gridding accuracy requirement of 20 miles was established by the NWS and NESS before the launch of the first of the operational geostationary satellites. The gridding errors on 31 July - 1 August were within this limit. This accuracy may not be adequate; gridding errors of this magnitude make it difficult, if not impossible, to use the pictures alone for precise location and movement of small scale storms.

Recommendation: NWS should review gridding requirements and establish new standards if appropriate. NESS should develop the technological and operational improvements to meet any new requirement. In addition, particularly until gridding accuracy improvements are made, NESS should examine the feasibility of routinely distributing gridding error information to WSFOs for more precise location of features in the pictures.

Finding 7: The heavy workload of the two meteorologists at the Kansas City SFSS during the late afternoon and early evening of July 31 may have been a contributing factor in their not detecting the significance of the localized activity in Colorado.

Recommendation: NESS should review the manning level and duties of the Kansas City SFSS, expecially in view of the recently added Gulf of Mexico responsibilities.

CHAPTER 3

METEOROLOGICAL CONDITIONS AND FORECASTS

During the past 25 years meteorologists have come to recognize that important atmospheric processes occur over a wide spectrum of interacting scales. The conditions contributing to the Big Thompson Canyon flash flood were no exception--large or synoptic scale conditions for substantial convective activity were present, but all data from radars, satellites, and surface observations indicate that small or meso-scale features, several hundred kilometers or less in size, were significant factors in triggering the very heavy rainfall. Unfortunately, there are substantial gaps in our knowledge and understanding of meso-scale meteorology.

Synoptic Scale Features

A nearly stationary upper atmospheric high pressure ridge with very light winds had persisted over Arizona, Utah, New Mexico, and Colorado for several days prior to the flood. Moisture at the 500 mb (50 kPa) level, about 6 kilometers above sea level, had been high over Colorado since 6:00 a.m. on July 29. Relative humidities from the surface to 500 mb had remained well below 50% over Colorado until 6:00 a.m. on July 31, when Grand Junction and Denver reported values of 68% and 82% respectively. Precipitable water values (another measure of atmospheric moisture) gradually doubled from just above one-half inch at 6:00 a.m. on July 29, to slightly more than one inch at 6:00 a.m. on July 31. This increase was unusual but not unprecedented for summer months. Lifted index values, showing atmospheric stability, had remained near zero throughout the period, indicating that the air mass was conditionally unstable and that thunderstorms would occur if deep convection were initiated by afternoon heating or orographic lifting.

During the 36-hour period preceding the flood, low level moisture began to concentrate in a zone about 200 miles (320 km) wide on the north side of the cold front and advect westward from the central plains. Surface dew points in central Colorado were generally in the 40's at 6:00 a.m. on July 30. These near-normal values had risen into the 50's 24 hours later. Dew points in northeastern Colorado rose from the 50's into the 60's during the same period. The rise in dew point values was greatest in Colorado, western Kansas, southeastern Wyoming, and eastern Utah. By 6:00 a.m. on July 31, surface dew point values in eastern Colorado were 10 to 15°F above July-August normals.

Surface pressures rose in the northern plains, moving a weak cold front slowly southward through the central plains. By 6:00 a.m. on July 31, the front extended from north-central Illinois across central Missouri into western Kansas and eastern Colorado. Easterly winds in the lower levels on the north side of the front continued to blow upslope toward the Front Range of the Rocky Mountains.

Figure 19 shows the NMC surface analysis at 6:00 a.m. and 6:00 p.m. on July 31. Figure 20 shows the 500 mb (50 kPa) analysis for the same times.

These synoptic features--well above normal moisture, conditionally unstable air mass, marked low level convergence and strong upslope flow--all pointed toward thunderstorm activity out of the ordinary for a summer afternoon and evening in Colorado. The light winds aloft indicated that the storms would move slowly, concentrating the rainfall in small areas. Despite these clues, there was no basis to predict the 12+ inches of rainfall and the disastrous flash flood that followed.

Guidance Received at WSFO Denver

To carry out its responsibility for warning of severe thunderstorms and flash floods, the National Weather Service has established forecast echelons at national and at state and local levels. The National Meteorological Center (NMC) in Camp Springs, Md., provides initial guidance on the location of synoptic scale features including expected rainfall. The National Severe Storms Forecast Center (NSSFC) in Kansas City provides guidance on severe thunderstorms on a national scale. Weather Service Forecast Offices (WSFOs) and Weather Service Offices (WSOs) use this guidance to prepare state and local forecasts and issue warnings of severe thunderstorms, tornadoes and flash floods. WSFOs also issue flash flood watches.

NMC, a largely computerized facility, provides a variety of analyses and prediction products covering the Northern Hemisphere with emphasis on the United States and surrounding waters. Subjective forecasts showing frontal positions, cloudiness, and precipitation areas and amounts are also prepared. This basic guidance material, covering periods out to 48 hours in the future, is distributed to NSSFC, WSFOs and WSOs over facsimile and teletypewriter networks.

NSSFC uses all available surface, upper air, radar and satellite data to provide 24-hour surveillance of the development of severe thunderstorms within the contiguous 48 states. Severe weather outlooks are issued on a scheduled basis at 3:00 and 9:00 a.m. Watches are issued as required to advise of areas of greatest potential for severe thunderstorm or tornado development. These products are distributed mainly over the Radar Report and Warning Coordination Circuit (RAWARC) to WSFOs and WSOs. A graphic version of the severe weather outlook is transmitted via the National Facsimile Network (NAFAX). There is no guidance issued on the potential for very heavy rainfall associated with localized thunderstorms. Predictions of this type are beyond the current state of the art and research and development will be necessary before they could be provided.

River Forecast Centers (RFCs) supply WSFOs and WSOs with river stage forecasts and with flash flood guidance specifying those threshold rainfall amounts which will produce minor flooding. This latter guidance covers zones or parts of states and in some cases contains information for a

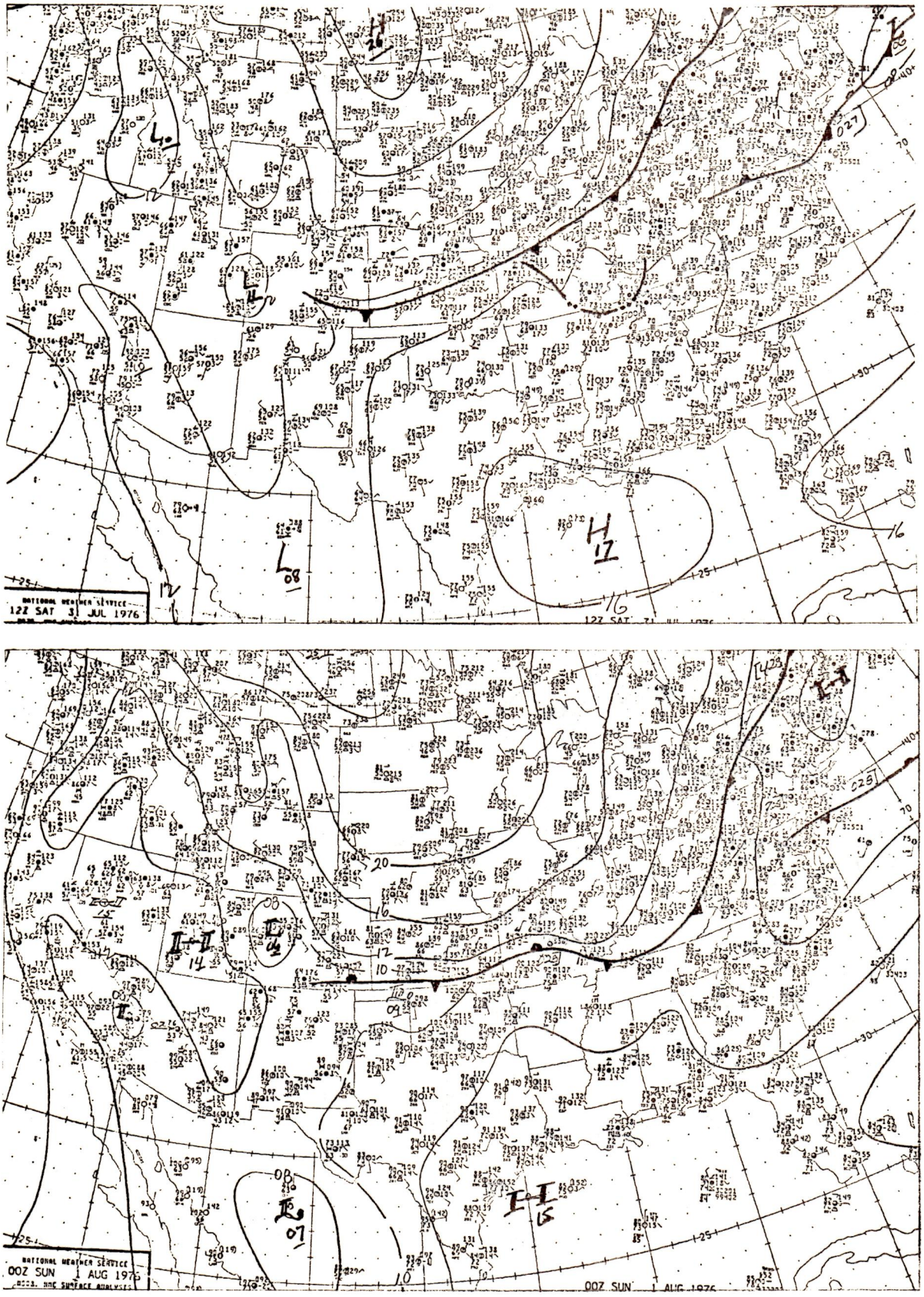


Figure 19. NMC surface analyses for 6:00 a.m. MDT (top) and 6:00 p.m. MDT (bottom) on July 31, 1976.

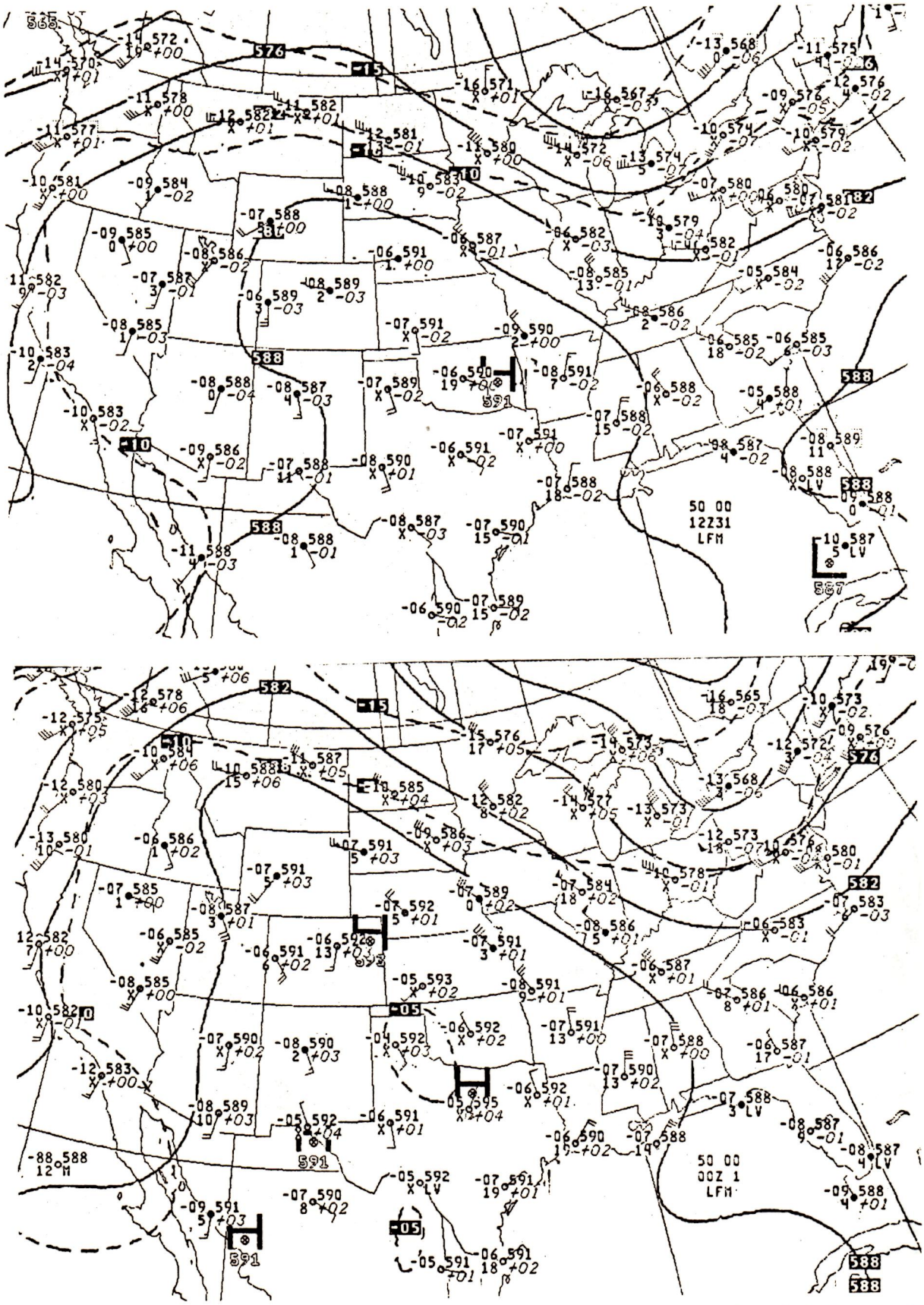


Figure 20. NMC 500-millibar analyses for 6:00 a.m. MDT (top) and 6:00 p.m. MDT (bottom) on July 31, 1976.

specific drainage basin. The guidance provided to WSFO Denver by the RFC in Kansas City was of the general type. Specific guidance is not issued for the Big Thompson River and many other basins in the mountains.

Guidance products available to WSFO Denver at noon on July 31 indicated that there would be relatively little change in the upper wind flow pattern. Weak upward vertical motion with mean relative humidities above 50% were shown for northern Colorado. The surface high pressure center and the cold front lying east-west across Kansas and into Colorado were predicted to move slowly southward. Modified NMC surface guidance moved the high pressure center a little faster and showed a stronger pressure gradient (stronger easterly surface winds) in eastern Colorado by 6:00 a.m. on August 1. The NMC quantitative precipitation forecasts (QPF) indicated that rainfall amounts from one half to one inch were possible over the plains of northeastern Colorado. The QPF discussion received at WSFO Denver about 6:00 a.m. on July 31 indicated increasing moisture for Colorado and Wyoming, but discounted somewhat the amounts predicted by the numerical models. The Kansas City RFC guidance indicated that more than two and one-half inches of rain in a three-hour period were needed to produce flash flooding in the forecast zones containing the Big Thompson Canyon.

Precipitation guidance available to Denver by 1:30 p.m. on July 31 showed increasingly higher probabilities for measurable rainfall for northeastern Colorado for the 12-hour period beginning at 6:00 p.m. on July 31. Thunderstorm guidance forecasts from NMC for the 6-hour period centered at 6:00 p.m. showed a relative maximum for eastern Colorado.

In summary, the synoptic situation as depicted by the data, maps, and charts available to WSFO Denver pointed toward greater than normal thunderstorm activity in Colorado. However, centrally prepared guidance forecasts of thunderstorms and rainfall indicated only normal activity. The maps and charts and forecast guidance as a whole did not provide a basis for specific forecasts of a catastrophic, localized storm and flash flood.

Local Forecasts, Warnings, and Mesoscale Considerations

Zone forecasts issued by WSFO Denver at 4:00 a.m. and 10:00 a.m. on July 31 for the area containing the Big Thompson Canyon predicted widely scattered showers and thunderstorms on Saturday becoming more numerous Saturday night and Sunday. Precipitation probabilities for the nighttime hours were 50 percent in the western half of Larimer County and 40 percent in the eastern sections. The zone forecast issued at 4:00 p.m. indicated a chance of afternoon and evening showers and thunderstorms, with nighttime precipitation probability of 40 percent. There was no mention of abnormally heavy rainfall in the forecasts.

During the 31st, upslope flow of moisture-laden air intensified over eastern Colorado, while a concentrated surface wind maximum of mesoscale dimensions moved westward across Kansas into eastern Colorado. The wind maximum reached Denver by 6:00 p.m. on the 31st. At this time, thunderstorms began developing rapidly along the Front Range to the west and northwest of Denver.

A gust front moved north and northwest from the Denver area, passing Boulder between 5:30 and 5:45 p.m. with gusts of 35 to 45 mph (56 to 72 km/hr) and a noticeable wall of dust. It reached Ft. Collins about 5:45 p.m., producing gusts to 40 mph (64 km/hr). Evidence points to increased low level convergence associated with this gust front as a significant factor in the explosive development of thunderstorms in western Larimer County.

At 7:35 p.m. WSFO Denver issued a severe thunderstorm warning for eastern Larimer County stating that local flooding in low areas was possible, especially just to the west of Ft. Collins. The warning was based on radar information and was in effect until 9:00 p.m. A special weather statement issued at 9:00 p.m. mentioned a line of moderate to heavy thunderstorms which could result in local flooding in the Colorado counties of Larimer, Boulder, northern Clear, and extreme eastern Jackson. This statement indicated that the rain could be heavy until about midnight. A flash flood warning for the portion of the Big Thompson River east of the canyon (i.e., from near Loveland to Greeley) was issued at 11:00 p.m.

FINDINGS AND RECOMMENDATIONS

Finding 1: Guidance forecasts of rainfall amounts and the zone forecasts issued by WSFO Denver gave no indication of the abnormally heavy rainfall that produced the flash flood. QPF guidance from NMC does not handle convective precipitation very well. This fact is well known to NWS forecasters. There is a need to provide NWS field offices with additional guidance material on the heavy rainfall amounts associated with convective activity as well as techniques to allow local offices to derive objective estimates of rainfall rates from upper air observations. A substantial research effort will be needed.

Recommendation: NOAA should initiate an R & D program to develop an improved capability for predicting rainfall amounts associated with convective activity. As soon as new technology can be developed, guidance for convective rainfall should be issued on an operational basis.

Finding 2: The warning issued by WSFO Denver at 7:35 p.m. made no mention of heavy rainfall or flash flooding but did mention the possibility of flooding in low areas. The 9:00 p.m. statement referred to the possibility of heavy rain and local flooding. No mention was made of flash flooding until 11:00 p.m. Issuance of a flash flood watch is a matter of professional judgement. The forecaster was a qualified professional and he made reasonable use of the information available to him. Feedback information on rainfall amounts, river stages, and conditions in the Big Thompson drainage basin was not available in time to allow WSFO Denver to issue a specific flash flood warning for the Big Thompson Canyon prior to onset of severe flooding.

CHAPTER 4

WARNING DISSEMINATION AND PUBLIC RESPONSE

The lead forecaster at WSFO Denver came on duty at 4:00 p.m., July 31, 1976. He replaced the day shift forecaster who had been issuing severe thunderstorm warnings for portions of Colorado eastward of the Front Range. It should be noted that WSFO Denver had issued 134 severe thunderstorm warnings and 10 tornado warnings since mid-April of this year, but that no flash flood warnings had been issued since July 31, 1975. In other words, they see many severe thunderstorms without flash flooding.

Warnings

Based on radar information, with no substantiating reports of heavy rainfall, high winds, or hail from the storm area, the lead forecaster at WSFO Denver issued a severe thunderstorm warning at 7:35 p.m.

BULLETIN IMMEDIATE BROADCAST REQUESTED
735 PM MDT JUL 31 1976
THE NATIONAL WEATHER SERVICE HAS ISSUED A SEVERE
THUNDERSTORM WARNING EFFECTIVE UNTIL 9 PM MDT
EASTERN LARIMER COUNTY COLORADO AT 735 PM MDT
RADAR INDICATED A SEVERE THUNDERSTORM 10 MILES
SOUTHWEST OF FORT COLLINS COLORADO MOVING TOWARD
THE NORTHNORTHWEST AT 10 MPH
THERE COULD BE SOME FLOODING OF LOW AREAS...
ESPECIALLY JUST TO THE WEST OF FORT COLLINS

During the next hour the lead forecaster was unsuccessful in his attempts to determine what rainfall amounts were in the storm area. He called the only rain gage observation points he knew or thought about. At one of these, on the Cache la Poudre River, the observer was not at home. He called Fort Collins police station and found that it wasn't raining there and that the Poudre River level was low. The radar continued to show the echoes with high tops over the Estes Park area with the storms moving northward about 10 mph. Accordingly, the lead forecaster decided to issue a special statement.

SPECIAL WEATHER STATEMENT
NATIONAL WEATHER SERVICE DENVER CO
9PM MDT SAT JUL 31 1976
THERE IS A LINE OF MODERATE TO HEAVY THUNDERSTORMS
FROM IDAHO SPRINGS NORTHWARD TO THE WYOMING BORDER.
THE THUNDERSHOWERS ARE MOVING SLOWLY WHICH COULD
RESULT IN SOME LOCAL FLOODING IN THE FOLLOWING
COLORADO COUNTIES...NORTHERN CLEAR..BOULDER..
LARIMER AND EXTREME EASTERN JACKSON.
PERSONS NEAR THE THUNDERSHOWERS SHOULD BE ON
THE ALERT FOR THE HEAVY THUNDERSHOWERS.
THE RAIN COULD BE HEAVY UNTIL ABOUT MIDNIGHT.

This statement is essentially a flash flood watch but is not so designated.

Because he was uncertain as to what was happening on the ground, he issued this statement to keep some warning in effect until he could get reports from ground observers. He was particularly concerned about the Cache la Poudre River which drains the next valley north of the Big Thompson.

It wasn't until 11:00 p.m., after WSFO Denver received reports indicating the location and seriousness of the flooding and that the "Big Thompson had already crested at the mouth of the Canyon", that a flash flood warning was issued.

BULLETIN
FLASH FLOOD WARNING
NATIONAL WEATHER SERVICE DENVER
11 PM MDT 31 JUL 1976
A FLASH FLOOD WARNING IS IN EFFECT UNTIL
4 AM MDT FOR PERSONS NEAR THE BIG THOMPSON RIVER
FROM NEAR LOVELAND TO GREELEY COLORADO
A FLASH FLOOD WARNING MEANS FLOODING IS IMMINENT.
TAKE NECESSARY PRECAUTIONS AS REQUIRED

Dissemination

NOAA WEATHER WIRE, a teletypewriter system, is the principal means of distributing weather information to the news media for dissemination to the public. The NOAA WEATHER WIRE SERVICE (NWWS) carried thunderstorm and/or flood messages at 7:35, 9:00, 11:00, and 11:15 p.m. The following summarizes dissemination actions by news media having NWWS drops:

AP Denver — They moved a severe thunderstorm warning for E. Larimer County at 9:07 p.m. This is either the warning sent out at 7:35 p.m. or a combination of that warning with the statement issued at 9:00 p.m.

At 11:10 p.m. they moved the flash flood warning issued at 11:00 p.m. Then, as information began to come in from the flooded area and the Larimer County Sheriff's office, they put out a story at 11:38 p.m. combining the flash flood warning information with what they had from the scene.

UPI Denver — At 7:57 p.m. they sent out on their radio line the warning issued at 7:35 p.m. The 9:00 p.m. special statement went out at 9:34 p.m.

Then, at 9:37 p.m. they ran a story to the effect that the Colorado State Patrol reported a number of cars washed off the road in Big Thompson canyon by a massive flash flood. This was followed at 12:28 a.m., August 1, by the 11:00 p.m. flash flood warning from WSFO Denver.

KTLK Denver — No newscasts were made after 1:51 p.m. on Saturday afternoon. Prerecorded news spots are used. No one looks at NWWS after the last live newscast until station opens the following morning.

KBOL Boulder — They were carrying a Denver Broncos football game during the warning period. They assume warnings received after the game went out, but they do not log such messages.

KERE Denver — Their recollection is that they ran "quite a bit" on Saturday night. First warnings were broadcast after 9:00 p.m. Calls then came in from listeners plus wire service word of event.

KOA & KOA TV Denver — They put out weather information at 10:26 p.m. as part of the scheduled 10:00 p.m. news program.

KDEN Denver — This is Denver's all-news station. Their news director said that they rely heavily on NWWS and ran all messages very hard, repeating them several times each half hour. He felt that the several messages received represented very minimal output from NWS for an event of this magnitude. He also urged that WSFO Denver join into METS, a hotline system in which the forecaster can go directly on the air over every radio station in the Denver metropolitan area and simultaneously reach the warning and emergency action agencies. Insisting he meant no criticism of WSFO-Denver, which he noted was quite cooperative with the media, he said that the office had turned down participation in the METS because the WSFO wasn't staffed to handle the workload.

KMGH TV Denver — The station's Denver news director said they first saw an alert about 10:00 or 10:15 p.m. during the late news program. Their reporter and photographer left for the scene soon after the program ended. The station did not run a crawl on the movie and apparently carried nothing about the storm on the news show.

KLAK Lakewood — They have no specific record or recollection regarding the warnings, but say they use such information almost immediately, around the clock.

KWGN-TV Denver — They began at 9:00 p.m. to save copy. The first indication they received came at 9:30 p.m., when they had a report of a severe rain storm near Drake. There were messages at 10:30 p.m. about radar reports of severe thunderstorms along the eastern slope of the Front Range. The first specific flash flood warning came at 11:00 p.m. KWGN-TV is Denver's Metromedia channel (2), with a 9:00 p.m. news show. At 10:30 p.m. the news staff goes home. They ran no warnings that night.

KHOW Denver

KBTV-TV Denver

The news director for KHOW does the weekend weather for KBTV-TV, Denver's Channel 9. He said that at KBTV-TV they had been receiving thunderstorm warnings on NWWS. A message was received from WSMO Limon indicating severe thunderstorm approximately ten miles west of Fort Collins. An hour later, he saw another radar report and noted that the storm had not moved eastward as they usually do. Just before 10:00 p.m., a KHOW stringer in Loveland, called in to report a "terrific storm," with slides, river rising, and butane tanks floating downstream. The news director sent him into the flood area and sent out another reporter from KHOW. The station ran warnings of severe thunderstorm and possible flooding at the top of their 10:00 p.m. news and at 10:20 p.m. ran a radio interview, with one of their people in the flood area saying that the road was blocked and partially washed away.

KLZ Denver

Their recollection is that all the NWS messages were aired as they came in.

KIMN Denver

The person on duty Saturday night in the newsroom said that they had thunderstorm warnings coming in on NWWS and aired them as they came in, reading the text off the wire. Then, at about 8:00 p.m., they heard that the Larimer County sheriff's office was calling all its people to duty and that, as a precautionary measure, they were being moved up into the canyon areas, where high water had been reported. They followed the sheriff's activities to find out what was happening and ran their first story shortly thereafter, based mainly on what they had from the sheriff's office. This person also pointed out that the METS arrangement would have been a good way to get the word on the storm out.

These stations have NOAA Weather Wire, but go off the air at sunset:

KLOV Loveland
KUAD Windsor
KIIX Fort Collins

KCOL radio in Fort Collins, close to the scene, has no weather wire because they get their weather data from the "Fort Collins Weather Service," a private meteorological service located in Fort Collins. Meteorologists John Henz and Vince Scheetz go on the air four times a day--at 6:25 a.m., 7:25 a.m., noon, and 5:25 p.m. Friday evening their forecast called for extensive mountain thunderstorms and the threat of flash floods. On Saturday their forecasts added a warning of heavy downpours with amounts up to 1 inch. On Saturday evening their broadcast noted that radar was reporting thunderstorm tops reaching nearly 50,000 feet, and that the slow movement of the storms makes them "potentially dangerous due to the heavy rains being confined over such a small area. The potential for flash flooding in downstream areas, even along small washes and dry creek beds,

can be considerable in cases like today." That was about 3 1/2 hours before the Big Thompson flood. Their forecasts had effective wording to convey the difference from a typical summer evening in the mountains. But like WSFO Denver, they did not provide categorical statements on the location or magnitude of the disastrous rainfall from the very localized storm.

Saturday night KCOL was carrying the Broncos game. The Fort Collins Weather Service called about 9:00 p.m. to issue statements that heavy rains were occurring and that people in the canyon areas should be prepared to take precautions against flash floods. The station ran these statements during the game. They continued on the air for more than 5 hours past their normal midnight signoff.

NOAA Weather radio is another method that the National Weather Service uses to alert the public of fast-breaking weather events. KEC-76 operated by WSFO Denver is one of about 100 facilities now in operation. Over the next two years more than 200 additional stations will be established to expand the NOAA Weather Radio system nationwide. The Denver station broadcasts weather information 24 hours daily on 162.55 MHz with a power output of 300 watts which gives it a useful range of about 35 miles from its transmitter located just east of Denver.

The triangular area from Loveland to Estes Park to Fort Collins is out of Denver's broadcast area and therefore, in accord with established National Weather Service procedures, only the special statement issued at 9:00 p.m. was transmitted. Residents in Big Thompson Canyon told members of the survey team that all radio and television reception in the Canyon is poor and that, except for freak cases caused by the rugged terrain, KEC-76 is not received in the canyon. However, it may be monitored by motorists passing on the major Interstate Highway through Larimer County.

A Colorado State Patrolman was on duty at Estes Park on the evening of July 31. Around 7:30 p.m. the patrol's dispatcher asked him to check a traffic problem somewhere on U.S. Highway 34 below Estes Park. The dispatcher had reports of rocks and mud slides on the road. It was a routine call but law enforcement officers know that a traffic problem in the Big Thompson Canyon can be a major headache with the heavy weekend traffic. It was raining very lightly when the patrolman responded to the call. As he drove down the canyon the rain quickly became a blinding downpour. The "traffic problem" was about 7 1/2 miles into the canyon--tree limbs, mud and rocks were piled onto the highway.

At about 8:00 p.m. the patrolman broadcast what he'd found. Larimer County sheriff's deputies and another Colorado State Patrolman responded from Fort Collins and a third patrolman tried to reach Drake from Loveland where no rain was falling.

The first real alarm came about 8:45 p.m. when the patrolman from Estes Park broadcast:

> ".....Advise them we have a flood. The whole mountainside is gone. We have people trapped on the other side. I'm going to have to move out. I'm up to my doors in water. Advise we can't get to them. I'm going to get out of here before I drown."

He reached safety as did all other law enforcement officers who tried to spread the word, except for the Colorado State Patrolman from Loveland. He never reached Drake, his destination. His body was found later several miles downstream.

The patrolman from Fort Collins reached Drake and began to warn campers and residents:

> "They looked at me like I was crazy, most of them," he said. "I had to turn on my lights and siren and turn back six or seven cars just about three-fourths of a mile above Drake.
>
> Then I came back to the town and turned on my loud-speaker and told people to evacuate. The next thing I knew, the water was up over the road. Campers were being washed away and big propane tanks were coming downstream, spinning like crazy, starting to explode. I don't think any of us fully understood the magnitude of this until it was on top of us."

Sheriff's deputies were doing the same. Some without bullhorns were going door to door.

While many residents heeded the law enforecement officers' warnings and fled to higher ground or tried to drive out of the Canyon, others stared in disbelief and did nothing. Still others were openly defiant.

It was difficult for most people, particularly residents, to realize that they weren't safe where they were. After all they had lived in the Canyon "all their lives and had taken everything nature had given."

One such resident at Glen Comfort told the survey team that he had never been able to understand how people faced with imminent danger and warned that flood waters or hurricane surge were about to hit would disregard the advice. "And yet when they came to the door warning us to get out, I said 'Why? We've had hard rain before and we got through it'." He added, "We just don't get those kind of storms and we felt that we had no reason to leave our home." He wasn't surprised, either, that many people made a fatal error of attempting to escape by automobile rather than abandon their cars for immediate high ground. "We've travelled

these roads in heavy rains with water on them before without mishap." And he repeated, "We just didn't get those kinds of storms here. You can just bet I won't be that foolish the next time."

The Larimer County Sheriff said, "We had trouble convincing them (the people in the Canyon) that the river was even coming up. The problem is that there wasn't time to convince the people, to get the urgency across to them."

A Larimer County Commissioner said most of the victims "have never seen a mountain flash flood" and therefore, doubted its potential impact.

Dr. Michael Weissberg, Director of the University of Colorado Medical Center's emergency psychiatry section explained it best. "Denial of danger is one way of dealing with danger," he said. "It is something we all do to some extent."

FINDINGS AND RECOMMENDATIONS

Finding 1: The warnings and statements issued by WSFO Denver on July 31 were worded in accordance with existing procedures and standards, but evidently did not convey to the users the needed sense of urgency. The State Director of Disaster Emergency Services commented along these lines and said that he felt that the wording of watches and warnings is "too bland and stereotyped." News media representatives said much the same thing. They felt that the NWS must somehow help them establish the appropriate urgency of each such message.

Recommendation: NWS should review its directives in regard to the wording of severe thunderstorm and flash flood watches and warnings. The degree of seriousness and urgency of the situation should be conveyed by the warnings.

Finding 2: The Metropolitan Emergency Telephone System (METS) is available in Denver. The media consensus was that better media dissemination of warning information would result if WSFO Denver joins the METS.

Recommendation: NWS should proceed with plans to have WSFO Denver participate in METS and carefully investigate the potential of similar networks in other locations.

Finding 3: Many people actually experiencing the flood demonstrated an inability to accept fully the reality of the situation and to take rational actions under the extremely dangerous conditions with which they were faced. Attempting to evacuate by auto on the canyon road rather than abandon their property and climb to higher ground may have cost people their lives. Even some law enforcement officials on the scene early had difficulty recognizing the magnitude of the disaster and the need for immediate life preserving measures. While there was no evidence of panic or wild flight by the public, it appeared that in general the background and experiences

of many of the people had not prepared them to take proper actions. NOAA disaster preparedness literature contains the admonition to go immediately to high ground, but it was apparent that many of the people in the canyon were unaware of the need for such action. The disaster preparedness contacts by WSFO Denver over the past two years have been inadequate to assure that the public and local officials are aware of the dangers involved and proper protective measures to be taken. WSFO Denver is one of 33 WSFOs which do not have disaster preparedness specialists assigned.

Recommendation: NOAA should take a number of steps to increase the effectiveness of its disaster preparedness activities:

(a) Complete manning the disaster preparedness program nationwide. Budgetary action will be needed. NWS contacts with local officials (safety, civil defense, and law enforcement) should be carried out on a scheduled basis with sufficient travel resources to assure that the schedule does not slip.

(b) NWS should continue to work with local officials by providing, where appropriate and requested, community self-help flash flood forecast schemes or assistance in the proper siting of flash flood alarms.

(c) The strongest possible representations should be made to Federal, State, and local agencies and to private owners and operators of recreation areas to assure that they are aware of the flash flood danger and proper safety actions to be taken if a disaster threatens. They must be made aware of their responsibilities to help educate and warn the people using their facilities.

(d) Arrangements should be made with various camping and outdoor publications for inclusion of materials on the flash flood threat and safety actions which must be taken by each person.

(e) Mass media and school systems should be enlisted in the disaster preparedness program to help educate the public on the dangers of heavy rainstorms and proper life-preserving measures.

Finding 4: NOAA Weather Radio was not used for the dissemination of the 7:35 p.m. and 11:00 p.m. warnings because the affected area was beyond the normal 35-mile broadcast range. This conforms to NWS instructions.

Recommendation: NWS instructions for NOAA Weather Radio should be revised to require dissemination of watches and warnings when they apply to areas in or adjacent to the normal broadcast area. This will help to insure that people will be alerted in the event they are traveling or planning to go into the affected area and that mass media stations can pick up the broadcast and relay it to their listeners.

Glossary of Acronyms

AHOS	Automatic Hydrologic Observing Station
AHOS/S	AHOS with Satellite Relay
AHOS/T	AHOS with Telephone Relay
DCPRS	Data Collection Platform Radio Sets
D/RADEX	Digitized Radar Experiment
FOFAX	Forecast Office Facsimile Network
FTS	Federal Telephone System
IR	Infrared
LIN	Linear
MDR	Manually Digitized Radar
METS	Metropolitan Emergency Telephone System
MIC	Meteorologist-in-Charge
NAFAX	National Facsimile Network
NAWAS	National Warning System
NMC	National Meteorological Center
NSSFC	National Severe Storms Forecast Center
NSSL	National Severe Storms Laboratory
NWWS	NOAA Weather Wire Service
OIC	Official-in-Charge
PPI	Plan Position Indicator
QPF	Quantitative Precipitation Forecast
RAWARC	Radar Reports and Warning Coordination System
RFC	River Forecast Center
SAWRS	Supplementary Aviation Weather Reporting Station
SFSS	Satellite Field Services Station
VIP	Video Integrator Processor
WBRR	Weather Bureau Radar Remote
WSFO	Weather Service Forecast Office
WSMO	Weather Service Meteorological Observatory
WSO	Weather Service Office