Storm and Flood of July 31–August 1, 1976, in the Big Thompson River and Cache la Poudre River Basins, Larimer and Weld Counties, Colorado

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 1115

Report prepared jointly by the
U.S. Geological Survey and the
National Oceanic and Atmospheric Administration
Cooperating Organization: Colorado Geological Survey

Storm and Flood of July 31–August 1, 1976, in the Big Thompson River and Cache la Poudre River Basins, Larimer and Weld Counties, Colorado

Part A. Meteorology and Hydrology in Big Thompson River and Cache la Poudre River Basins

By JERALD F. MCCAIN *of the* U.S. GEOLOGICAL SURVEY *and* LEE R. HOXIT, ROBERT A. MADDOX, CHARLES F. CHAPPELL, *and* FERNANDO CARACENA *of the* NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Part B. Geologic and Geomorphic Effects in the Big Thompson Canyon Area, Larimer County

By RALPH R. SHROBA, PAUL W. SCHMIDT, ELEANOR J. CROSBY, *and* WALLACE R. HANSEN *of the* U.S. GEOLOGICAL SURVEY

With a section on

DAMAGE CAUSED BY GEOLOGIC PROCESSES DURING FLOOD PRODUCING STORMS

By JAMES M. SOULE *of the* COLORADO GEOLOGICAL SURVEY

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GLOSSARY

[References in "Glossary" are listed under "Selected References" in Part B]

Aggradation. The deposition of sediment by a stream of water.

Alluvium. Sediment including clay, silt, sand, and gravel in transit and(or) deposited by a stream. Excludes detritus deposited in standing water such as lakes or oceans.

Altimeter setting. The pressure required to make an altimeter indicate zero altitude at an elevation of 10 feet above mean sea level.

Cirrus anvil. High clouds which spread outward from the tops of thunderstorms.

Colluvium. A deposit of unconsolidated detritus or earthy material that has been carried downslope chiefly by gravity, as opposed to running water. Generally is heterogeneous, poorly sorted, and poorly bedded. Includes but is not limited to talus, soil creep, landslides, avalanche deposits, and sheetwash.

Colorado Piedmont. A section of the Great Plains. The part of the Great Plains lying between the Southern Rocky Mountains and the High Plains. In the Big Thompson region it is the area east of the hogback belt at the foot of the Front Range. The name "High Plains" is sometimes used erroneously for this section.

Convection. Vertical motions and mixing resulting when the atmosphere becomes thermodynamically unstable.

Cubic feet per second (cfs or ft^3/s). A rate of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section 1 foot wide and 1 foot deep flowing at an average velocity of 1 foot per second.

dBZ. A measure of the relative power (in decibels) of returned energy to transmitted energy.

Debris avalanche. In the Big Thompson Canyon area, term is applied to a very heterogeneous mixture of water-saturated bouldery debris flowing very rapidly down a long, narrow steep channel and leaving behind a conspicuous linear scar on the mountainside. Similar to a debris flow but moving at a higher velocity down a steeper gradient (fig. A).

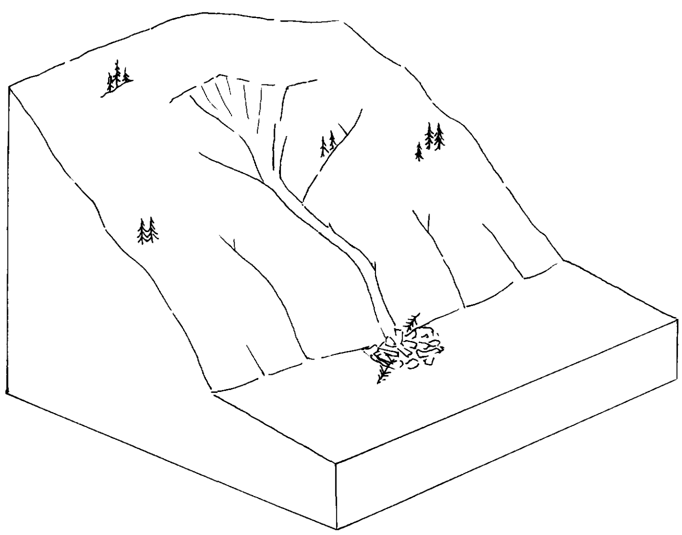

FIGURE A.—Debris avalanche deposit and scar.

Debris fan. A fanlike or conelike subaerial accumulation of sand, gravel, cobbles, boulders, and more or less organic trash deposited where the velocity of a stream is abruptly checked by a change of gradient, as at the mouth of a gulch. Deposit is generally poorly sorted and poorly stratified. Generally, a product of torrential runoff. The fanlike form results from the shifting of the channel as the stream blocks and diverts itself repeatedly with its own debris (fig. B).

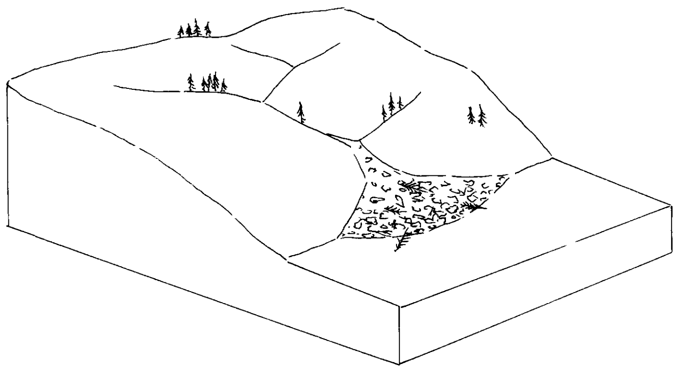

FIGURE B.—Debris fan.

Debris flow. A very heterogeneous mixture of water-saturated debris flowing slowly to very rapidly down a ravine and discharging onto a debris fan. In the Big Thompson Canyon area, many debris flows contained abundant woody trash, such as logs and brush. Some debris flows evidently discharged directly into the Big Thompson River and were swept away by the flood. Similar to a debris avalanche but flowing down a flatter gradient at lesser velocity.

Debris slide. The most common type of landslide set off by the Big Thompson storm. In the Big Thompson area, a moist stony heterogeneous landslide that moved downward and outward without backward rotation. Motion may have been slow to rapid. Mostly in colluvium.

Degradation. As applied to streams, synonymous with erosion. In a more general geomorphic sense, the gradual lowering of the landscape by weathering and erosive processes.

Detritus. Any material worn or broken from rocks by mechanical means. The composition and dimensions are extremely variable (Stokes and Varnes, 1955, p. 37).

Dewpoint (or dew-point temperature). The temperature to which a parcel of air must be cooled at constant pressure and constant water-vapor content in order for saturation to occur.

Discharge. The quantity of fluid mixture including dissolved and suspended particles passing a point during a given period of time.

Drainage area. The area, measured in a horizontal plane, which is enclosed by a topographic divide.

Echoes. In radar terminology, a general term for the appearance on a radar indicator of the electromagnetic energy returned from a target.

Entrainment. The mixing of environmental air into a preexisting cloud parcel.

Fault. A fracture in the Earth's crust along the sides of which there has been movement parallel to the fracture plane.

Flood. Any abnormally high streamflow that overtops natural or artificial banks of a stream.

Flood plain. The nearly flat ground bordering a river and occupied by the river at flood stage, built up from sediment deposited when the river overtops its banks and spreads outside its low-water channel.

Floodway. The channel of a river or stream and those parts of the flood plains adjoining the channel, which are reasonably required to carry and discharge the floodwater (Erbe and Flores, 1957, p. 443, quoted in Langbein and Iseri, 1960, p. 11). Usually applied to the part of the flood plain reserved or zoned to accommodate expectable flooding.

Front. Boundary separating two different air masses.

Gage height. The water-surface elevation referred to some arbitrary gage datum.

Gaging station. A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Gneiss. A foliated metamorphic rock having alternate layers of visibly dissimilar minerals, especially feldspar-rich layers alternating with mica-rich layers. Very common in Big Thompson Canyon.

Gradient. As applied to streams, the inclination of the bed, usually expressed as a percentage, or feet per mile.

Granite. A visibly granular igneous rock of interlocking texture composed essentially of alkalic feldspar and quartz, commonly with a small percentage of mica and hornblende. Very common in upper reaches of Big Thompson Canyon.

Granodiorite. A visibly granular igneous rock of interlocking texture similar to granite in general appearance but with soda-lime feldspar predominant over alkalic feldspar in a ratio of from 2:1 to 7:1 and with hornblende as the common mafic accessory mineral.

Grus. An accumulation of waste consisting of angular, coarse-grained fragments resulting from the granular disintegration of crystalline rocks, especially granite, generally in an arid or semiarid region (Gary and others, 1972, p. 317).

Hydrograph. A graph showing stage, discharge, velocity, or other property of water with respect to time.

Inversion (Temperature inversion). A layer in the atmosphere where the temperature increases with height.

Isotherm. A line of equal or constant temperature.

Knot (kt). A rate of speed of 1 nautical mile per hour, equal to 1.105 miles per hour. Commonly used to express wind speed.

Landslide. The downward and outward movement by falling and (or) sliding or flowing of slope-forming materials composed of natural rock, soils, artificial fills, or combinations of these materials. (See Varnes, 1958, p. 20; see also fig. C).

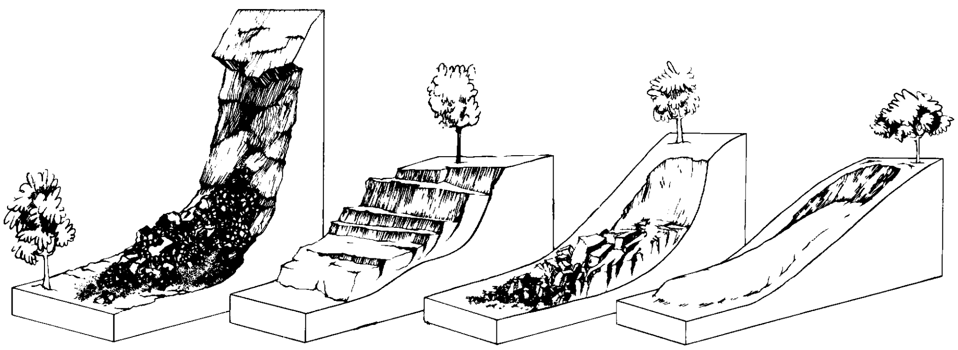

FIGURE C.—Landslide types common along the east slope of the Front Range. From left to right: I, *rockfall* moves mostly by free fall, bounding, and rolling; II, *slump* by rotational slippage on concave-upward shear surfaces; III, *debris slide* by complex internal adjustments of highly deformed, sheared slide mass; IV, *earthflow* by displacements and velocities similar to those of viscuous fluids (Varnes, 1958, pl. 1). Types *A* and *C* were prevalent in the Big Thompson Canyon area. Small-scale slumping, type *B*, took place along riverbanks east of the mountains. Illustrations by Natalie J. Miller, from Nilsen (1972).

Level of free convection. The level at which a parcel of air lifted dry adiabatically until saturated, and moist adiabatically thereafter, would first become warmer than its surroundings.

Lifted condensation level. The level at which a parcel of moist air lifted adiabatically would become saturated.

Lifted index. An index based on the difference (in °C) between the 500-millibar (mb) environmental temperature and the temperature of a parcel of air lifted adiabatically from or near the surface.

Mass wasting. A general term for the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stresses. In contrast to other erosion processes, the debris removed by mass wasting processes is not carried within, on, or under another medium possessing contrasting properties. The mass strength properties of the material being transported depend on the interaction of the soil and rock particles with each other. It includes slow displacements such as creep and solifluction and rapid movements, such as earthflows, rockslides, avalanches, and falls (Gary and others, 1972, p. 434).

Metamorphic rock. Rock changed materially in composition or appearance, after consolidation, by heat, pressure, or infilitrations at some depth in the Earth's crust below the surface zone of weathering.

Migmatite. An intimate mixture of granitelike igneous rock and a metamorphic host rock (schist or gneiss) in which the mixture is on a small scale but is sufficiently coarse to be easily recognized by eye (Stokes and Varnes, 1955, p. 92). Common in Big Thompson Canyon.

Mean sea level (msl). The average height of the surface of the sea for all stages of the tide over a 19-year period.

Millibars. A pressure unit equivalent to 1,000 dynes per square centimeter, convenient for reporting atmospheric pressure.

Mixing ratio. The ratio of the mass of water vapor to the mass of dry air.

Peak discharge attenuation. The reduction in peak discharge of a stream along the direction of flow.

Peak stage. The maximum height of a water surface above an established datum plane; same as peak gage height.

Pegmatite. An igneous rock of deep-seated origin having a very coarse average grain size and an interlocking texture, composed of predominant feldspar and quartz, subordinate mica, and various accessory minerals.

Percent slope. The vertical rise in slope per horizontal distance expressed as a percentage. Thus, a 10-percent slope rises 10 feet in a distance of 100 feet.

Point bar. One of a series of low, arcuate ridges of sand and gravel developed on the inside of a growing meander by the slow addition of individual accretions accompanying migration of the channel toward the outer bank (Gary and others, 1972, p. 552).

Precipitable water. The amount of water contained in an atmospheric column if all the vapor between two levels (usually the surface and 500 mb) was condensed.

Radiosonde. A balloon-borne instrument package for measuring and transmitting meteorological data.

Rawinsonde. Meteorological data-collection system including a radiosonde and reflectors for measuring winds by radar.

Recurrence interval. As applied to flood events, recurrence interval is the average number of years within which a given flood peak will be exceeded once.

Rockfall. Rock material that plummets, bounds, or rolls down a precipitous slope. Rapid to extremely rapid movement. (See Varnes, 1958, fig. 6, p. 22.)

Runoff. That part of precipitation which appears in surface streams.

Schist. A visibly crystalline foliated metamorphic rock composed chiefly of platy mineral grains, such as mica, oriented so that the rock tends to split into layers or slabs. Very common in Big Thompson Canyon.

Sediment. Fragmental material that originated from weathering of rocks and is transported by, suspended in, or deposited by water or is accumulated in beds by other natural agencies.

Sheetflood. A broad or nearly continuous cover of floodwater flowing sheetlike down a slope, as opposed to water concentrated in rills or rivulets. A result of intense but short-duration rainfall.

Sheetwash. Sediment picked up and redeposited by sheetflooding.

Slump. A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip face (concave upward) and about an axis parallel to the slope from which it descends, and by backward tilting of the mass with respect to that slope so that the slump surface often exhibits a reversed slope facing uphill (Gary and others, 1972, p. 667).

Stage. The height of a water surface above an established datum plane.

Stage-discharge relation. The relation between gage height and the amount of water flowing in a stream channel.

Stream competence. The measure of the ability of a stream to transport sediment.

Strike valley. A valley formed by differential erosion of alternate layers of relatively resistant and nonresistant rocks, so that the valley coincides with the trend (strike) of the nonresistant layers and the bounding ridges coincide with the resistant layers.

Talus. An accumulation of more or less angular rock fragments derived from and lying below a steep slope or cliff.

Time of day. Expressed in 24-hour time. For example, 6:00 p.m. is expressed as 1800 hours Mountain Daylight Time (MDT).

Totals index. Defined as $2(T_{850}-T_{500})-D_{850}$ where T_{850} is the 850 mb temperature, T_{500} is the 500 mb temperature and D_{850} is the 850 mb dewpoint depression, all expressed in °C.

Unit discharge. The average number of cubic feet per second flowing from each square mile of area drained by a stream, assuming that the runoff is distributed uniformly in time and area.

PHOTOGRAPH CREDITS

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CONVERSION FACTORS

The following factors may be used to convert U.S. customary units to Standard International (S. I.) units:

Multiply U.S. customary units	*By*	*To obtain metric units*
inch (in.)	2.54	centimeter (cm)
	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
	.0003048	kilometer (km)
yard (yd)	.9144	meter (m)
mile (mi)	1.609	kilometer (km)
knot (kt)	.5148	meter per second (m/s)
Square mile (mi^2)	2.590	square kilometer (km^2)
foot per second (ft/s)	.3048	meter per second (m/s)
foot per mile (ft/mi)	.189	meter per kilometer (m/km)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
cubic foot per second (ft3/s)	.02832	cubic meter per second (m3/s)
cubic foot per second per square mile ((ft^3/s)/mi^2)	.01093	cubic meter per second per square kilometer ((m^3/s)/km^2)
cubic yard (yd^3)	.7646	cubic meter (m^3)
millibar (mb)	.1	kilopascal (kPa)
ton	.9072	metric ton (t)

Temperatures are converted from degrees Fahrenheit (F) to degrees Celsius (C) by the formula $F=\frac{9}{5}C+32$; from degrees Celsius (C) to Fahrenheit (F) by the formula $C=\frac{9}{5}(F-32)$.

Part A.
Meteorology and Hydrology in the Big Thompson River and Cache la Poudre River Basins

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STORM AND FLOOD OF JULY 31-AUGUST 1, 1976, IN THE BIG THOMPSON RIVER AND CACHE LA POUDRE RIVER BASINS, LARIMER AND WELD COUNTIES, COLORADO

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ABSTRACT

Devastating flash floods swept through the canyon section of Larimer County in north-central Colorado during the night of July 31-August 1, 1976, causing 139 deaths, 5 missing persons, and more than $35 million in total damages. The brunt of the storms occurred over the Big Thompson River basin between Drake and Estes Park with rainfall amounts as much as 12 inches being reported during the storm period. In the Cache la Poudre River basin to the north, a rainfall amount of 10 inches was reported for one locality while 6 inches fell over a widespread area near the central part of the basin.

The storms developed when strong low-level easterly winds to the rear of a polar front pushed a moist, conditionally unstable airmass upslope into the Front Range of the Rocky Mountains. Orographic uplift released the convective instability, and light south-southeasterly winds at middle and upper levels allowed the storm complex to remain nearly stationary over the foothills for several hours. Minimal entrainment of relatively moist air at middle and upper levels, very low cloud bases, and a slightly tilted updraft structure contributed to a high precipitation efficiency.

Intense rainfall began soon after 1900 MDT (Mountain Daylight Time) in the Big Thompson River and the North Fork Cache la Poudre River basins. A cumulative rainfall curve developed for Glen Comfort from radar data indicates that 7.5 inches of rain fell during the period 1930-2040 MDT on July 31. In the central part of the storm area west of Fort Collins, the heaviest rainfall began about 2200 MDT on July 31 and continued until 0100 MDT on August 1.

Peak discharges were extremely large on many streams in the storm area—exceeding previously recorded maximum discharges at several locations. The peak discharge of the Big Thompson River at the gaging station at the canyon mouth, near Drake was 31,200 cubic feet per second or more than four times the previous maximum discharge of 7,600 cubic feet per second at the site during 88 years of flood history. At the gaging station on the North Fork Big Thompson River at Drake, the peak discharge on July 31 was 8,710 cubic feet per second as compared to the previous maximum discharge during 29 years of record of 1,290 cubic feet per second. Peak discharges for three small tributaries near the area of heaviest rainfall northeast of Estes Park exceeded previously recorded maximum discharges for basins of less than 4 square miles in Colorado.

Stream velocities were rapid along the tributaries near the storm center and on the Big Thompson River in the canyon section, with average velocities of 20-25 feet per second being common. The flood crest on the Big Thompson River moved through the 7.7-mile reach between Drake and the canyon mouth in about 30 minutes for an average travel rate of 15 miles per hour, or about 23 feet per second.

The peak discharge of the flood on the Big Thompson River at the canyon mouth exceeded the 100-year flood discharge for the site by a ratio of 1.8. Upstream in the Big Thompson River basin, the flood was even more rare being 3.8 times the estimated 100-year flood discharge at the site on the Big Thompson River just upstream from Drake. In the Cache la Poudre River basin, recurrence intervals were computed to be 100 years for the flood on Deadman Creek and 16 years for Rist Canyon and the Cache la Poudre River at the canyon mouth near Fort Collins.

Although the rainfall and flood discharges were unusually large, they are not unprecedented for some areas along the eastern foothills and plains of Colorado. The May 1935 and June 1965 floods on some streams along the eastern plains greatly exceeded the 1976 flood peaks in the storm area. Prior floods on several other streams in the foothills have approximately equaled the 1976 peak discharges.

INTRODUCTION

During the night of July 31-August 1, 1976, a complex system of thunderstorms produced intense rainfalls along the eastern foothills of the Rocky Mountains in northern Colorado (fig. 1). Devastating flash floods quickly swept through several streams in the area causing an appalling amount of death and destruction. The purpose of this report is to present an analysis of the genesis, growth, and culmination of the severe storm system and the disastrous floods which followed.

Coming on the eve of Colorado's 100th anniversary of statehood, the storm and flood quickly occupied the centerstage of attention. Centennial Sunday was still observed throughout most of the State but in a much subdued manner as the tragic news slowly filtered from a large area almost stripped bare of normal channels of communication. During the ensuing days of

FIGURE 1.—Location of flood area in relation to west-central United States.

search, rescue, and readjustment, as the death toll and damage estimates continued to rise, it became obvious that the flood would be classified as Colorado's worst natural disaster. The official tabulation by Larimer County officials lists 139 deaths, 5 persons reported as missing, and about $35.5 million in property damage.

ACKNOWLEDGMENTS

The data and interpretations contained in this report were obtained through the combined efforts of many individuals and local, State, and Federal agencies. This assistance, including factual information and financial support, is gratefully acknowledged.

Because of the sparsity and destruction of recording instruments, much of the hydrologic and meteorologic data were provided by residents of the area. Also, access to private property was readily granted to the many field personnel working in the flooded area. Sincere appreciation also is extended to Larimer County officials and to local municipal officials for their aid and patience during the data-collection period.

The Colorado Department of Natural Resources, Division of Water Resources, Office of the State Engineer furnished funds to support data-collection activities and furnished streamflow data for gaging stations operated by that agency. The Colorado Water Conservation Board of the same department developed flood and streambed profiles for the affected streams, assisted in the collection of other hydrologic data, and participated in the preparation of a basic flood-data report. Appreciation also is extended to the Colorado National Guard and private firms for providing helicopter transportation during the fieldwork.

The Department of Atmospheric Science, Colorado State University, provided meteorological data for Fort Collins. Dr. C. Glenn Cobb supplied meteorological data for Greeley, measured at Ross Hall, University of Northern Colorado. John M. West of Rockwell International Corp. obtained the meteorological data for the Rocky Flats plant near Boulder. The National Center for Atmospheric Research Field Observing Facility obtained and supplied the invaluable sounding, radar, and surface data from the National Hail Research Experiment site in northeastern Colorado.

The U.S. Army Corps of Engineers collected hydrologic data for parts of the area and provided estimates of flood damage. The Corps also provided funds for collection and reporting of hydrologic data.

The U.S. Bureau of Reclamation assisted the National Weather Service in the collection of rainfall data and provided funds for the collection and analysis of hydrologic data. The Bureau also provided hydrologic data, including an independent estimate of the peak discharge at the mouth of Big Thompson Canyon.

THE SETTING

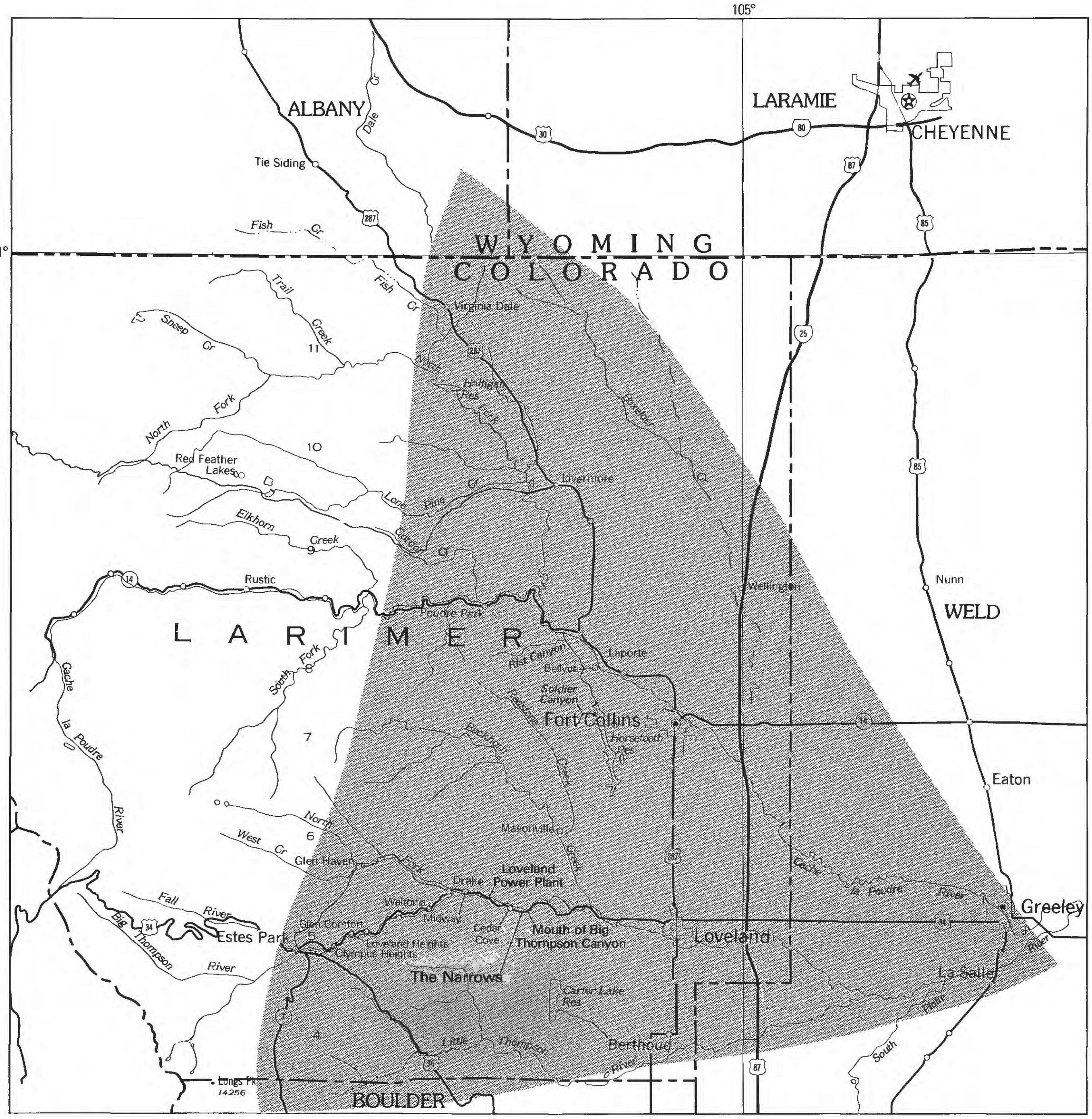
LOCATION

The area from which the flood of July 31–August 1 originated lies in central Larimer County along the Front Range of the Rocky Mountains (fig. 2). The southern limit of flooding was near Estes Park about 50 miles northwest of Denver, while the northern limit was approximately 50 miles farther north near the Wyoming border. In the southern part of the storm area, the band of intense rainfall was only about 6 miles wide with the western edge located near Estes Park and the eastern edge located about 2 miles west of Drake. The western edge of the storm near the Wyoming border was located just west of Virginia Dale, and the eastern edge was about 10 miles east of Virginia Dale. According to information from the U.S. Army, Corps of Engineers (1976), rainfall of 5 inches or greater covered an area of more than 1,000 square miles during the storm period.

The southern part of the flooded area is drained by the Big Thompson River and the northern part, by the Cache la Poudre River. Both streams flow in a generally eastward direction through Larimer and western Weld Counties to join the South Platte River in the vicinity of Greeley. Principal tributaries affected by flooding in the Big Thompson River basin were the North Fork Big Thompson River which enters at Drake, Buckhorn Creek which drains the northern part of the basin, and the Little Thompson River, which heads just southeast of Estes Park. The Little Thompson River flows eastward and generally parallels the main stem to the confluence near LaSalle. The North Fork Cache la Poudre River is the principal tributary of the Cache la Poudre River in the flooded area. Several small tributaries in the Bellvue area northwest of Fort Collins, including Rist and Soldier Canyons, also received severe flooding.

TERRAIN FEATURES RELATED TO FLOODING

The intense rains of July 31 fell on a part of the Colorado Front Range, commonly referred to as the foothills area. This area is underlain by a complex assortment of metamorphic rocks of Precambrian age with numerous intrusives of igneous origin. Many faults and shear zones also complicate the bedrock geology of the area and appear to exert considerable



Base modified from U.S. Geological Survey 1:500,000, State base map, 1969

0 10 20 MILES

FIGURE 2.—Detailed location of flood area.

control on the surface-drainage network because many stream courses generally coincide with faults. Almost all stream valleys are covered by alluvium and slopewash material and the larger streams are bordered by gravel terraces and colluvium.

The topography of the area is characterized by narrow valleys bordered by side slopes generally ranging from 10 to 80 percent. Rugged rock faces of even steeper slope occur at many locations along the canyon floors and along the jagged ridges which rise as much as 3,000 feet above the valleys (fig. 3). Soils, where present, are shallow, consisting of coarse material derived from both alluvial processes and from slope wash or colluvial processes. Soils generally grade from very gravelly and stoney near the ridges to a sandy to gravelly assortment near stream levels. Permeability of soils is rapid, ranging from 6 to 20 inches per hour with available water capacity generally less than 0.10 inch per inch. Soils are excessively drained with rapid runoff potential and are highly susceptible to severe erosion. North-facing slopes have a much denser forest cover than south-facing slopes, with Ponderosa pine most abundant at lower altitudes and Douglas-fir predominant near the mountain tops. Grasses and shrubs fill the open spaces between trees, being more abundant on south-facing slopes than on the denser forested north-facing slopes. Under the trees, the vegetation is sparse and much of the ground surface is exposed. Abundant growths of cottonwood, willow, and birch occur along the stream valleys where they are highly susceptible to the erosive process of the streams.

The Big Thompson and the Cache la Poudre Rivers head near the same point on the Continental Divide at an altitude of about 11,000 feet. The altitude of the area from which the flood derived ranges from about 9,000 feet to about 7,500 feet as shown in figure 4. On both the Big Thompson and the North Fork Big Thompson Rivers, the western limit of flooding occurred at an altitude of about 7,500 feet just west of Estes Park and Glen Haven, respectively. Downstream, the altitudes along the Big Thompson River range from 6,140 feet at Drake to 5,300 feet at the canyon mouth and 4,670 feet at the confluence with the South Platte River. Tributaries in the Big Thompson River basin near the storm center west of Drake range in altitude from about 7,000 feet to about 9,000 feet along the ridges. An area-altitude relation for the approximate storm area of 53 square miles in the Big Thompson River basin upstream from Drake is shown in figure 5. About 64 percent, or 33.5 square miles, lies in the range of 7,500–8,500 feet while the area above 8,500 feet comprises only 8.5 square miles, or about 16 percent of the total storm area in the Big Thompson River basin.

Streambed gradients along the Big Thompson River average about 107 feet per mile in the canyon reach and about 10 feet per mile near the mouth at LaSalle. On the North Fork Big Thompson River, the average streambed gradient is 128 feet per mile in the reach between Glen Haven and Drake. Most of the small tributaries west of Drake are extremely steep with streambed gradients as much as 700 feet per mile.

In the Cache la Poudre River basin, altitudes along the main stem are about 5,700 feet near the western limit of flooding at Poudre Park, 5,240 feet at the canyon mouth, and 4,610 feet at the mouth near Greeley. The streambed gradient from Poudre Park to the canyon mouth is about 46 feet per mile and about 9 feet per mile near the mouth. Altitudes along the North Fork Cache la Poudre River range from about 8,000 feet near the Wyoming border to 5,360 feet at the mouth. Streambed gradients on the North Fork are about 48 feet per mile in the northern part of the flood area and 43 feet per mile near the mouth. In the vicinity of Bellvue, small tributaries of the Cache la Poudre River head at about 8,000 feet. These small streams are fairly steep, averaging about 330 feet per mile.

SEASONAL DISTRIBUTION OF FLOODS

Three types of floods occur in the Colorado Front Range: snowmelt floods, floods produced by a combination of rain on snow, and rainfall floods. Snowmelt floods predominantly occur during May and June of each year and usually cause little or no damage. In fact, this type of runoff is usually welcomed as it is stored in off-channel reservoirs and provides a water supply during the dry summer months. Occasionally, low-intensity rainfall associated with frontal activity occurs over large areas of the Front Range hastening the snowmelt and producing severe flooding, especially on large streams. The third type, into which classification the July 31, 1976 flood falls, is the flash flood produced by convective thunderstorms usually during the months of June, July, and August. Rainfall associated with this type of flooding is very intense and occurs in short periods. Surface runoff rapidly concentrates in nearby channels and flash flooding occurs in downstream areas. Both overland and stream velocities are swift, causing severe erosion along hillsides and in streams. Property damage is usually high and fatalities frequently occur. The short period of time between the intense rainfall and flash flooding frequently precludes advance warning to downstream areas. Often associated with this type of flood is the reported "virtual wall of water." In almost all aspects, the flash flood is the most dangerous of the three types of floods.

PRECIPITATION

A smoothed analysis of the average precipitation occurring during July in Colorado is shown in figure 6 (National Oceanic and Atmospheric Administration, 1973). Typically, summer precipitation in northeastern Colorado is light and comes from afternoon and early evening thunderstorms that form over the mountains and move eastward over the plains. While

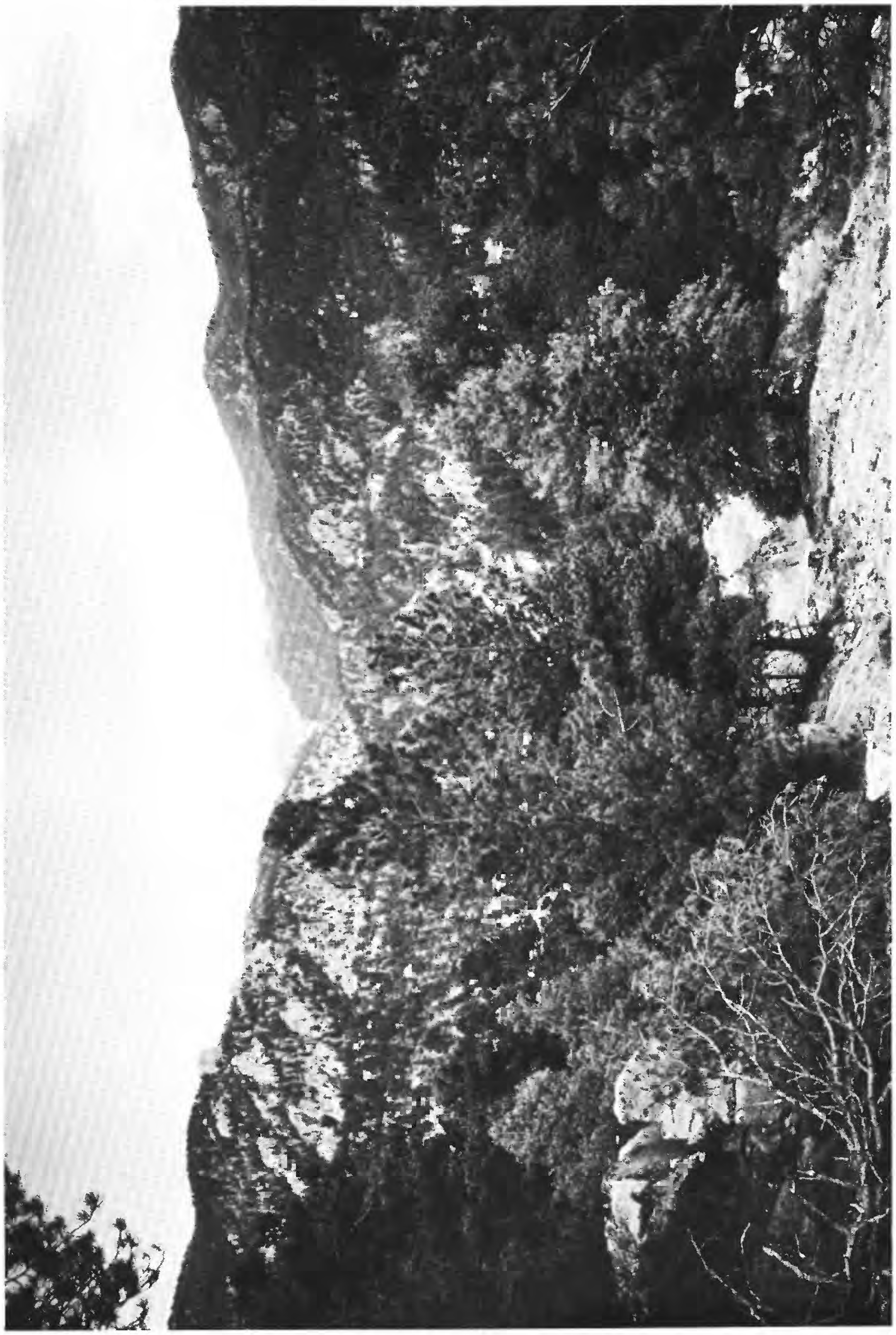


FIGURE 3.—Typical views of terrain in the Big Thompson River basin near the storm center.

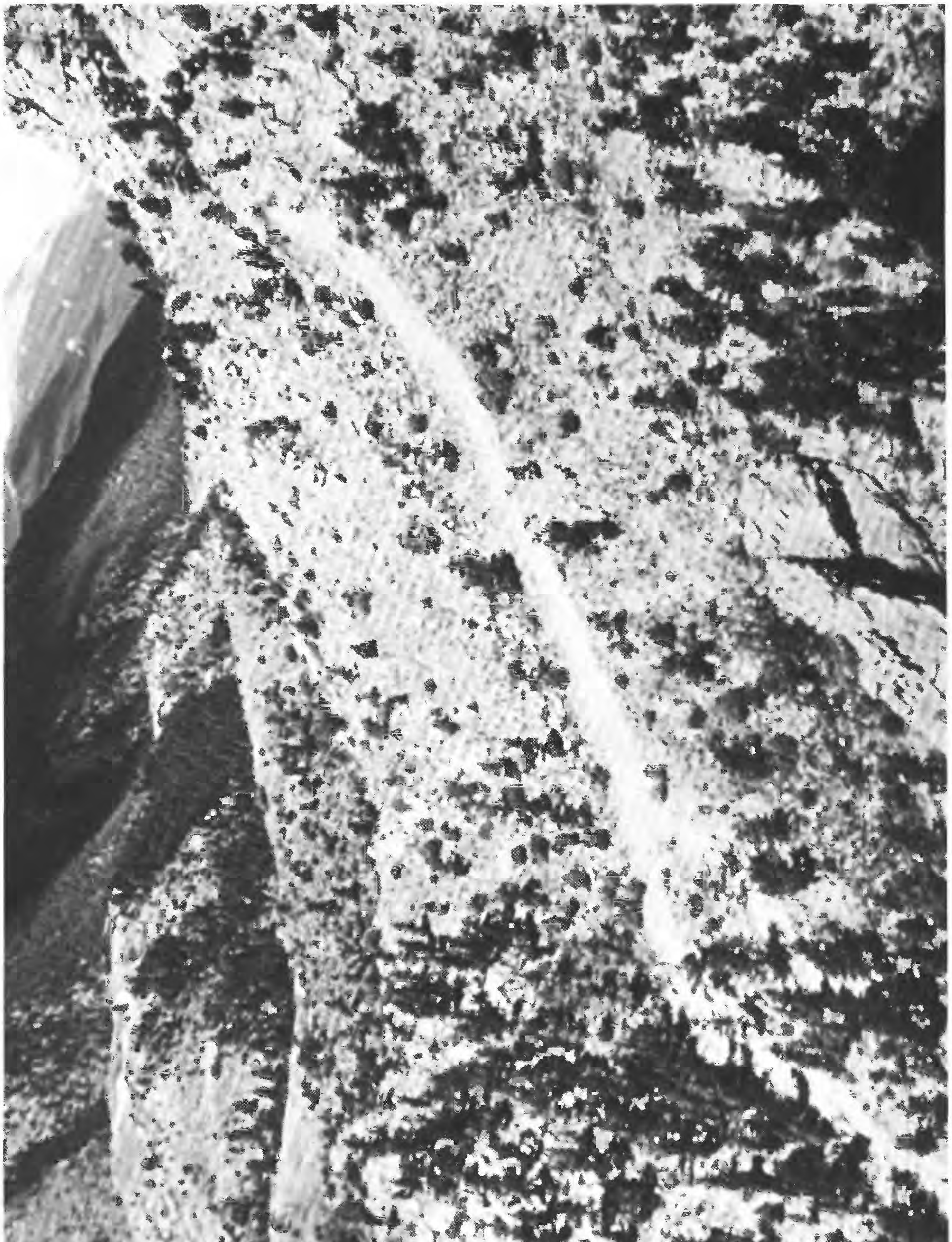
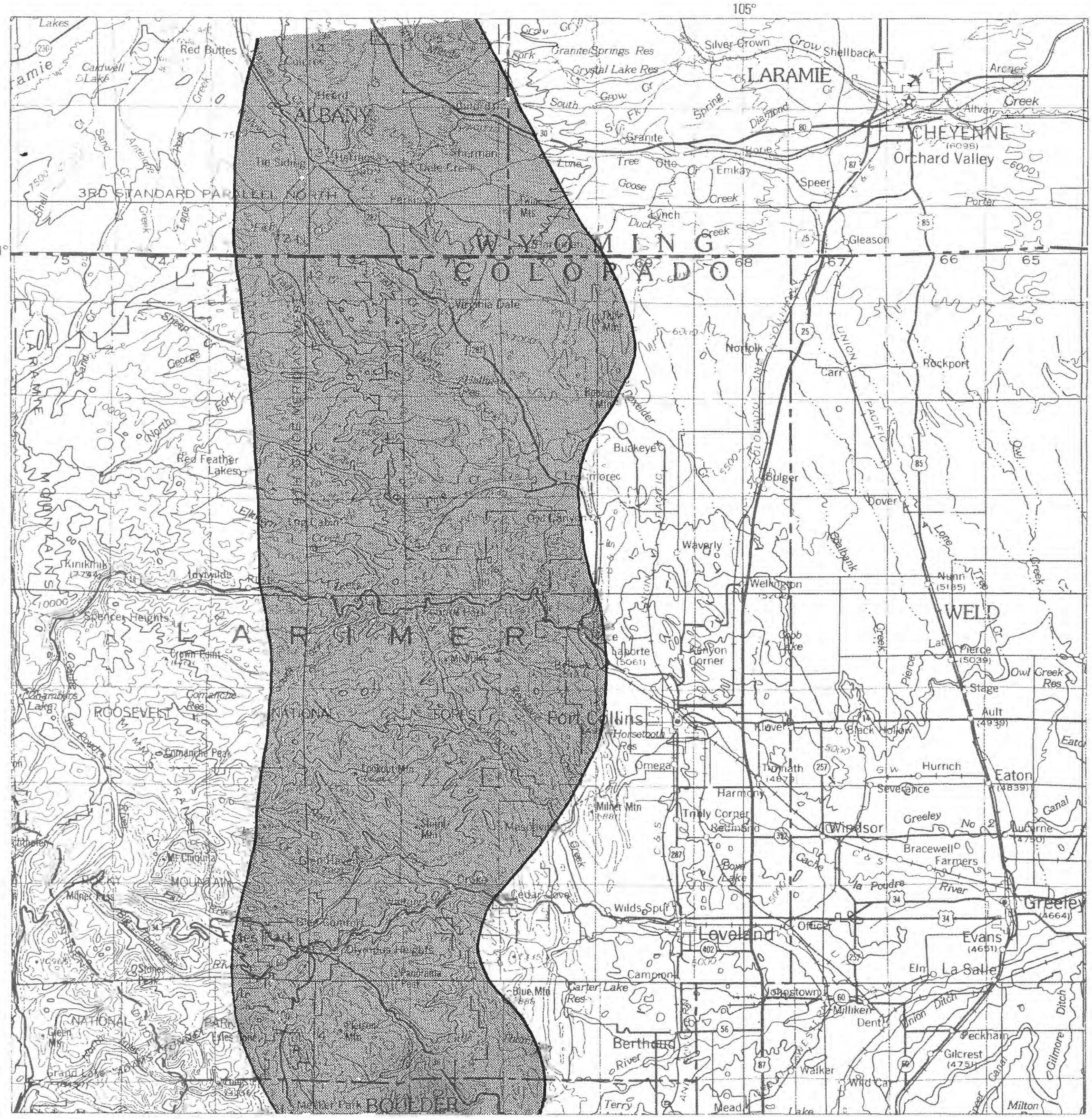


FIGURE 3.—Continued.



Base modified from U.S. Geological Survey
1:500,000, State base map, 1969

0 10 20 MILES

CONTOUR INTERVAL 500 FEET

FIGURE 4.—Altitude range in area where flood originated.

large amounts of rain and hail often fall with these storms, the precipitation is localized and of short duration. The 6–12 inches of rainfall observed on the evening of July 31, 1976, was several times the average monthly value for July in northeastern Colorado.

METEOROLOGY OF THE STORM

Although the intense rainfall was confined to a narrow band along the foothills in northeastern Colorado, meteorological processes on a much larger scale were

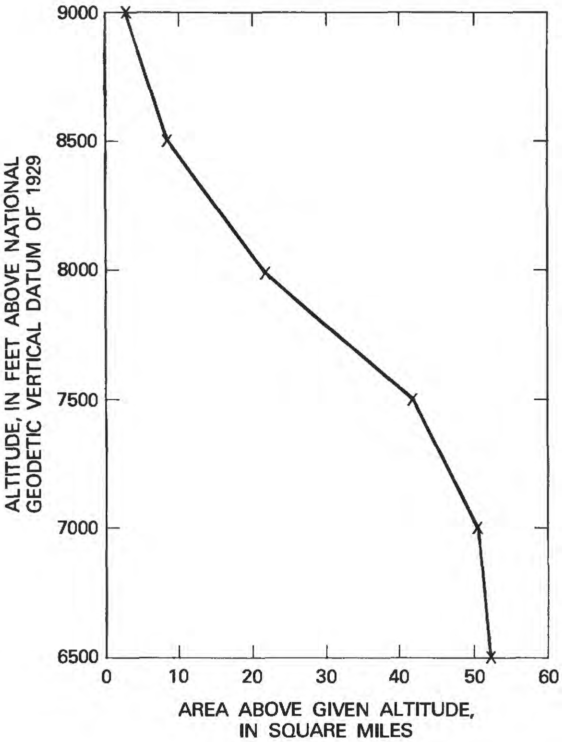


FIGURE 5.—Relation of area to altitude for approximate storm area upstream from Drake.

responsible for creating the thunderstorms that caused the floods. Surface and upper-air data, stability analyses, rawinsonde data, radar summaries, and satellite photographs are used in summarizing the meteorological events. Geographic locations mentioned in the discussions are shown in figure 7.

CONDITIONS PRIOR TO STORM DEVELOPMENT

Atmospheric conditions for western North America at 0600 MDT (Mountain Daylight Time) on July 31, 1976, are shown in figures 8-11. A strong polar high-pressure area was centered in southern Canada. A double frontal structure extended from the Great Lakes through Kansas and then northwestward into central Montana and defined the southern boundary of the polar air. The leading front was characterized by a wind shift and pressure trough while the trailing front was characterized by a pressure trough with a strong thermal gradient. To the west of the fronts, a weak low-pressure area was located over western Colorado (fig. 8).

Surface-dewpoint temperatures equal to or greater than 60°F extended northwestward from Kansas into Colorado and Nebraska. A narrow band of very moist surface air with dewpoints equal to or greater than 65°F was moving into southwestern Nebraska behind the trailing front (fig. 8). In general, surface dewpoints were 5°–15°F higher than normal over much of the intermountain west and central High Plains.

At the 700-millibar (fig. 9) and 500-millibar levels (fig. 10), the dominant large-scale feature was a ridge extending from southern Texas into southwestern Canada. Moisture values were high over much of the area west of the pressure ridge. A weak trough extended from Utah to southern New Mexico (fig. 9). At the 500-millibar level, the weak trough was farther south, located over Arizona and New Mexico. A second weak trough at the 500-millibar level was located over northern Mexico (fig. 10).

The stability analysis (fig. 11) shows the Totals Index and Lifted Index for 0600 MDT, July 31, 1976. Values of the Totals Index equal to or greater than 46 indicate favorable conditions for convective development and values greater than 50 indicate potential for moderate to heavy thunderstorms (Miller, 1972). The Lifted Index was computed for a parcel of air with mean-thermodynamic characteristics of the lowest 100-millibar layer. Negative values indicate a conditionally unstable environment. Both indices showed the potential for moderate to heavy thunderstorms over northern Arizona, most of Utah and Nevada, western Kansas, and northeastern Colorado.

Rawinsonde data obtained during the early morning of July 31, 1976, at Denver and Sterling, Colo., are shown in figures 12 and 13. The data for Denver at 0600 MDT (fig. 2) indicate that the air was very moist with an average mixing ratio for the lowest 100-millibar layer of 12 g/kg (grams per kilogram) below a temperature inversion at the 670-millibar level. Winds above the inversion were light and variable while winds in the cool airmass below the inversion were generally easterly with speeds less than 10 knots. The Lifted Index was −1, but the level of free convection was at the 530-millibar level indicating considerable lifting and (or) heating would be needed to initiate deep convection. The high moisture content of the air was the most unusual feature of the rawinsonde data. Precipitable water contents of 0.67 inch in the lowest 150-millibar layer, and 1.00 inch in the layer from the surface to the 500-millibar level were approximately 50 percent greater than the means for July at Denver of 0.40 inch and 0.69 inch, respectively (Lott, 1976). A low overcast at 1,200 feet was reported at Denver at the time of the rawinsonde observation.

The rawinsonde data obtained at Sterling, Colo., at 0740 MDT (fig. 13) was part of the National Hail Research Experiment. A pronounced radiational inversion near the land surface was topped by a weaker inversion at the 725-millibar level. Winds in the cool airmass were easterly with speeds less than 10 knots. The

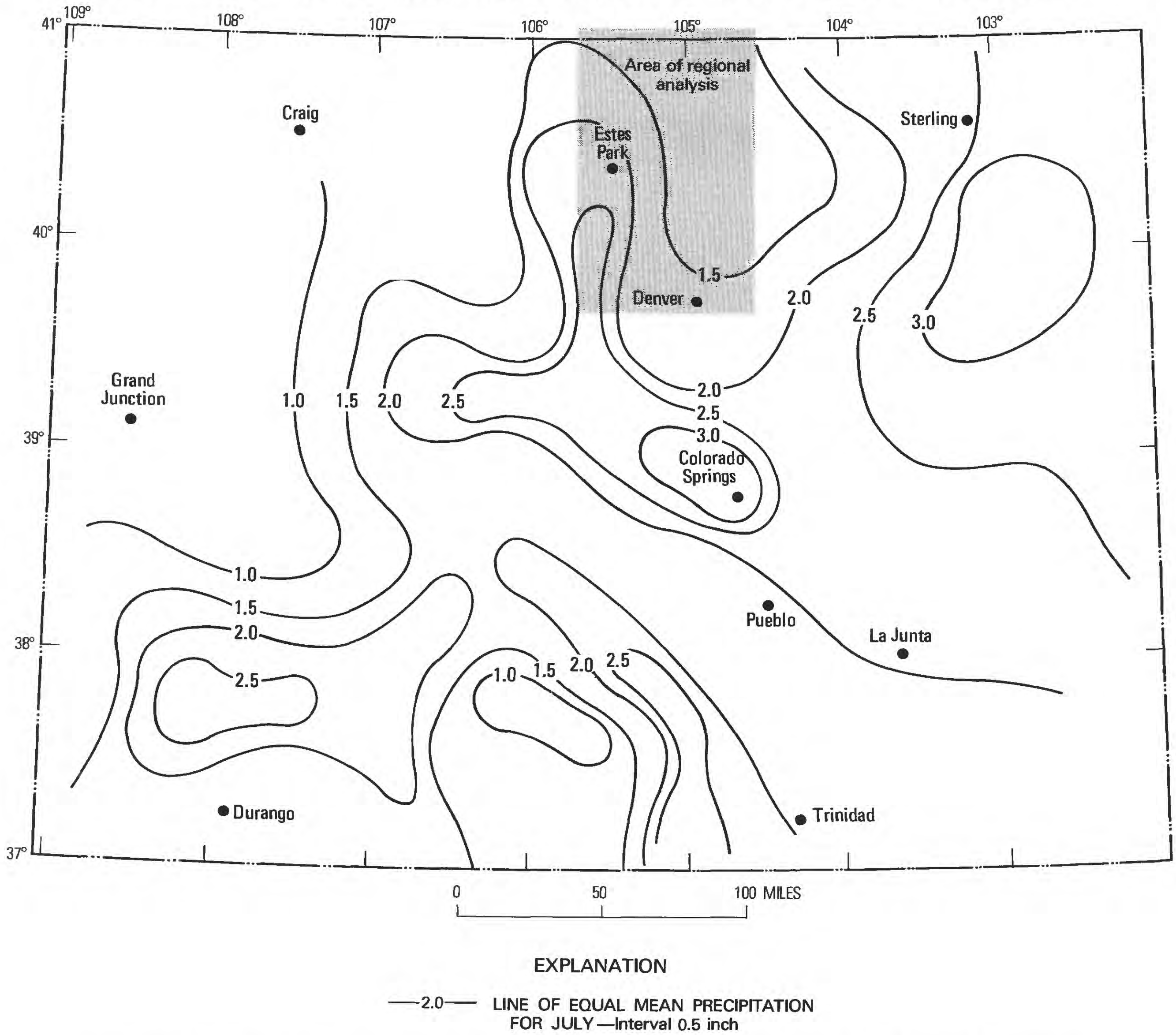


FIGURE 6.—Mean values of precipitation, in inches, occurring during July in Colorado (from National Oceanic and Atmospheric Administration, 1973).

Lifted Index was +1 and the level of free convection was at the 480-millibar level. The average mixing ratio in the lowest 100 millibars was 11 g/kg. Precipitable water contents of 0.59 inch in the lowest 150-millibar layer and 1.04 inches in the layer from the surface to the 500-millibar level were similar to the amounts occurring at Denver, Colo.

In summary, the morning analyses indicated that the stage was set for significant thunderstorm activity over a large area of the West. Abundant moisture, a conditionally unstable thermal structure, and weak vertical motions driven by the northward-moving pressure trough were the major features of this environment.

The changing meteorological conditions during the afternoon of July 31, 1976, are shown in figures 14–24. A surface analysis, radar summary, and Geostationary Operational Environmental Satellite (GOES) photograph are presented for 2-hour intervals beginning at 1200 MDT and ending at 1800 MDT. Afternoon rawinsonde data taken at Sterling, Colo., supplement the analyses. To make use of all available data, aircraft altimeter settings were used to define the surface pressure fields.

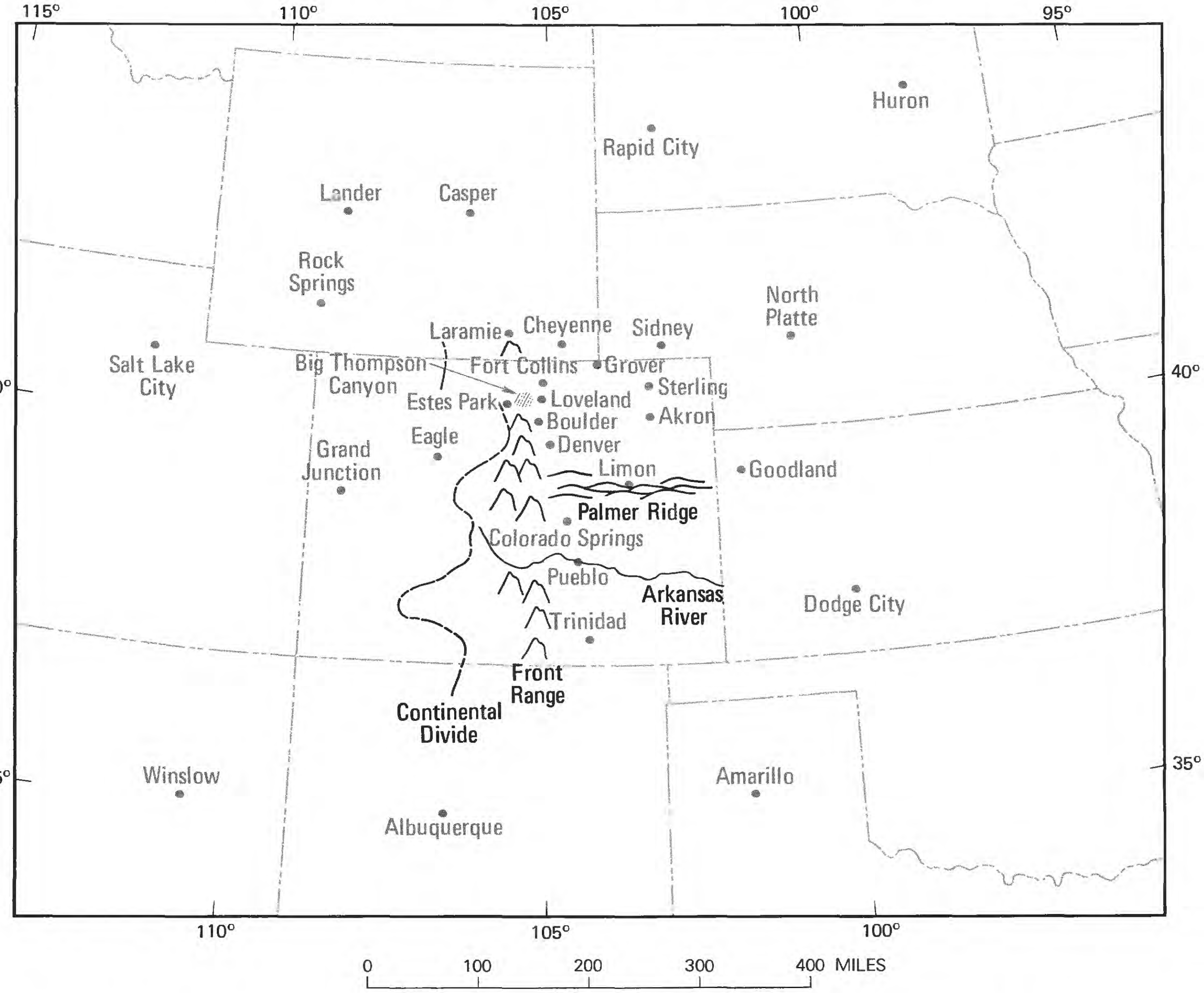
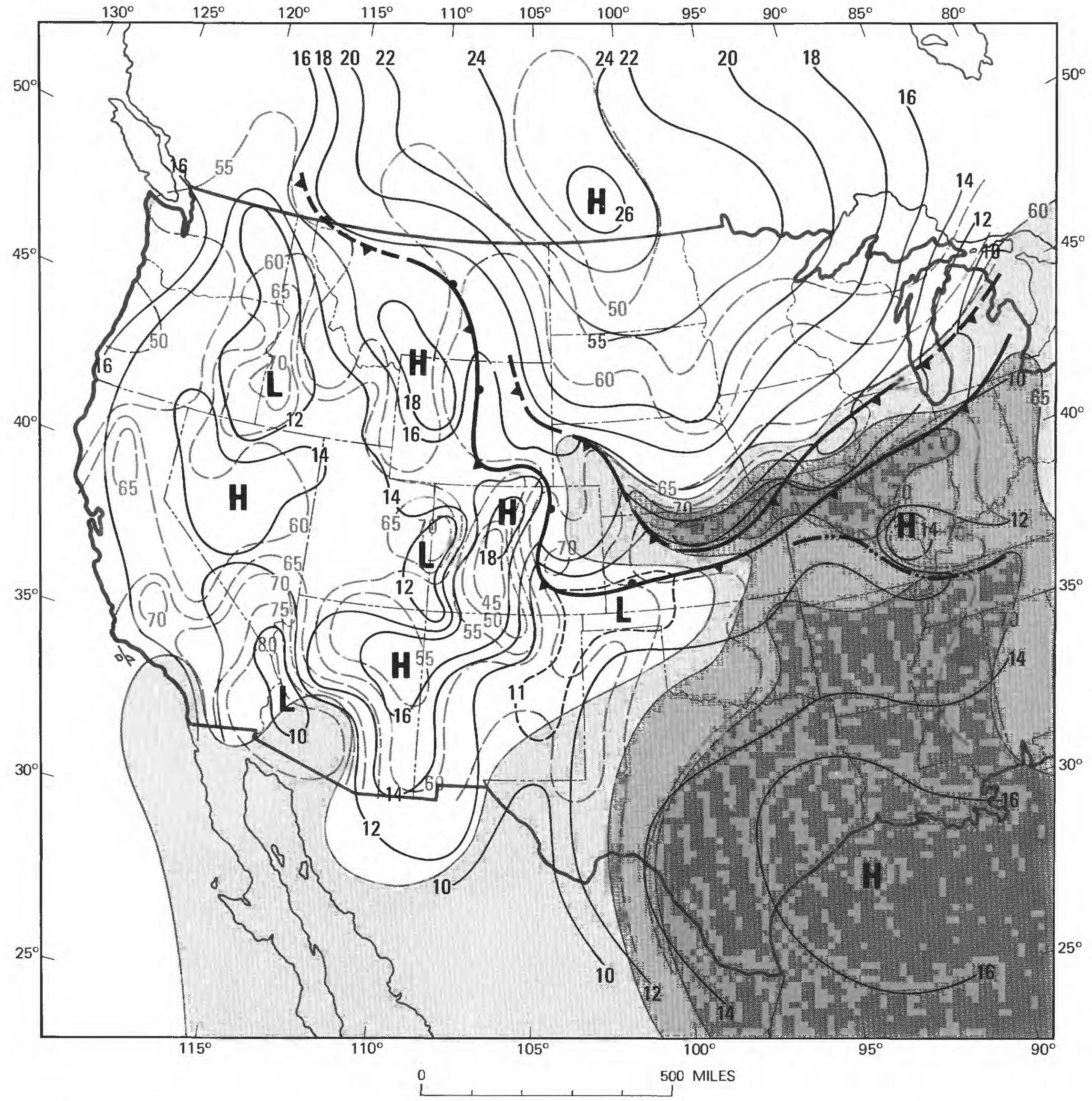


FIGURE 7.—Location of geographic features in Colorado and surrounding States referred to in the meteorological discussion.

By 1200 MDT, the trailing front had moved into extreme northeastern Colorado (figs. 14, 15). Behind this front the winds were easterly with gusts as much as 25 knots. Dewpoint temperatures remained equal to or greater than 60°F to the north of the leading front. During the afternoon, the leading front remained almost stationary along the foothills in northeastern Colorado while the trailing front moved southwestward at 15-20 knots. The cloud cover over the area at 1200 MDT is shown in figure 16.

At 1320 MDT, a second rawinsonde was released at Sterling, Colo. (fig. 17). By this time, the trailing front was located 15-30 miles southwest of Sterling. The data obtained from the rawinsonde were considerably different from those data obtained earlier in that morning by the rawinsondes released from Denver and Sterling, Colo. Low-level moisture content had increased; the average mixing ratio of the lowest 100-millibar layer was 13.8 g/kg, an increase of 2.8 g/kg. The Lifted Index had decreased from +1 to −4, and the lifted condensation level had decreased to the 780-millibar level. More importantly, the level of free convection had decreased from the 480-millibar-level to the 640-millibar level. Precipitable water contents of 0.78 inch in the lowest 150-millibar layer and 1.3 inches in the layer from the surface to the 500-millibar level were almost double the mean July values for Denver, Colo. Below the inversion at the 720-millibar level, the winds were easterly at 10-15 knots. Above the inversion, the winds were westerly but light, indicating that Sterling, Colo., was almost directly below the upper-level ridge. The air behind the trailing front was characterized by a



EXPLANATION

60 65 70 75 — AREA WHERE DEWPOINT TEMPERATURE EXCEEDED 60 DEGREES FAHRENHEIT

—70— LINE OF EQUAL DEWPOINT TEMPERATURE.—Interval 5 degrees Fahrenheit

— —65— — LINE OF EQUAL AIR TEMPERATURE.—Interval 5 degrees Fahrenheit

—12— LINE OF EQUAL ATMOSPHERIC PRESSURE AT SEA LEVEL.—12=1012 millibars. Interval 2 millibars; 1-millibar interval shown by dashed line

COLD FRONT.—Dashed where dissipating

STATIONARY FRONT.—Dashed where dissipating

SQUALL LINE

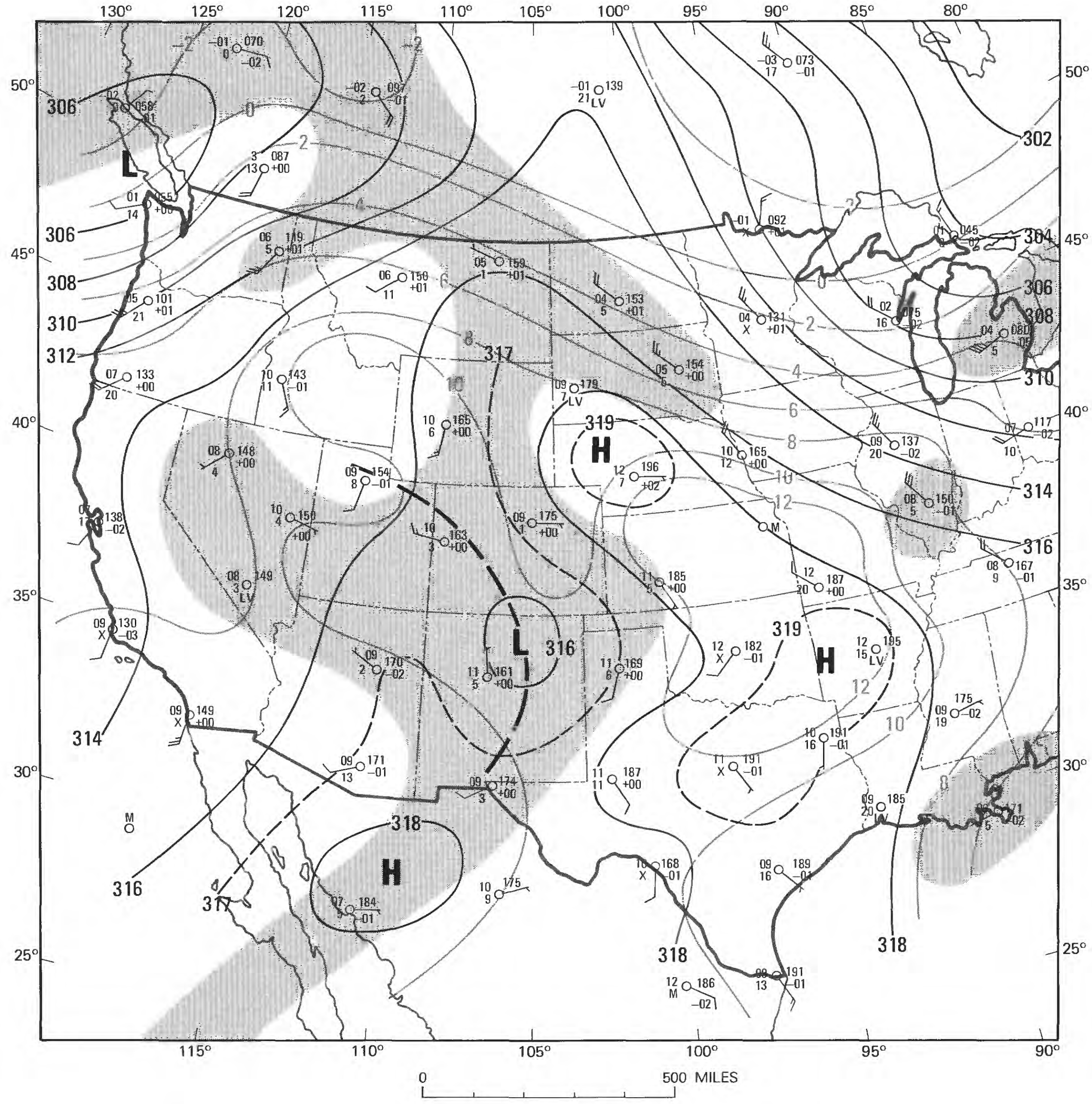
H GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM

L GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM

FIGURE 8.—Surface analysis, 0600 MDT, July 31, 1976.

deep, unusually moist boundary layer which was conditionally very unstable but which would have to be lifted about 4,000 feet to release its instability.

During the afternoon, the surface pressures were steady or increasing slightly over much of Nebraska and were decreasing in western Colorado (figs. 18, 21),



EXPLANATION

AREA WHERE DEWPOINT TEMPERATURE WAS WITHIN 6 DEGREES CELSIUS OF AIR TEMPERATURE

—316— CONTOUR SHOWING ALTITUDE OF 700-MILLIBAR SURFACE.—316=3160 meters. Contour interval 20 meters; 10-meter interval shown by dashed contours. Datum is mean sea level

—10— LINE OF EQUAL AIR TEMPERATURE.—Interval 2 degrees Celsius

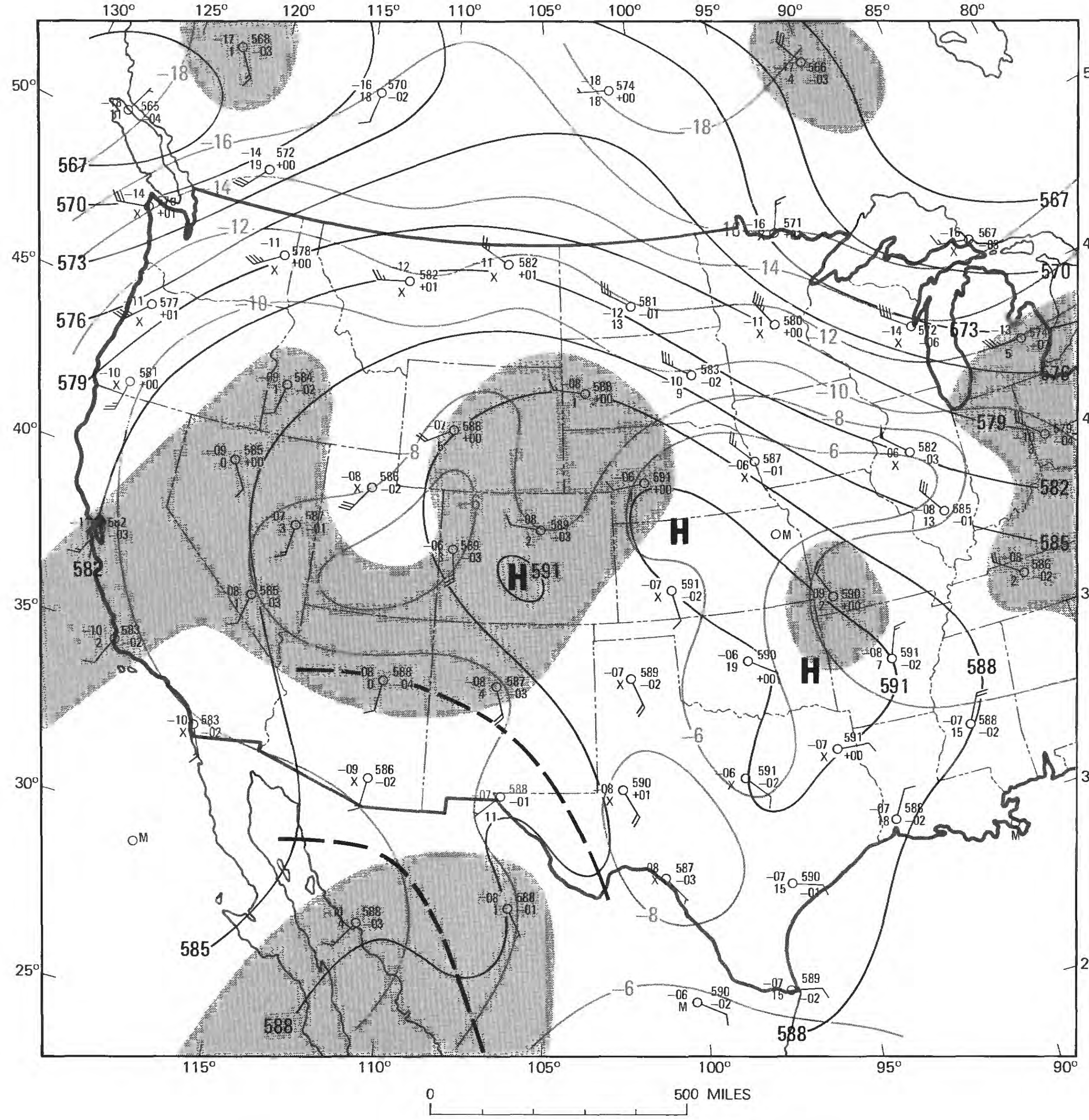
— — AXIS OF PRESSURE TROUGH

H GEOGRAPHIC CENTER OF HIGHEST ALTITUDE OF 700-MILLIBAR SURFACE

L GEOGRAPHIC CENTER OF LOWEST ALTITUDE OF 700-MILLIBAR SURFACE

10 143 / 11 −01 OBSERVATION STATION.—Upper left number is air temperature, in degrees Celsius. Lower left number is depression of dewpoint temperature below air temperature, in degrees Celsius; X shown when depression greater than 30 degrees Celsius. Upper right number is altitude of 700-millibar surface, in meters; 143=3143 meters. Lower right number is 12-hour altitude change of 700-millibar surface, in meters; −01=−10 meters. Shaft indicates wind direction. Barbs on shaft indicate wind speed, in knots. Long barb=10 knots; short barb=5 knots. LV in place of shaft and barbs indicates wind speeds were less than 3 knots and direction was variable. M indicates missing data

FIGURE 9.—700-millibar analysis, 0600 MDT, July 31, 1976.



EXPLANATION

AREA WHERE DEWPOINT TEMPERATURE WAS WITHIN 6 DEGREES CELSIUS OF AIR TEMPERATURE

—582— CONTOUR SHOWING ALTITUDE OF 500-MILLIBAR SURFACE.—582=5820 meters. Contour interval 30 meters. Datum is mean sea level

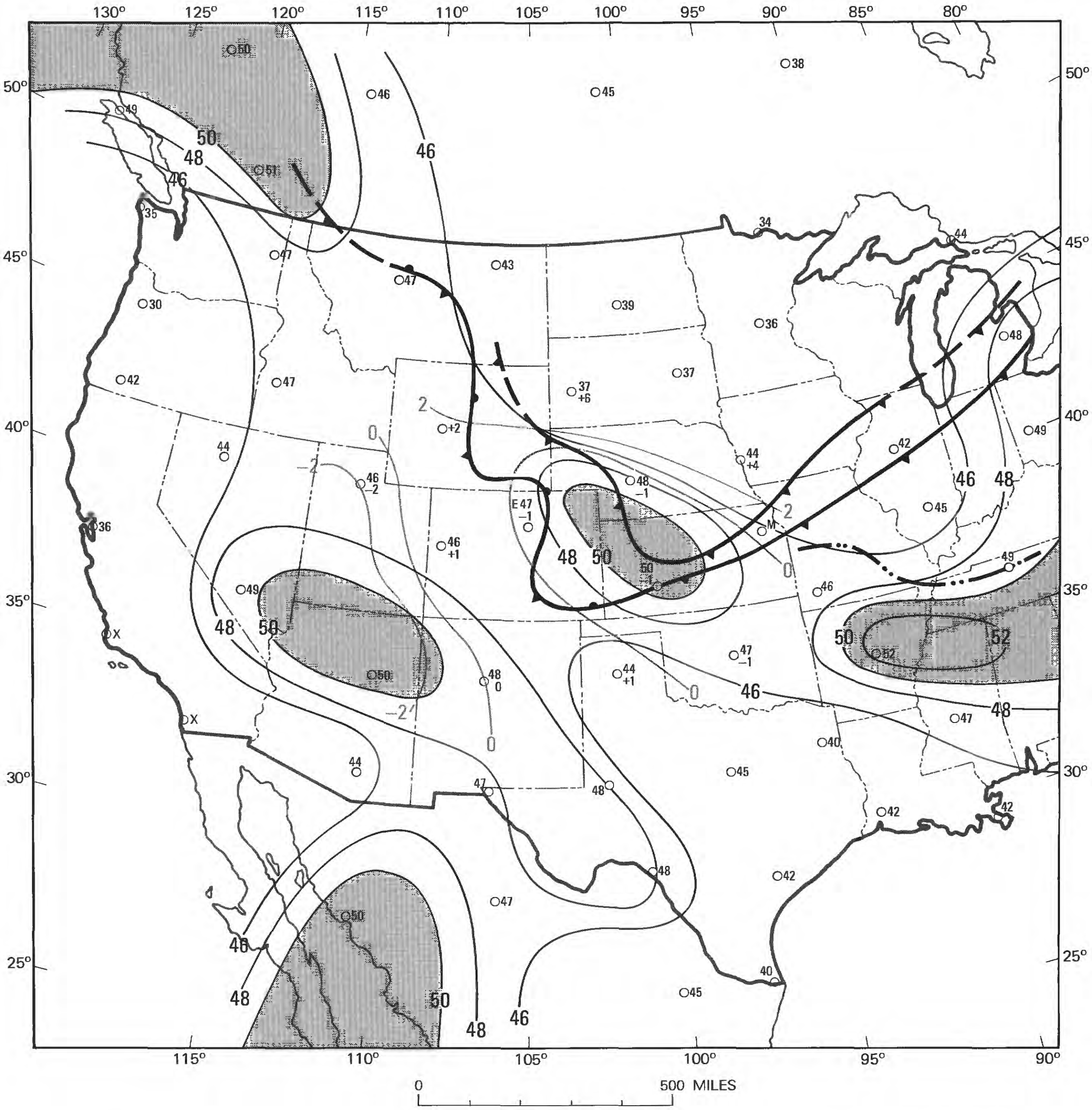
—18— LINE OF EQUAL AIR TEMPERATURE.—Interval 2 degrees Celsius

AXIS OF PRESSURE TROUGH

H GEOGRAPHIC CENTER OF HIGHEST ALTITUDE OF 500-MILLIBAR SURFACE

−07 587 3 −01 OBSERVATION STATION.—Upper left number is air temperature, in degrees Celsius. Lower left number is depression of dewpoint temperature below air temperature, in degrees Celsius; X shown when depression greater than 30 degrees Celsius. Upper right number is altitude of 500-millibar surface, in meters; 581=5810 meters. Lower right number is 12-hour altitude change of 500-millibar surface, in meters; −01=−10 meters. Shaft indicates wind direction. Barbs on shaft indicate wind speed, in knots. Long barb=10 knots; short barb=5 knots. M indicates missing data

FIGURE 10.—500-millibar analysis, 0600 MDT, July 31, 1976.



EXPLANATION

AREA WHERE TOTALS INDEX EXCEEDED 50

—46— LINE OF EQUAL TOTALS INDEX.—Interval 2 units

—2— LINE OF EQUAL LIFTED INDEX.—Interval 2 units

$○^{48}_{-1}$ OBSERVATION STATION.—Upper number, where shown, is Totals Index. Lower number, where shown, is Lifted Index. X indicates Totals Index and(or) Lifted Index not determined. E indicates estimated value. M indicates missing data

COLD FRONT.—Dashed where dissipating

STATIONARY FRONT.—Dashed where dissipating

SQUALL LINE

FIGURE 11.—Stability analysis, 0600 MDT, July 31, 1976.

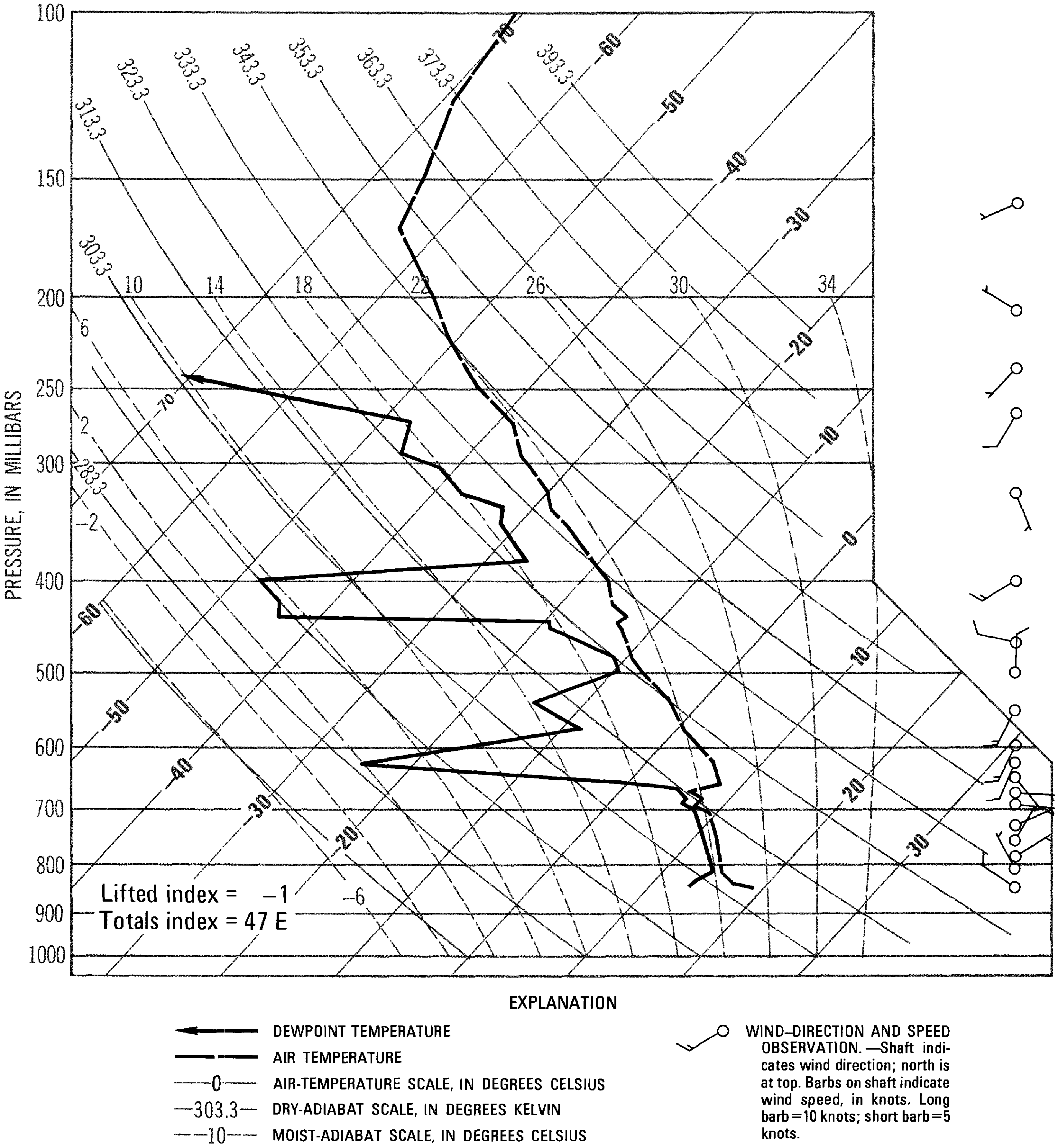


FIGURE 12.—Plot of rawinsonde data obtained at Denver, Colo., 0600 MDT, July 31, 1976.

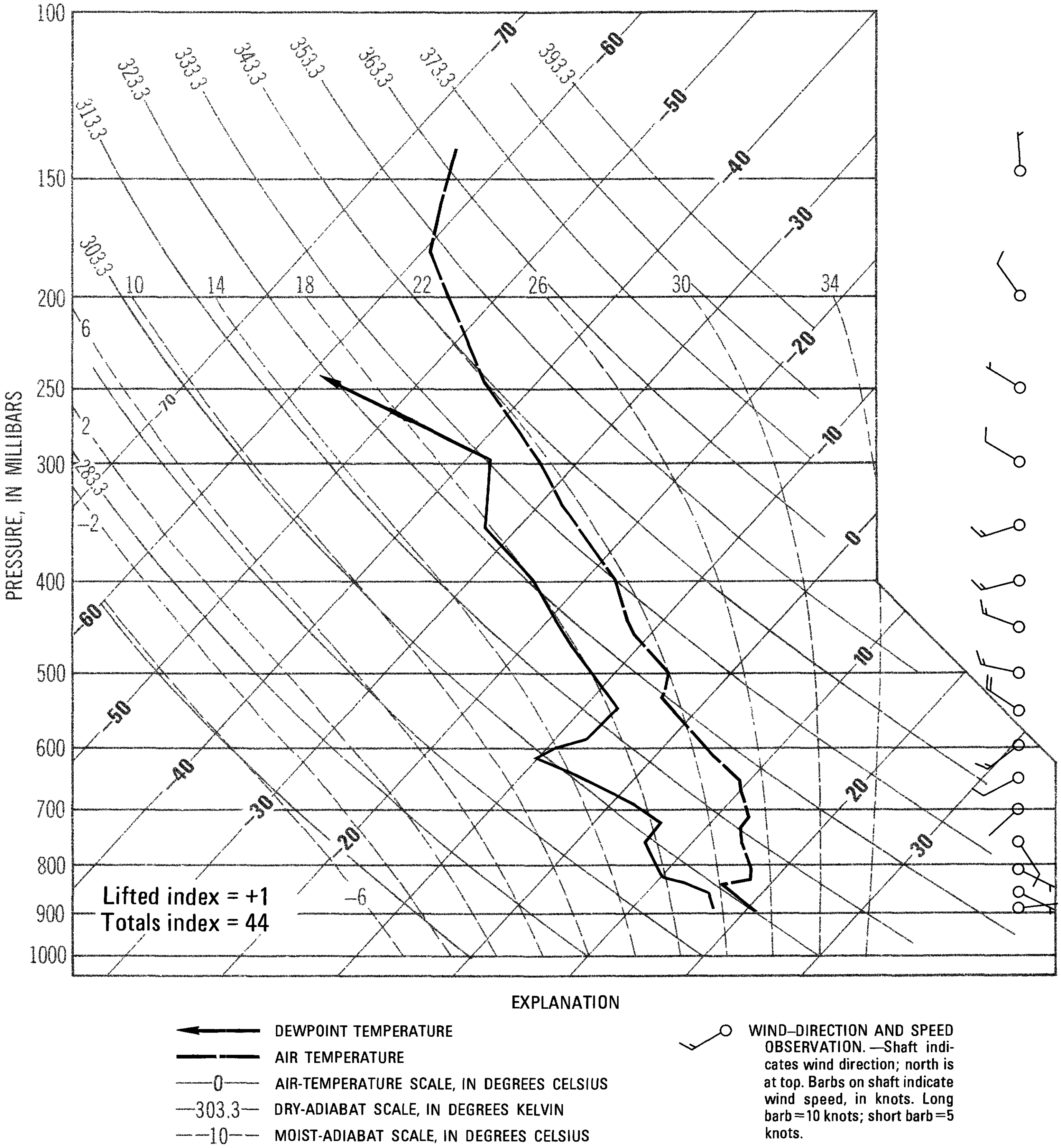
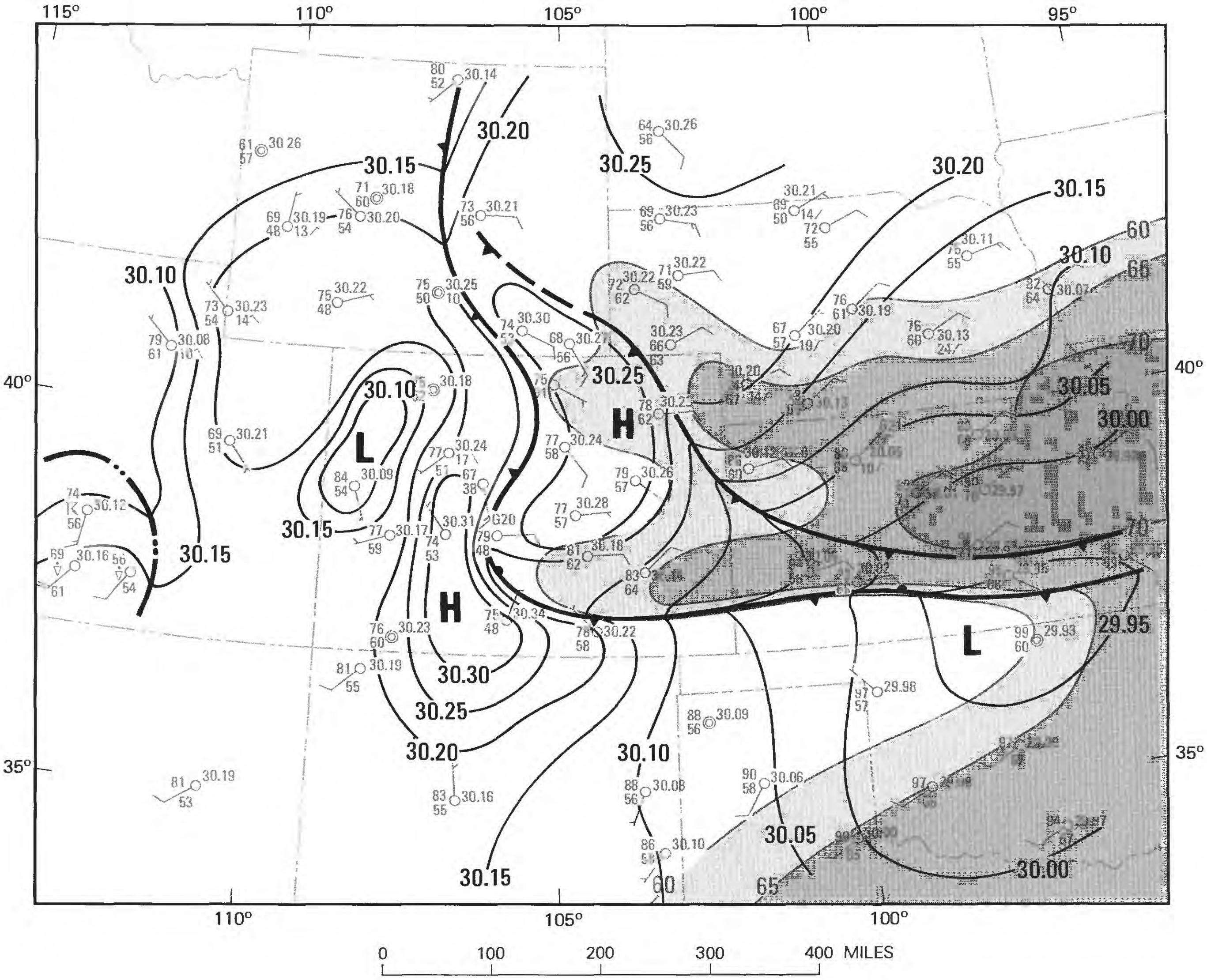


FIGURE 13.—Plot of rawinsonde data obtained at Sterling, Colo., 0740 MDT, July 31, 1976.



EXPLANATION

60 65 70 75

AREA WHERE DEWPOINT TEMPERATURE EXCEEDED 60 DEGREES FAHRENHEIT

—70— LINE OF EQUAL DEWPOINT TEMPERATURE.—Interval 5 degrees Fahrenheit

—30.15— LINE OF EQUAL ALTIMETER SETTING, IN INCHES OF MERCURY.—Interval 0.05 inch

COLD FRONT.—Dashed where dissipating

STATIONARY FRONT

SQUALL LINE

H GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM

L GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM

73 30.23
54 14

OBSERVATION STATION.—Upper left number is air temperature, in degrees Fahrenheit. Lower left number is dewpoint temperature, in degrees Fahrenheit. Upper right number is altimeter setting, in inches of mercury. Lower right number is 3-hour pressure change, in tenths of a millibar; ⧵=decrease, ⁄=increase, and /=no change. Shaft indicates wind direction. Barbs on shaft indicate wind speed, in knots. Long barb=10 knots; short barb=5 knots. ◎=calm winds, less than 2 knots. Additional symbols and notes explained below:

ꓘ=Thunder heard, but no precipitation at station

∇̇ =Slight rain shower(s)

G20=Peak wind gust observed during last hour

FIGURE 14.—Regional surface analysis, 1200 MDT, July 31, 1976.

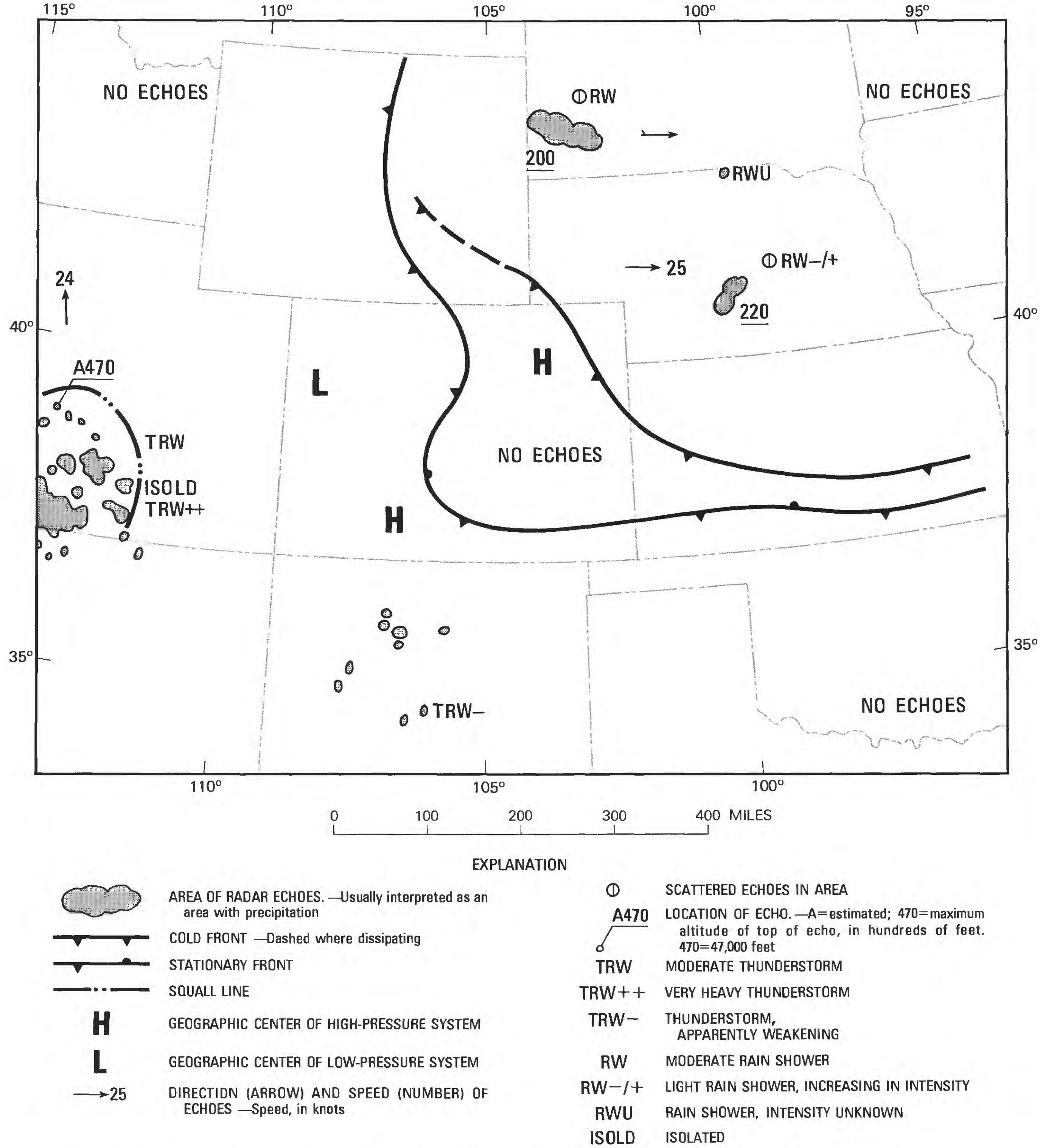


FIGURE 15.—Radar summary for 1135 MDT, with locations of fronts and squall line for 1200 MDT, July 31, 1976.

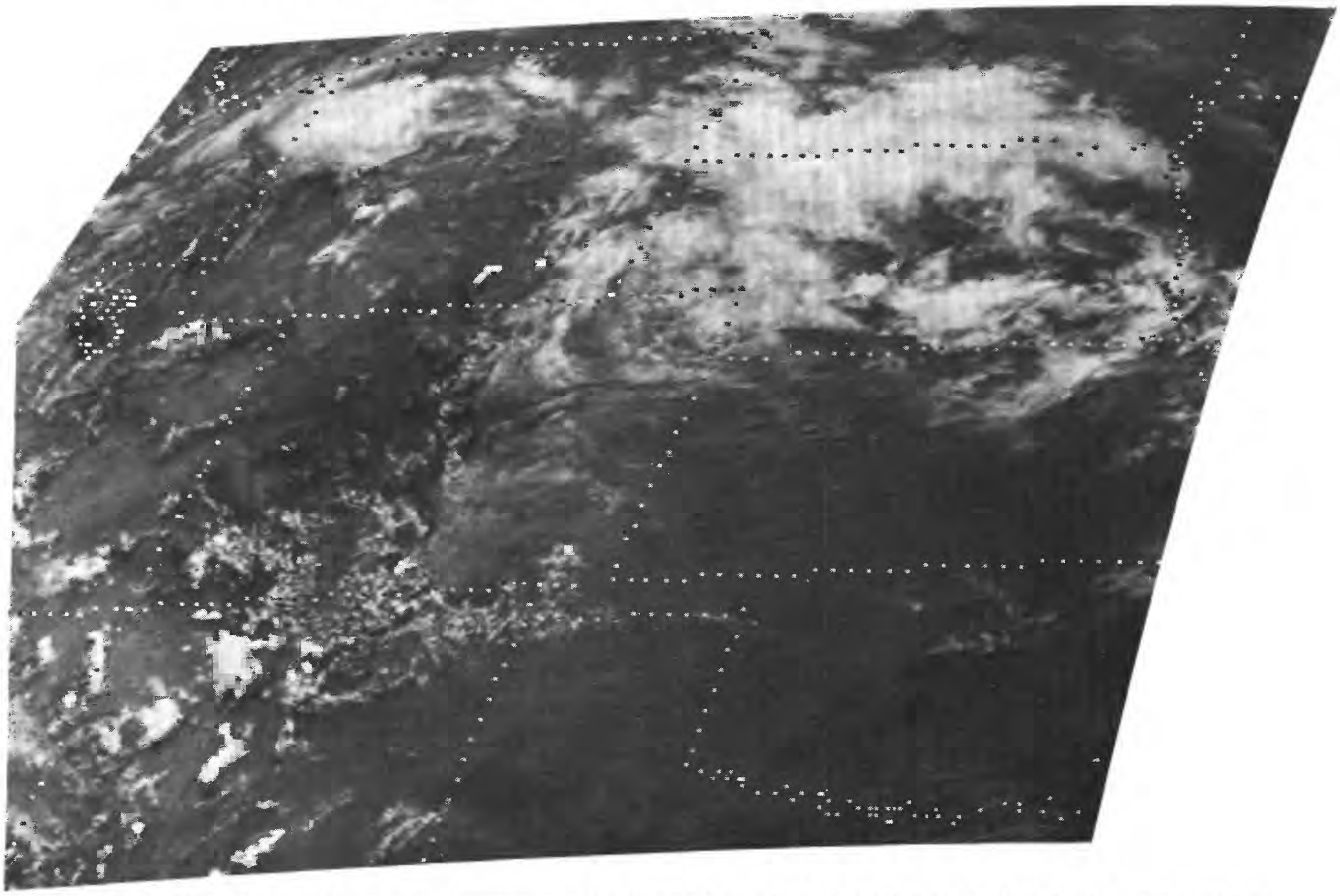


FIGURE 16.—Geostationary Operational Environmental Satellite photograph, 1200 MDT, July 31, 1976. Bright areas are clouds.

where surface temperatures peaked at 90°F or more. A combination of increasing temperatures and weak dynamics associated with the northward-moving pressure trough are believed to be responsible for the lower pressures west of the Continental Divide. The pattern of increasing and decreasing pressures contributed to an increase in the east-to-west pressure gradient across northeastern Colorado.

The radar summaries and satellite photographs (figs. 15, 16, 19, 20, 22, 23) show that deep convection developed over a large part of the Rocky Mountains and central High Plains. Several large thunderstorms occurred along and just north of the trailing front in eastern Colorado and southern Kansas. A large area of showers and thunderstorms also developed over the mountains of northern New Mexico and southwestern Colorado. In southern Utah, a well-defined squall line was moving north-northeastward at 20–25 knots. In the late afternoon, widespread convective activity also spread over east-central Wyoming. Generally, the storms that developed in western Kansas and eastern Colorado and Wyoming were slow-moving or stationary, while those to the west of the Continental Divide moved to the north or northeast at 15–25 knots.

By 1600 MDT the trailing front had merged with the leading front over most of Kansas and was only 30–50 miles east of the foothills in northeastern Colorado (fig. 21). At this time, scattered cumulus and towering cumulus clouds were over the foothills area of northeastern Colorado, which includes the drainage areas of the Big Thompson and the Cache la Poudre Rivers, but little or no precipitation fell (figs. 22, 23). Scattered thunderstorms were forming along the northern slopes of the Palmer Ridge southeast of Denver, Colo., and moderate convective activity had developed in the mountains of north-central Colorado.

At 1602 MDT, a third rawinsonde was released at

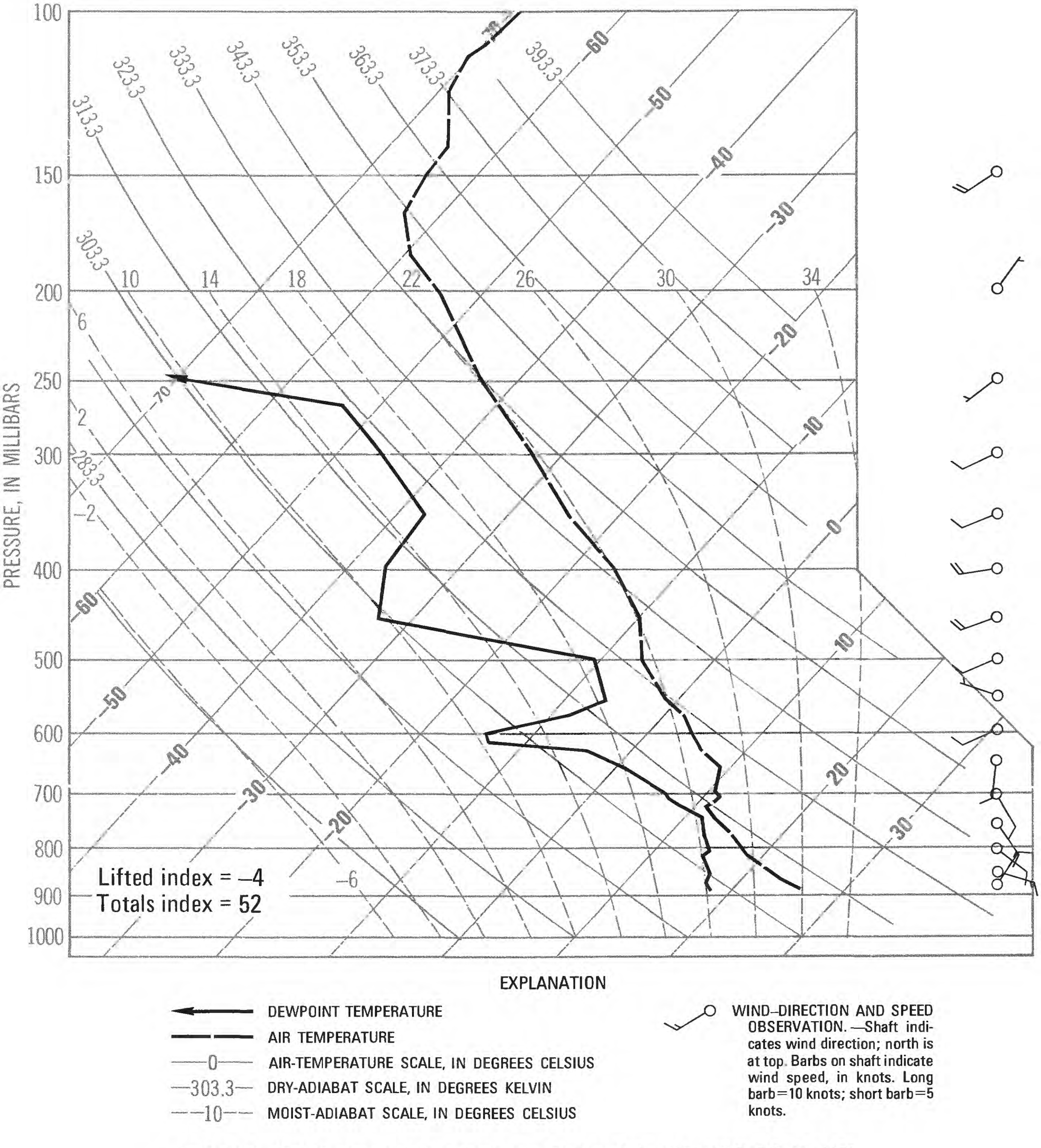
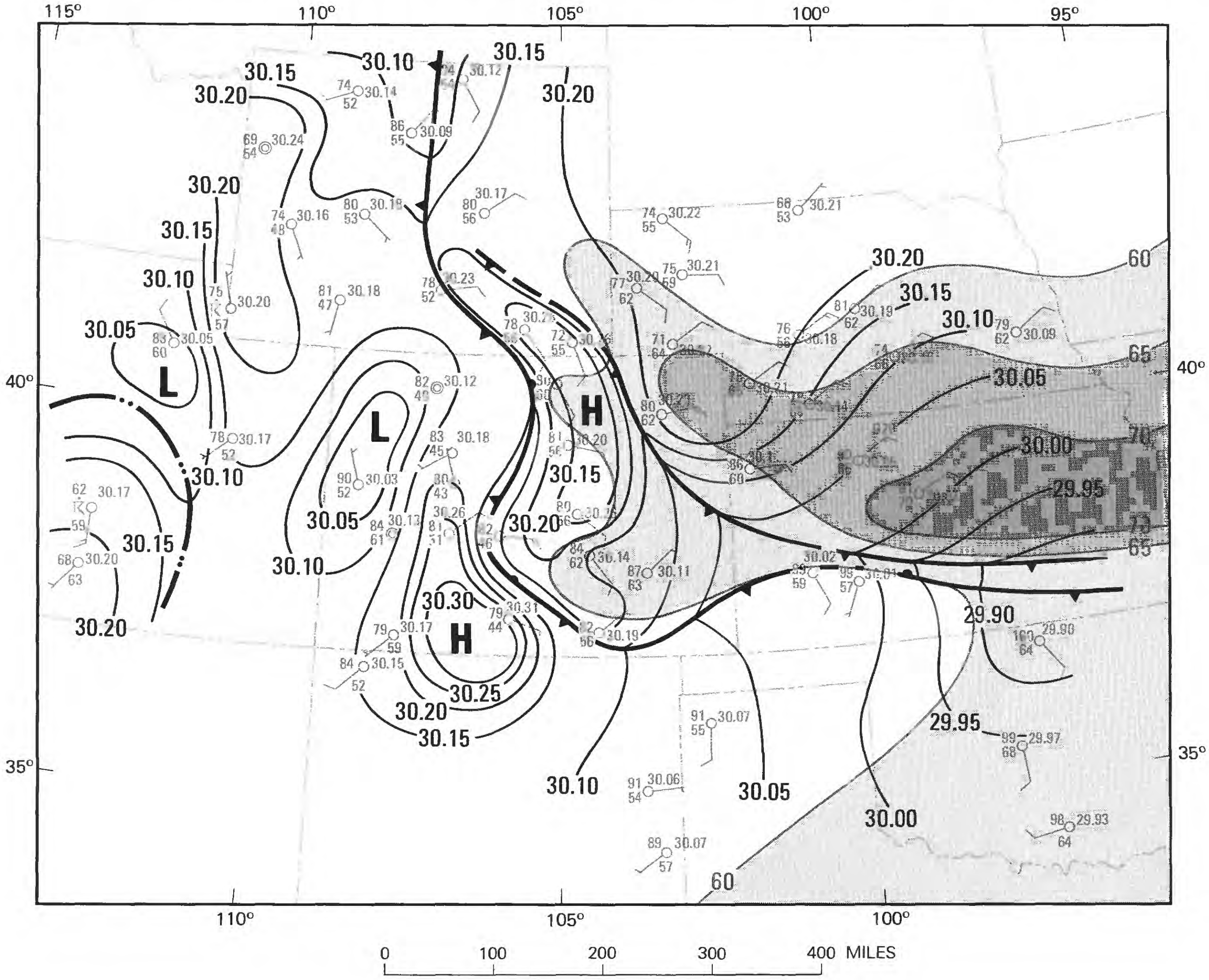


FIGURE 17.—Plot of rawinsonde data obtained at Sterling, Colo., 1320 MDT, July 31, 1976.



EXPLANATION

60 65 70 75

AREA WHERE DEWPOINT TEMPERATURE EXCEEDED 60 DEGREES FAHRENHEIT

—70— LINE OF EQUAL DEWPOINT TEMPERATURE.—Interval 5 degrees Fahrenheit

—30.15— LINE OF EQUAL ALTIMETER SETTING, IN INCHES OF MERCURY.—Interval 0.05 inch

COLD FRONT.—Dashed where dissipating

STATIONARY FRONT

SQUALL LINE

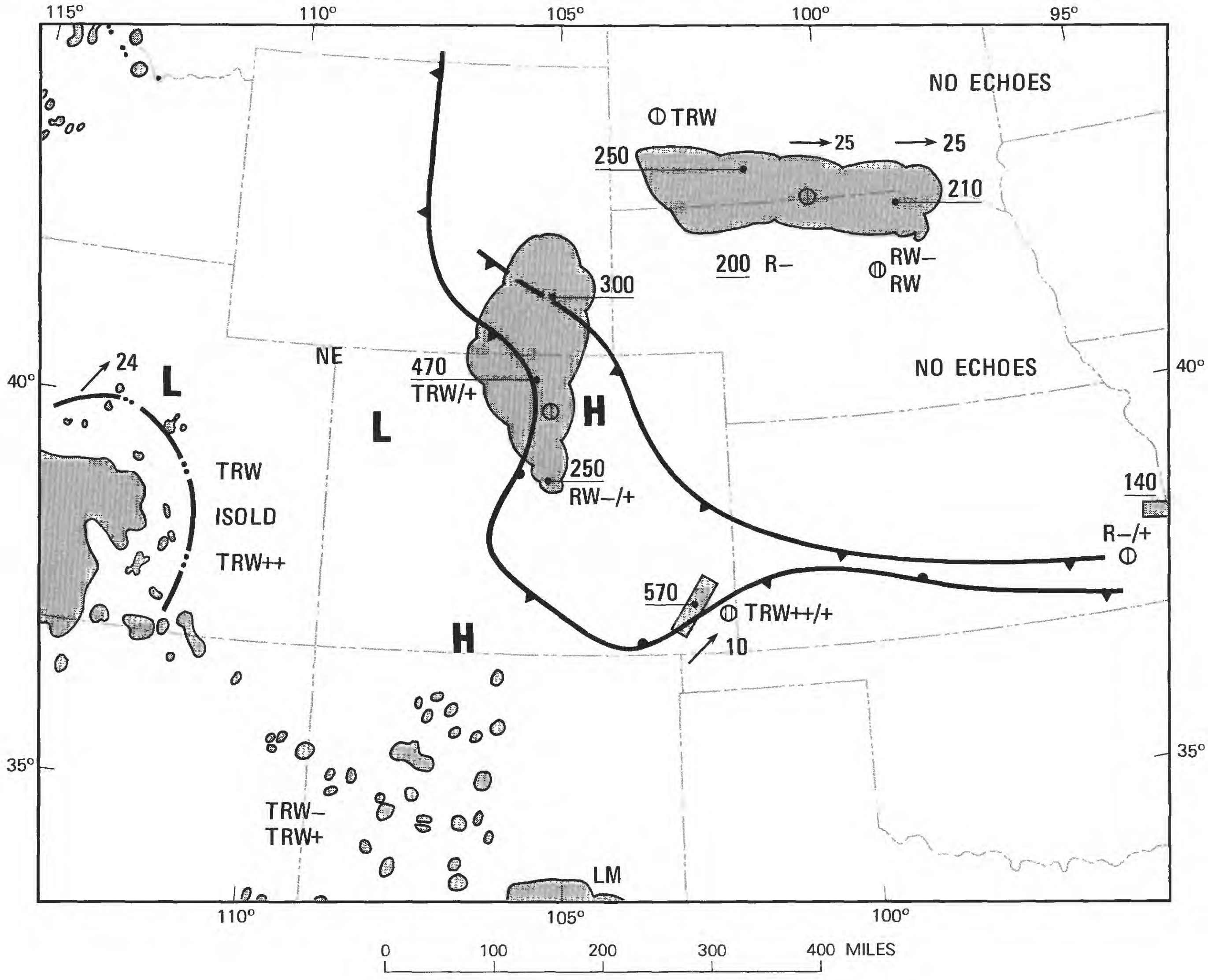
H GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM

L GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM

99 30.01 57 OBSERVATION STATION.—Upper left number is air temperature, in degrees Fahrenheit. Lower left number is dewpoint temperature, in degrees Fahrenheit. Number at right is altimeter setting, in inches of mercury. Shaft indicates wind direction. Barbs on shaft indicate wind speed, in knots. Long barb=10 knots, short barb=5 knots. ◎=calm winds, less than 2 knots. Additional symbols and notes explained below:

Ꝁ =Thunderstorm with rain

FIGURE 18.—Regional surface analysis, 1400 MDT, July 31, 1976.



EXPLANATION

	AREA OF RADAR ECHOES.—Usually interpreted as an area with precipitation
	AREA WHERE RADAR ECHOES ORIENTED IN A LINE
	COLD FRONT.—Dashed where dissipating
	STATIONARY FRONT
	SQUALL LINE
H	GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM
L	GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM
→ 25	DIRECTION (ARROW) AND SPEED (NUMBER) OF ECHOES.—Speed, in knots
⦶	SCATTERED ECHOES IN AREA
⦶	BROKEN AREAS WITH ECHOES
570	LOCATION OF ECHO.—570=maximum observed altitude of top of echo, in hundreds of feet. 570=57,000 feet

TRW–	LIGHT THUNDERSTORM
TRW	MODERATE THUNDERSTORM
TRW+	HEAVY THUNDERSTORM
TRW++	VERY HEAVY THUNDERSTORM
TRW/+	MODERATE THUNDERSTORM, INCREASING IN INTENSITY
TRW++/+	VERY HEAVY THUNDERSTORM, INCREASING IN INTENSITY
R–	LIGHT RAIN
R–/+	LIGHT RAIN INCREASING IN INTENSITY
RW–	LIGHT RAIN SHOWER
RW	MODERATE RAIN SHOWER
RW–/+	LIGHT RAIN SHOWER, INCREASING IN INTENSITY
LM	RADAR OPERATING IN LIMITED MODE
ISOLD	ISOLATED

FIGURE 19.—Radar summary for 1335 MDT, with location of fronts and squall line for 1400 MDT, July 31, 1976.

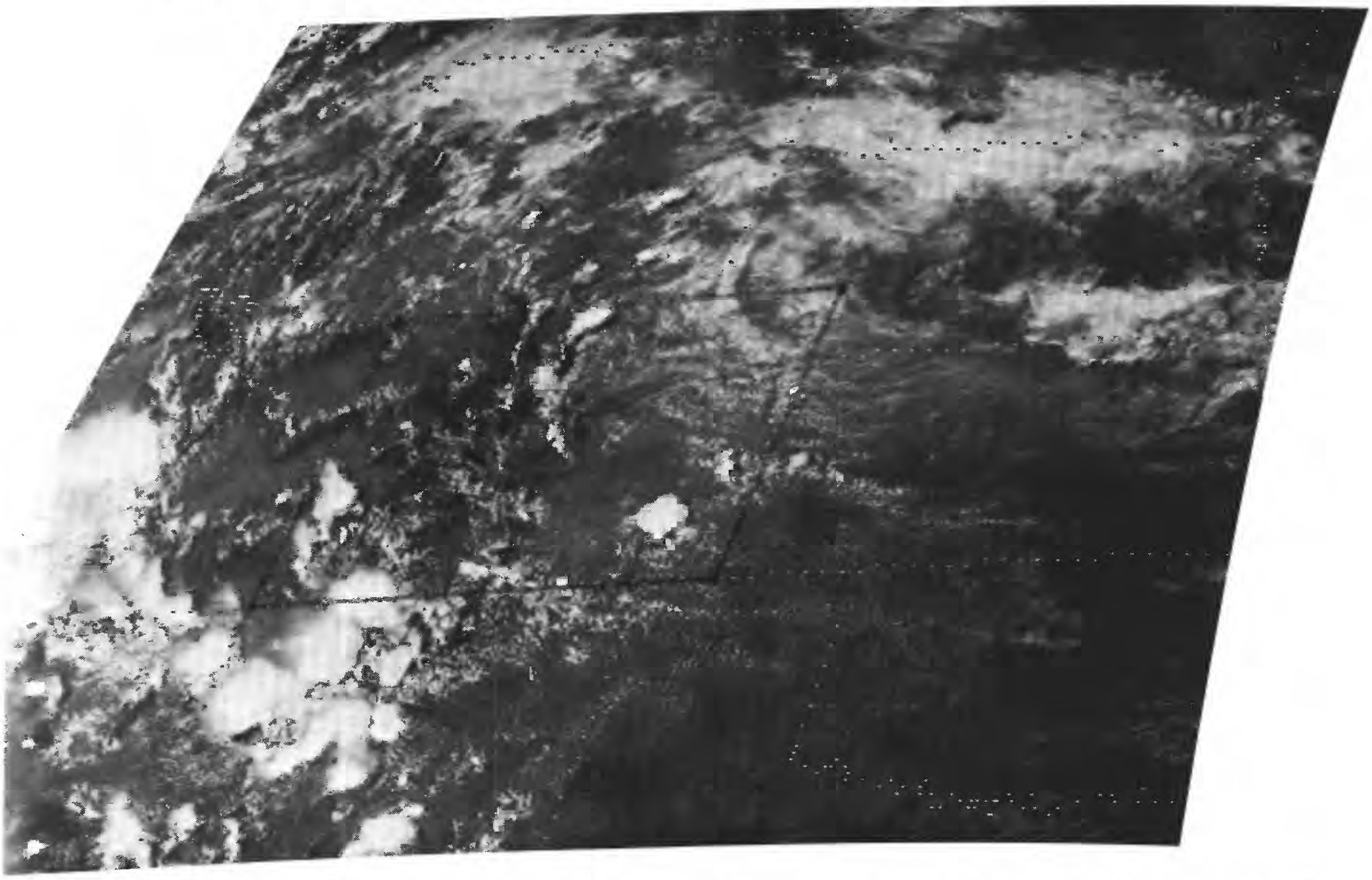


FIGURE 20.—Geostationary Operational Environmental Satellite photograph, 1400 MDT, July 31, 1976. Bright areas are clouds.

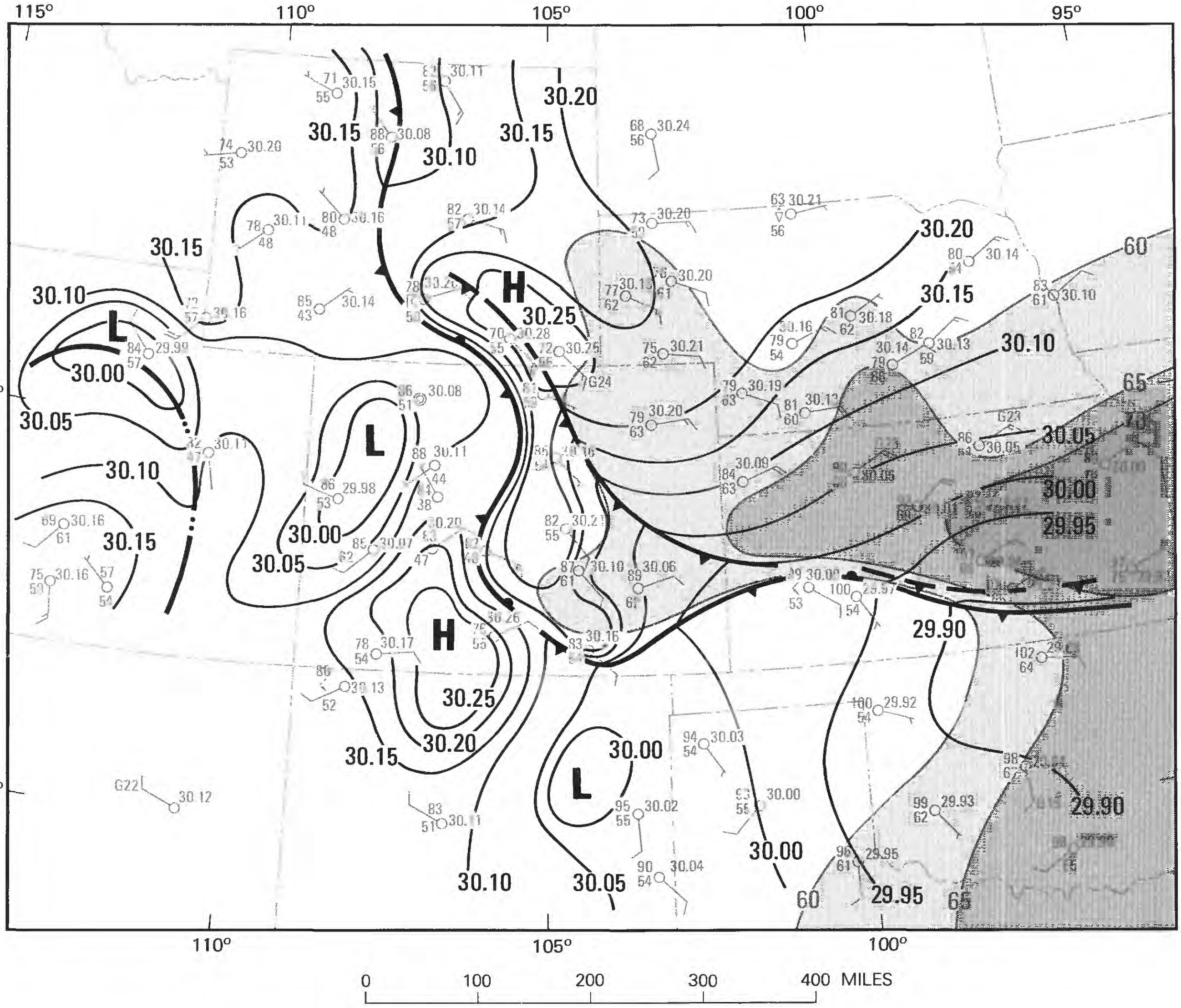
Sterling, Colo. (fig. 24). By this time, the trailing front was located about 75 miles southwest of Sterling. The rawinsonde recorded a mean mixing ratio of 12.5 g/kg, a Lifted Index of −2, and a level of free convection at the 600-millibar level. Evidently, the air with the greatest potential for strong convection had moved southwestward in a narrow band behind the trailing front.

Conditions that existed at 1800 MDT while the storms that caused the flash flooding were forming are depicted in figures 25–32. In western Colorado, the surface low had reached its maximum intensity. The trailing front had moved into the foothills in northeastern Colorado and had merged with the leading front everywhere except in the Arkansas River valley in southeastern Colorado. Easterly surface winds behind the trailing front were 15—30 knots in a broad band from central Kansas to eastern Wyoming.

At the 700-millibar and 500-millibar levels (figs. 29, 30), the large ridge had increased in amplitude over Montana and southwestern Canada. The trough at the 700-millibar level had moved only slightly while the two troughs at the 500-millibar level had evolved into a single northward-moving trough extending from central Nevada to northern New Mexico. The radar summary for 1735 MDT (fig. 26) and the satellite photograph for 1800 MDT (fig. 27) indicated that the squall line in Utah and most of the widespread thunderstorms over the mountains of New Mexico and Colorado were alined along and to the northeast of the trough at the 500-millibar level.

The stability analysis for 1800 MDT (fig. 31) indicated that the area having the thermodynamic potential for strong thunderstorms had increased during the day. Very unstable conditions extended from northern New Mexico to Montana.

For operational purposes, rawinsonde are released about 45 minutes prior to the 0600 and 1800 MDT standard upper-air analyses time. On the evening of July 31, the rawinsonde from Denver, Colo., was released at 1715 MDT. Data from that rawinsonde are shown in figure 32. Diurnal heating had modified the airmass over Denver, Colo., significantly. The inversion had risen to the 590-millibar level with the lapse rate below the inversion near dry adiabatic. The mean mixing ratio in the lowest 100-millibar layer had decreased from 12.0 to 9.5 g/kg; the Lifted Index was −2. Precipitable water in the lowest 150-millibar layer



EXPLANATION

60 65 70 75

AREA WHERE DEWPOINT TEMPERATURE EXCEEDED 60 DEGREES FAHRENHEIT

—70— LINE OF EQUAL DEWPOINT TEMPERATURE.—Interval 5 degrees Fahrenheit

—30.15— LINE OF EQUAL ALTIMETER SETTING, IN INCHES OF MERCURY.—Interval 0.05 inch

COLD FRONT.—Dashed where dissipating

STATIONARY FRONT

SQUALL LINE

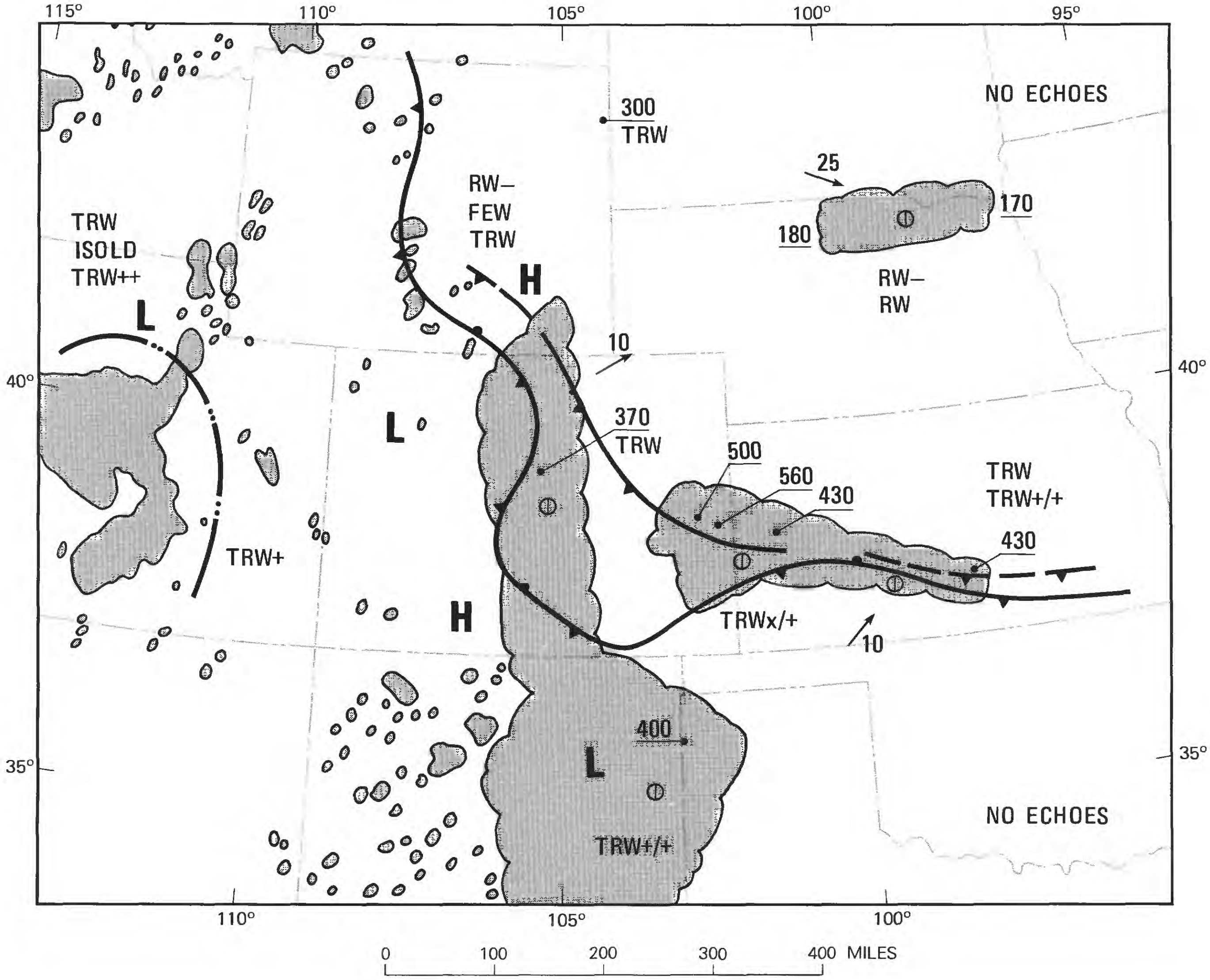
H GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM

L GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM

82 30.11 56 OBSERVATION STATION.—Upper left number is air temperature, in degrees Fahrenheit. Lower left number is dewpoint temperature, in degrees Fahrenheit. Number at right is altimeter setting, in inches of mercury. Shaft indicates wind direction. Barbs on shaft indicate wind speed, in knots. Long barb=10 knots, short barb=5 knots. ◎=calm winds, less than 2 knots. Additional symbols and notes explained below:

- =Thunder heard, but no precipitation at station
- =Slight rain shower(s)
- =Lighting observed
- G22=Peak wind gust observed during last hour

FIGURE 21.—Regional surface analysis, 1600 MDT, July 31, 1976.



EXPLANATION

- AREA OF RADAR ECHOES.—Usually interpreted as an area with precipitation
- COLD FRONT —Dashed where dissipating
- STATIONARY FRONT
- SQUALL LINE
- H GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM
- L GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM
- →25 DIRECTION (ARROW) AND SPEED (NUMBER) OF ECHOES —Speed, in knots
- ⦶ SCATTERED ECHOES IN AREA
- 430 LOCATION OF ECHO.—430=maximum observed altitude of top of echo, in hundreds of feet. 430=43,000 feet
- TRW MODERATE THUNDERSTORM
- TRW+ HEAVY THUNDERSTORM
- TRW++ VERY HEAVY THUNDERSTORM
- TRW+/+ HEAVY THUNDERSTORM, INCREASING IN INTENSITY
- TRWx/+ INTENSE THUNDERSTORM, INCREASING IN INTENSITY
- RW– LIGHT RAIN SHOWER
- RW MODERATE RAIN SHOWER
- ISOLD ISOLATED

FIGURE 22.—Radar summary for 1535 MDT, with locations of fronts and squall line for 1600 MDT, July 31, 1976.

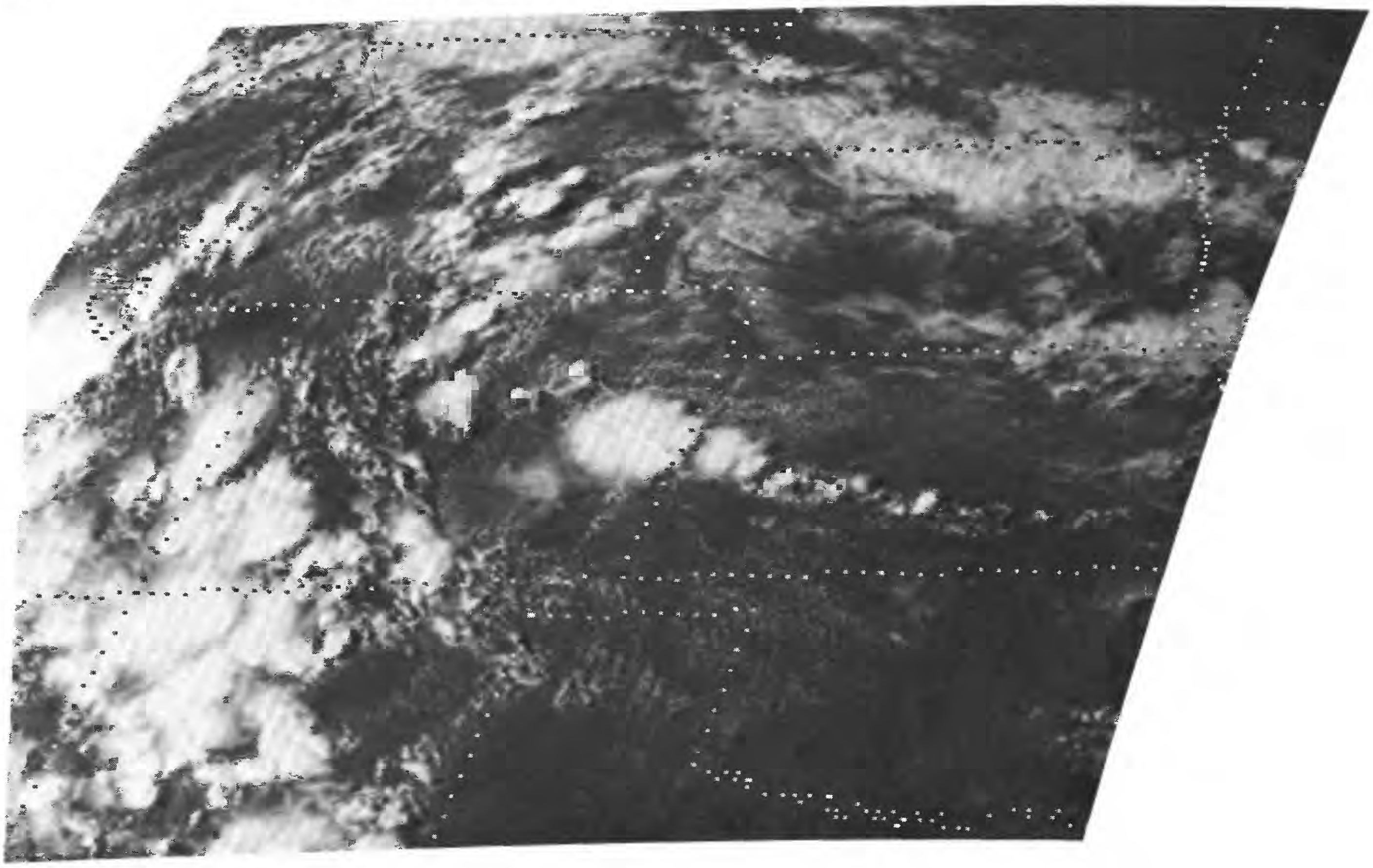


FIGURE 23.—Geostationary Operational Environmental Satellite photograph, 1600 MDT, July 31, 1976. Bright areas are clouds.

was 0.55 inch, substantially lower than 12 hours earlier. However, precipitable water in the layer from the surface to the 500-millibar level was 0.97 inch, nearly the same as the morning value. Heating and mixing had redistributed the moisture through a thicker layer. The trailing front moved through Denver, Colo., 15–20 minutes after the rawinsonde was released. Therefore, the rawinsonde provided no information about the extremely moist airmass just a few miles to the northeast.

CONDITIONS DURING THE STORM

Prior to 1800 MDT, there had been almost no precipitation falling on the foothills in northeastern Colorado. Two to three hours later, catastrophic flooding was occurring. This section describes meteorological conditions along the Front Range from Denver, Colo., to north of Fort Collins, Colo., from 1700 MDT to about 2200 MDT on July 31, 1976.

Data were available from the following locations: Fort Collins, Colo. (Colorado State University, Atmospheric Science Building); Greeley, Colo. (University of Northern Colorado, Ross Hall); Table Mountain near Boulder, Colo. (National Oceanic and Atmospheric Administration, Environmental Research Laboratories); Rocky Flats plant near Boulder, Colo. (Rockwell International Corp.); Jefferson County and Arapahoe County Airports, Colo. (Federal Aviation Administration); and Stapleton International Airport in Denver, Colo. (National Oceanic and Atmospheric Administration, National Weather Service). Radar reflectivity data were available for the entire storm from the radar operated by the National Weather Service at Limon, Colo., located about 125 miles southeast of the Big Thompson River area. Reflectivity data for 45 minutes at the beginning of the storm were available from the radar used for the National Hail Research Experiment at Grover, Colo., located about 70 miles east-northeast of the Drake-Estes Park area.

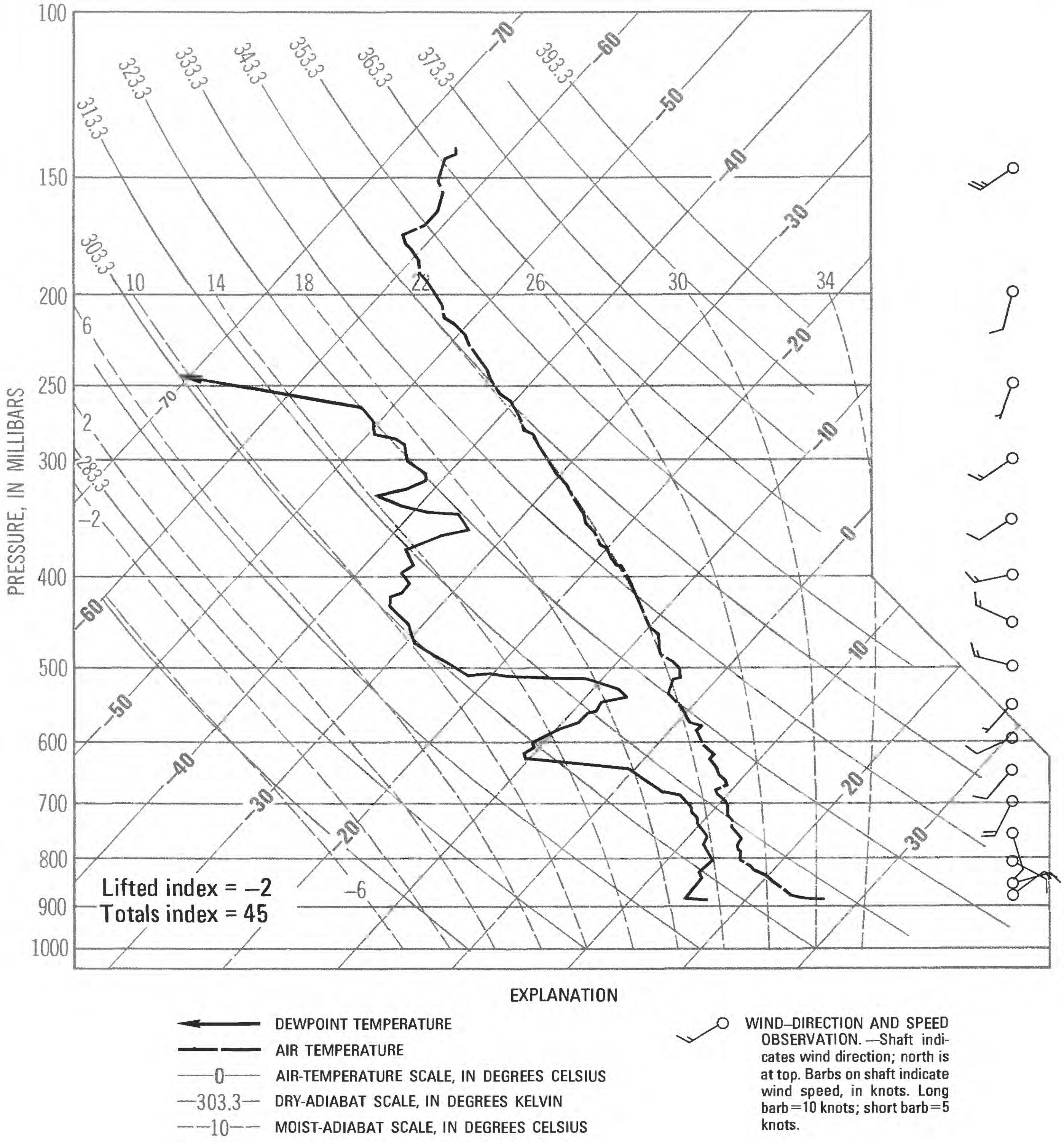
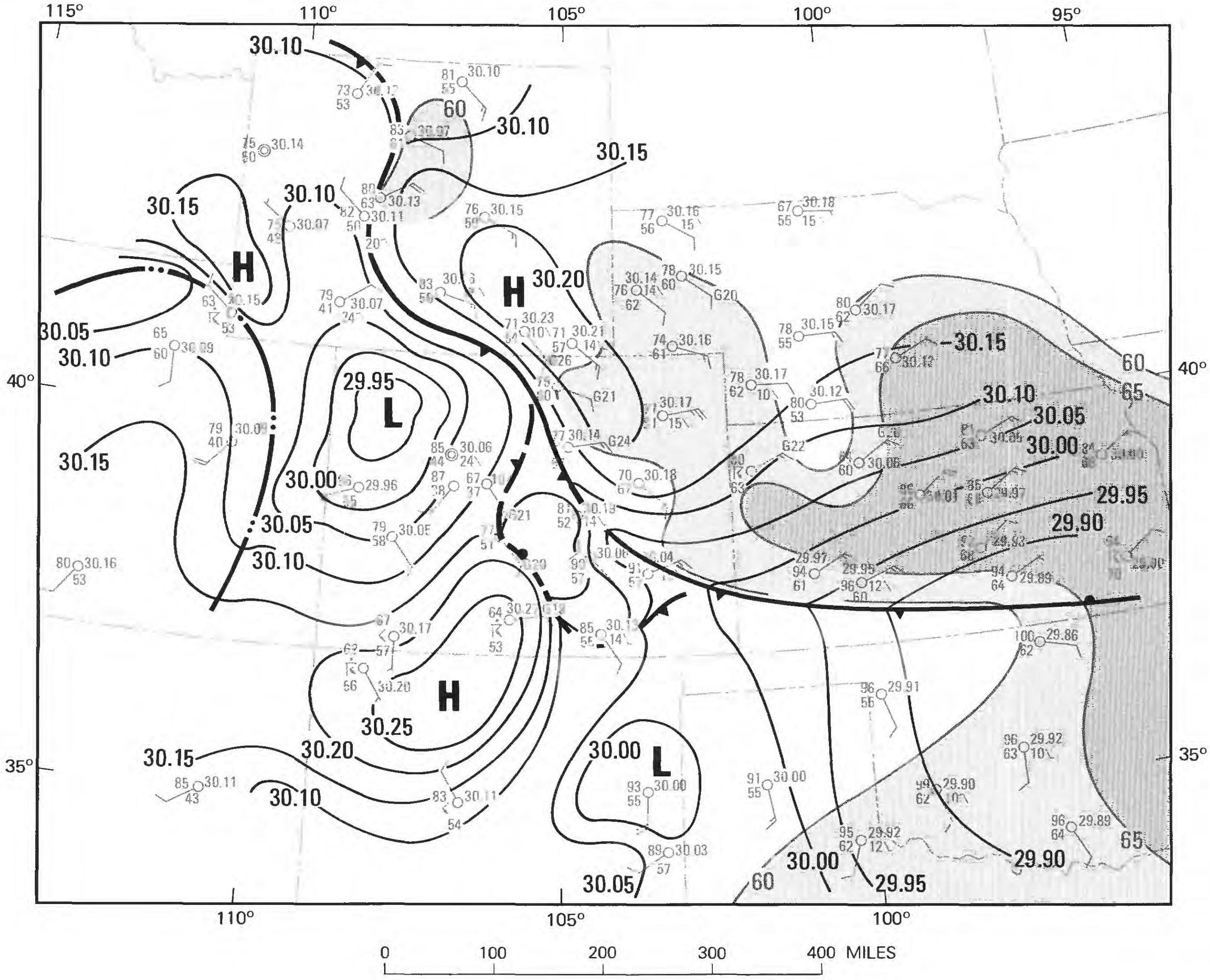


FIGURE 24.—Plot of rawinsonde data obtained at Sterling, Colo., 1602 MDT, July 31, 1976.



EXPLANATION

60 65 70

AREA WHERE DEWPOINT TEMPERATURE EXCEEDED 60 DEGREES FAHRENHEIT

65 — LINE OF EQUAL DEWPOINT TEMPERATURE.—Interval 5 degrees Fahrenheit

30.15 — LINE OF EQUAL ALTIMETER SETTING, IN INCHES OF MERCURY.—Interval 0.05 inch

COLD FRONT.

STATIONARY FRONT —Dashed where dissipating

SQUALL LINE

H GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM

L GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM

71 30.21 57 14 OBSERVATION STATION.—Upper left number is air temperature, in degrees Fahrenheit. Lower left number is dewpoint temperature, in degrees Fahrenheit. Upper right number is altimeter setting, in inches of mercury. Lower right number is 3-hour pressure change, in tenths of a millibar; ⟍ =decrease, ⟍ =increase, and =no change. Shaft indicates wind direction. Barbs on shaft indicate wind speed, in knots. Long barb=10 knots; short barb=5 knots. ◎=calm winds, less than 2 knots. Additional symbols and notes explained below:

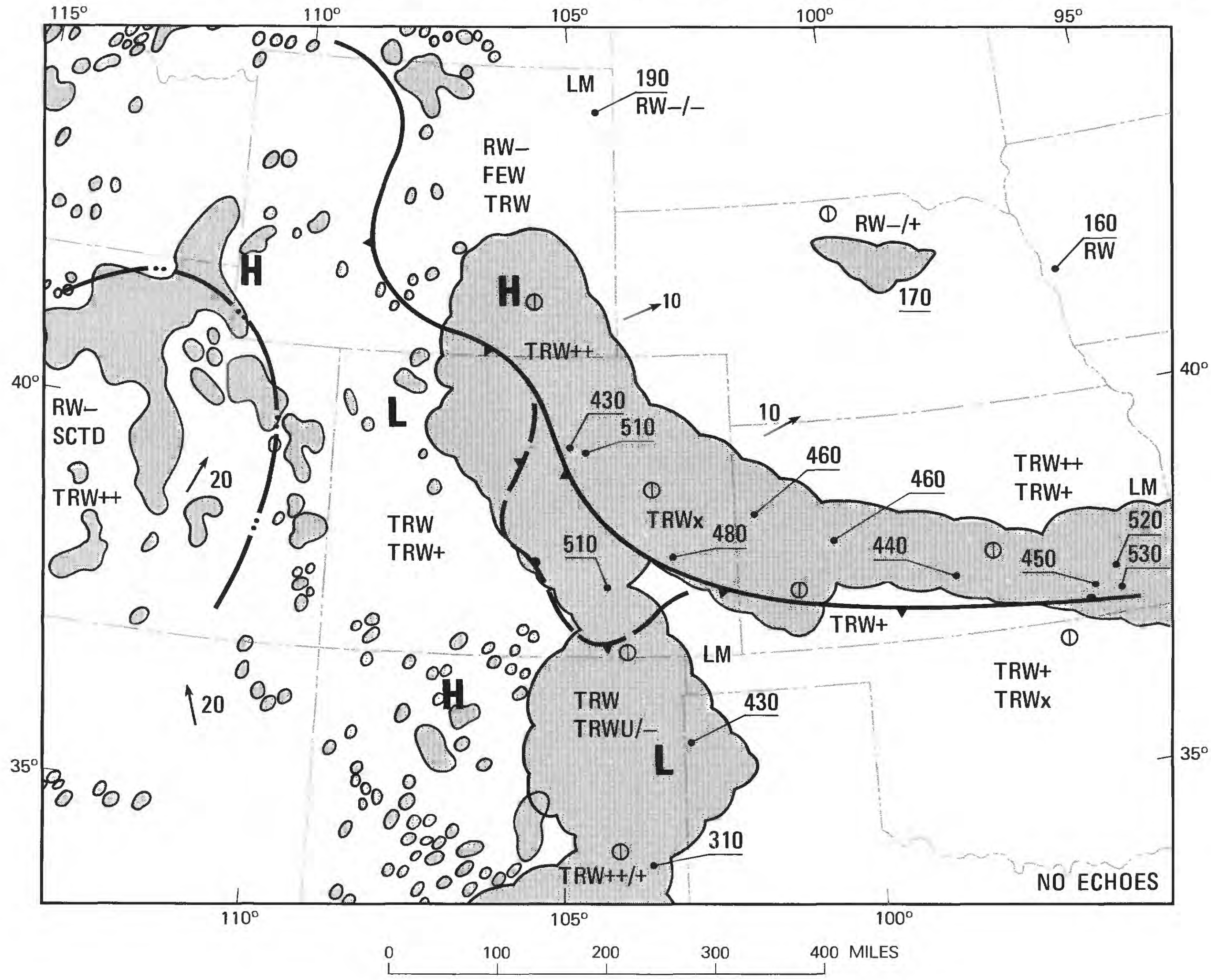
Ꝁ =Thunder heard, but no precipitation at station

Ꝁ̇ =Thunderstorm with rain

⟨ =Lighting observed

G24=Peak wind gust observed during last hour

FIGURE 25.—Regional surface analysis, 1800 MDT, July 31, 1976.



EXPLANATION

(shaded area)	AREA OF RADAR ECHOES.—Usually interpreted as an area with precipitation
(line with triangles)	COLD FRONT
(line with triangle and semicircle)	STATIONARY FRONT.—Dashed where dissipating
(dash-dot line)	SQUALL LINE
H	GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM
L	GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM
⟶10	DIRECTION (ARROW) AND SPEED (NUMBER) OF ECHOES.—Speed, in knots
⦶	SCATTERED ECHOES IN AREA
520	LOCATION OF ECHO.—520=maximum observed altitude of top of echo, in hundreds of feet. 520=52,000 feet
TRW	MODERATE THUNDERSTORM
TRW+	HEAVY THUNDERSTORM
TRW++	VERY HEAVY THUNDERSTORM
TRWx	INTENSE THUNDERSTORM
TRW++/+	VERY HEAVY THUNDERSTORM, INCREASING IN INTENSITY
TRWU/–	THUNDERSTORM OF UNKNOWN INTENSITY, APPARENTLY WEAKENING
R–	LIGHT RAIN
RW–	LIGHT RAIN SHOWER
RW	MODERATE RAIN SHOWER
RW–/+	LIGHT RAIN SHOWER, INCREASING IN INTENSITY
RW–/–	LIGHT RAIN SHOWER, DECREASING IN INTENSITY
LM	RADAR OPERATING IN LIMITED MODE

FIGURE 26.—Radar summary for 1735 MDT, with locations of fronts and squall line for 1800 MDT, July 31, 1976.

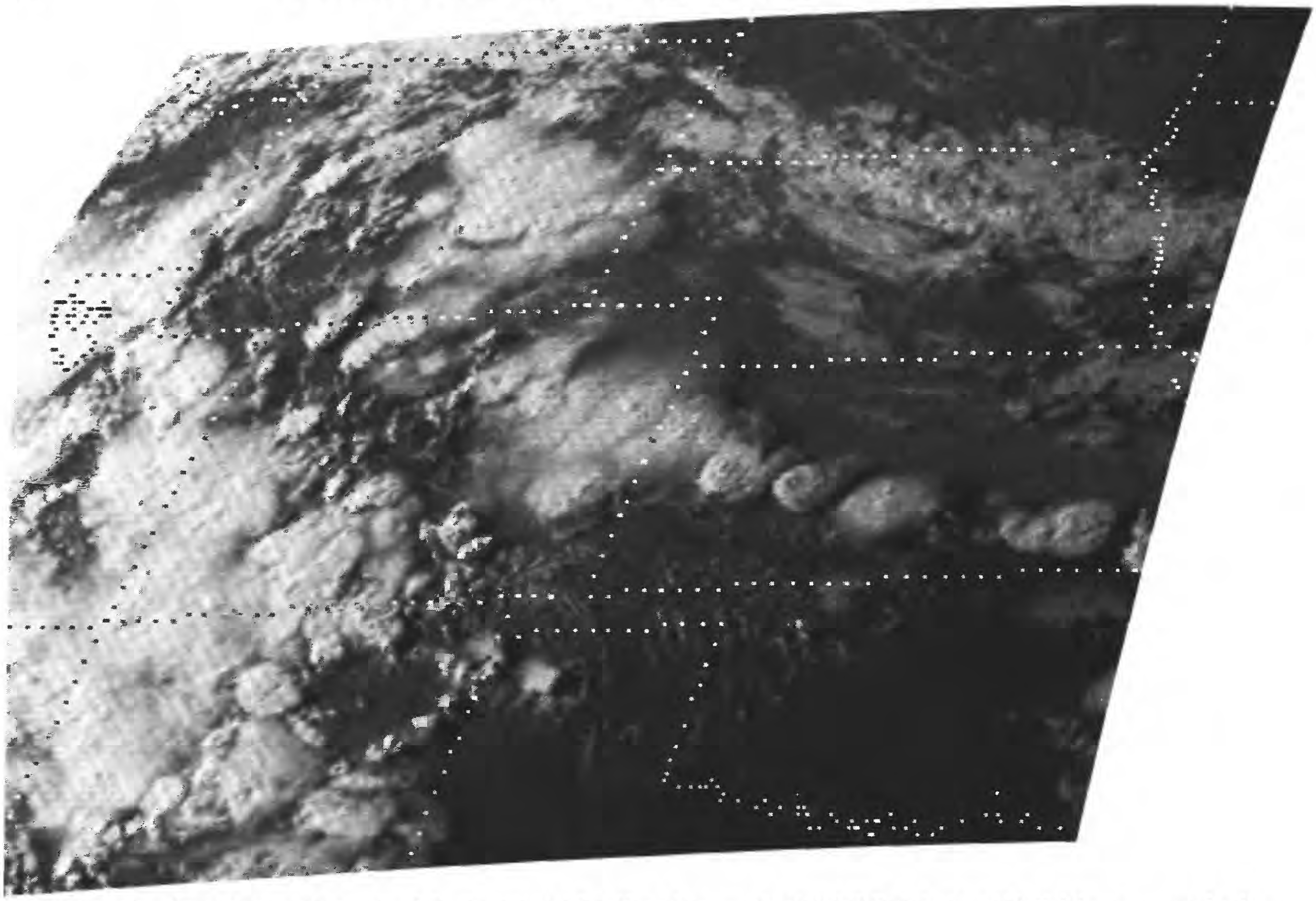


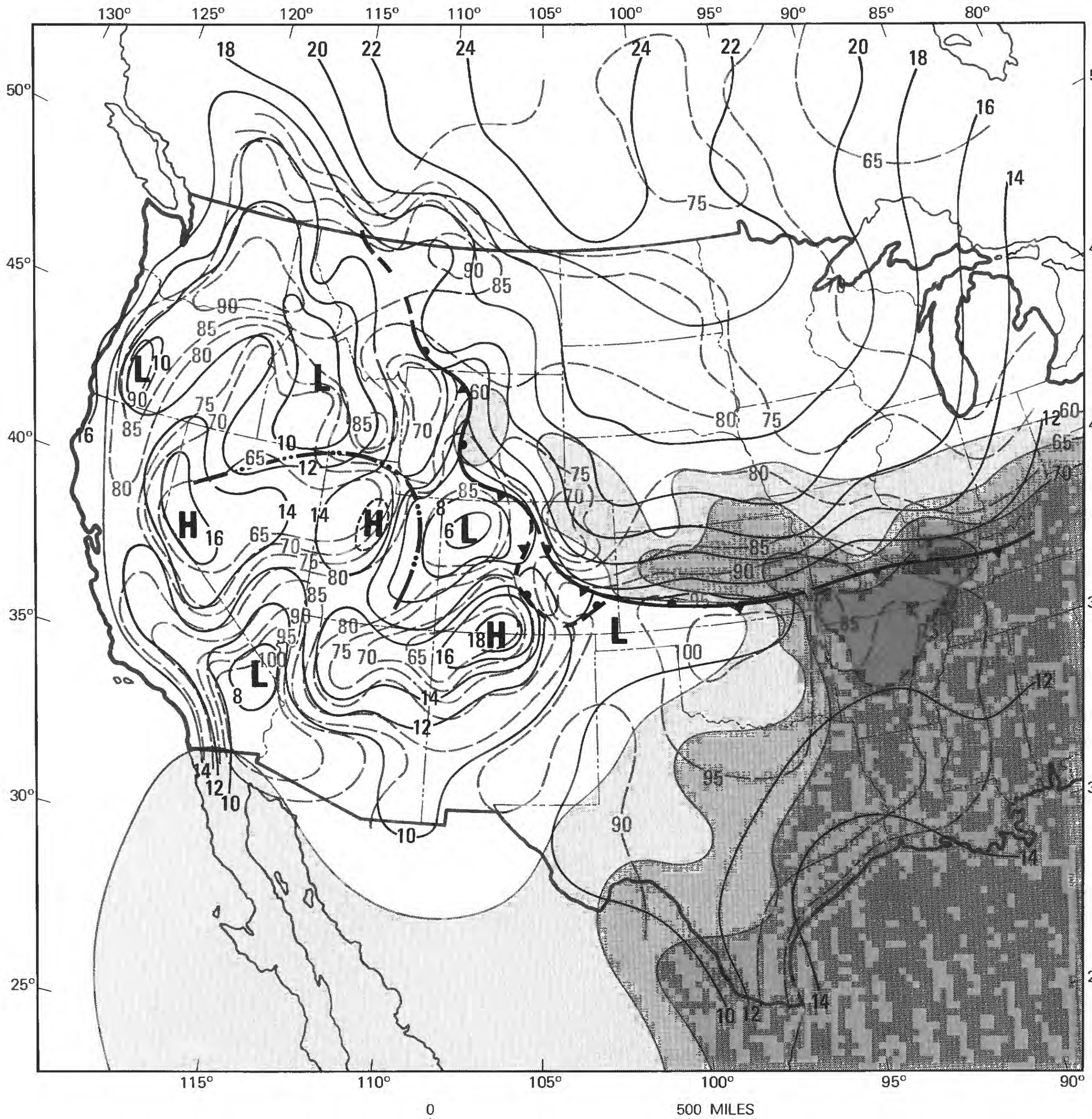
FIGURE 27.—Geostationary Operational Environmental Satellite photograph, 1800 MDT, July 31, 1976. Bright areas are clouds.

ANALYSIS OF CONDITIONS IN REGION OF FLASH FLOODING

Surface data were recorded almost continually at Stapleton International Airport, Rocky Flats, and Table Mountain. Detailed time series were constructed using these data (figs. 33-35). At Table Mountain, about 6 miles north of Boulder, Colo., the east-west component of the wind was measured from the surface to about 2,000 feet by a Doppler acoustic-echo sounder operated by the Wave Propagation Laboratory of the Environmental Research Laboratories. These time series, hourly observations from the remaining sites, and radar data from Limon, Colo., were used to construct the analyses of surface conditions shown in figure 36. Radar echoes for Video Integrator Processor levels 1, 2, and 3 are shown on the maps (fig. 36). These echoes correspond to the minimum detectable signal, 30 and 41 dBZ, respectively.

In the Fort Collins, Loveland, and Greeley, Colo., areas, an increase in wind speed and gustiness were the only indications of the passage of the trailing front. The sky over the areas remained partly cloudy during the afternoon with southeasterly winds, resulting in small temperature differences across the front. In the Denver-Boulder, Colo., area, however, afternoon cloudiness was minimal and the resulting heating and mixing had increased the surface-air temperatures and decreased the dewpoints. The winds also were more southerly. The trailing front passed both Stapleton International Airport and Table Mountain at about 1730 MDT. At these sites, the passage of the front was accompanied by a significant increase in easterly or southeasterly winds. Dewpoint temperatures increased 10°-13°F and air temperatures decreased 10°-12°F in 30 minutes.

Prior to 1730 MDT, a large thunderstorm had developed southeast of Denver, Colo., as the trailing front moved into this region (fig. 36*A*). The thunderstorm moved northwestward and merged with



EXPLANATION

60 65 70 75 80

AREA WHERE DEWPOINT TEMPERATURE EXCEEDED 60 DEGREES FAHRENHEIT

—70— LINE OF EQUAL DEWPOINT TEMPERATURE.—Interval 5 degrees Fahrenheit

— —65— — LINE OF EQUAL AIR TEMPERATURE.—Interval 5 degrees Fahrenheit

—12— LINE OF EQUAL ATMOSPHERIC PRESSURE AT SEA LEVEL.—12=1012 millibars. Interval 2 millibars; 1-millibar interval shown by dashed line

COLD FRONT.—Dashed where dissipating

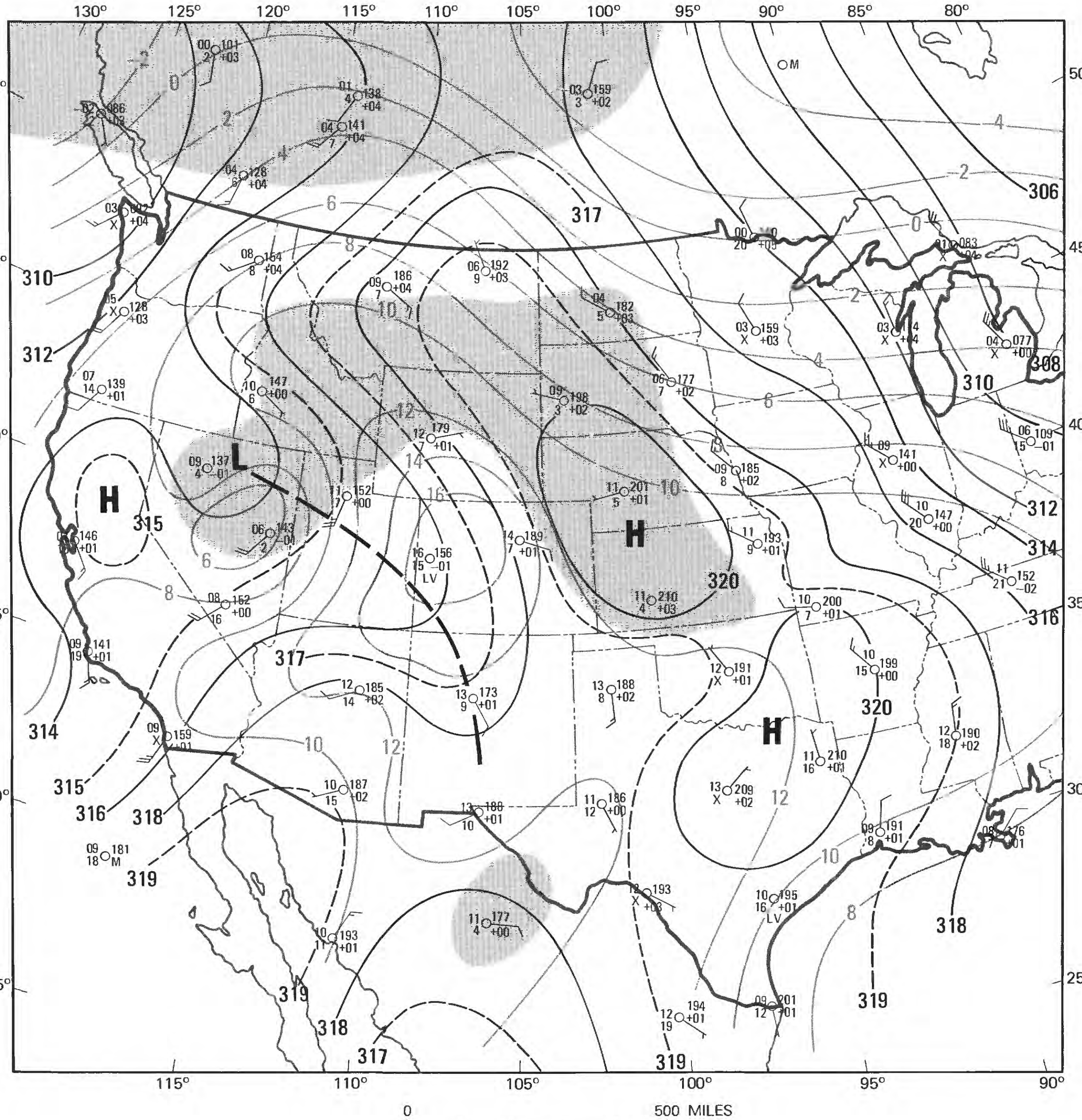
STATIONARY FRONT.—Dashed where dissipating

SQUALL LINE

H GEOGRAPHIC CENTER OF HIGH-PRESSURE SYSTEM

L GEOGRAPHIC CENTER OF LOW-PRESSURE SYSTEM

FIGURE 28.—Surface analysis, 1800 MDT, July 31, 1976.



EXPLANATION

AREA WHERE DEWPOINT TEMPERATURE WAS WITHIN 6 DEGREES CELSIUS OF AIR TEMPERATURE

—316— CONTOUR SHOWING ALTITUDE OF 700-MILLIBAR SURFACE.—316=3160 meters. Contour interval 20 meters; 10-meter interval shown by dashed contours. Datum is mean sea level

—10— LINE OF EQUAL AIR TEMPERATURE.—Interval 2 degrees Celsius

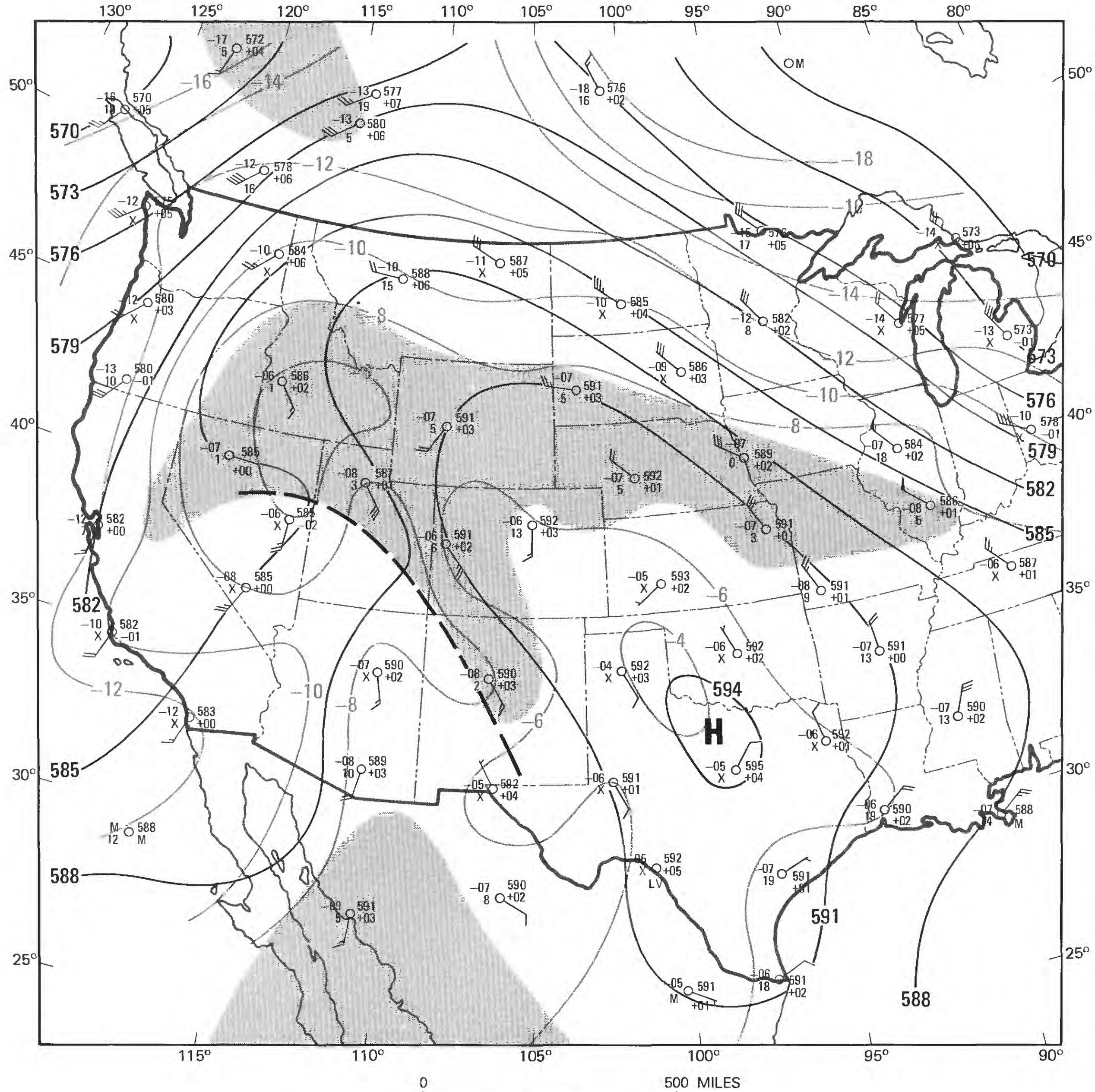
AXIS OF PRESSURE TROUGH

H GEOGRAPHIC CENTER OF HIGHEST ALTITUDE OF 700-MILLIBAR SURFACE

L GEOGRAPHIC CENTER OF LOWEST ALTITUDE OF 700-MILLIBAR SURFACE

10 143 / 11 −01 OBSERVATION STATION.—Upper left number is air temperature, in degrees Celsius. Lower left number is depression of dewpoint temperature below air temperature, in degrees Celsius; X shown when depression greater than 30 degrees Celsius. Upper right number is altitude of 700-millibar surface, in meters; 143=3143 meters. Lower right number is 12-hour altitude change of 700-millibar surface, in meters; −01=−10 meters. Shaft indicates wind direction. Barbs on shaft indicate wind speed, in knots. Long barb=10 knots; short barb=5 knots. LV in place of shaft and barbs indicates wind speeds were less than 3 knots and direction was variable. M indicates missing data

FIGURE 29.—700-millibar analysis, 1800 MDT, July 31, 1976.



EXPLANATION

AREA WHERE DEWPOINT TEMPERATURE WAS WITHIN 6 DEGREES CELSIUS OF AIR TEMPERATURE

—582— CONTOUR SHOWING ALTITUDE OF 500-MILLIBAR SURFACE. — 582=5820 meters. Contour interval 30 meters. Datum is mean sea level

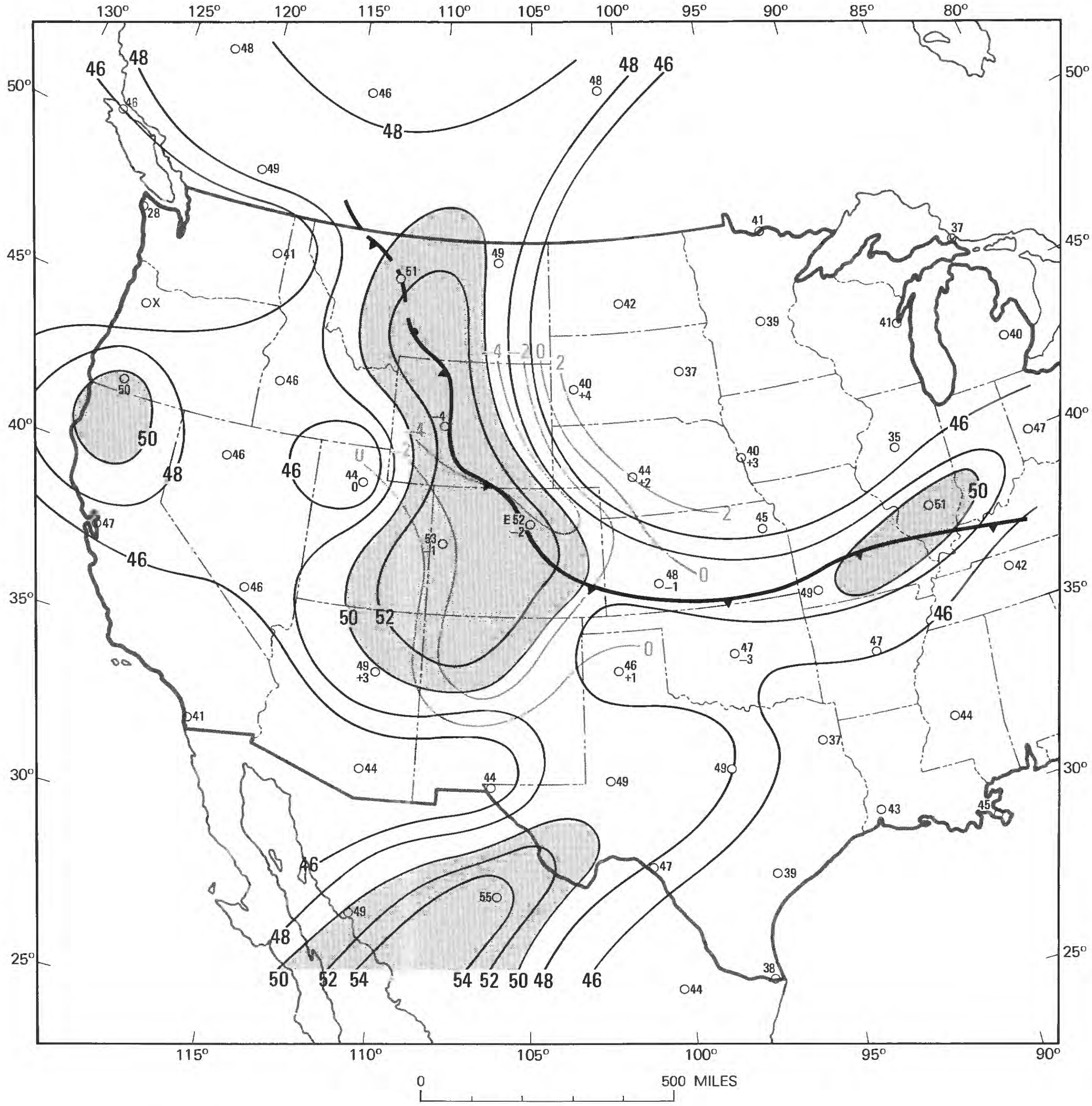
—18— LINE OF EQUAL AIR TEMPERATURE. —Interval 2 degrees Celsius

AXIS OF PRESSURE TROUGH

H GEOGRAPHIC CENTER OF HIGHEST ALTITUDE OF 500-MILLIBAR SURFACE

−07 587 3 −01 OBSERVATION STATION.—Upper left number is air temperature, in degrees Celsius. Lower left number is depression of dewpoint temperature below air temperature, in degrees Celsius; X shown when depression greater than 30 degrees Celsius. Upper right number is altitude of 500-millibar surface, in meters; 581=5810 meters. Lower right number is 12-hour altitude change of 500-millibar surface, in meters; −01=−10 meters. Shaft indicates wind direction. Barbs on shaft indicate wind speed, in knots. Long barb=10 knots; short barb=5 knots. M indicates missing data

FIGURE 30.—500-millibar analysis, 1800 MDT, July 31, 1976.



EXPLANATION

AREA WHERE TOTALS INDEX EXCEEDED 50

—46— LINE OF EQUAL TOTALS INDEX.—Interval 2 units

—2— LINE OF EQUAL LIFTED INDEX.—Interval 2 units

○ 48 / −1 OBSERVATION STATION.—Upper number, where shown, is Totals Index. Lower number, where shown, is Lifted Index. X indicates Totals Index and(or) Lifted Index not determined. E indicates estimated value

COLD FRONT.—Dashed where dissipating

STATIONARY FRONT.—Dashed where dissipating

FIGURE 31.—Stability analysis, 1800 MDT, July 31, 1976.

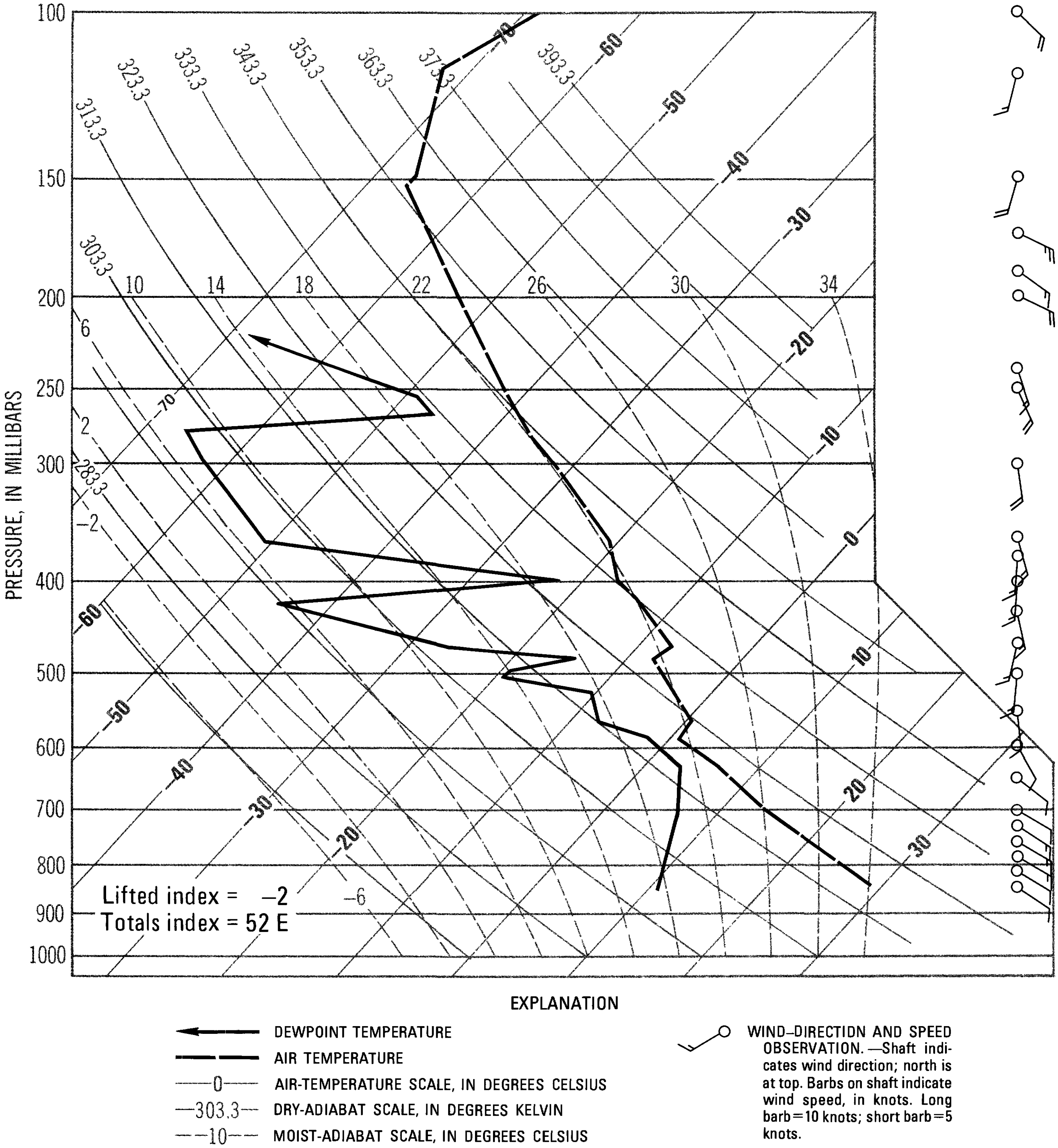


FIGURE 32.—Plot of rawinsonde data obtained at Denver, Colo., 1800 MDT, July 31, 1976.

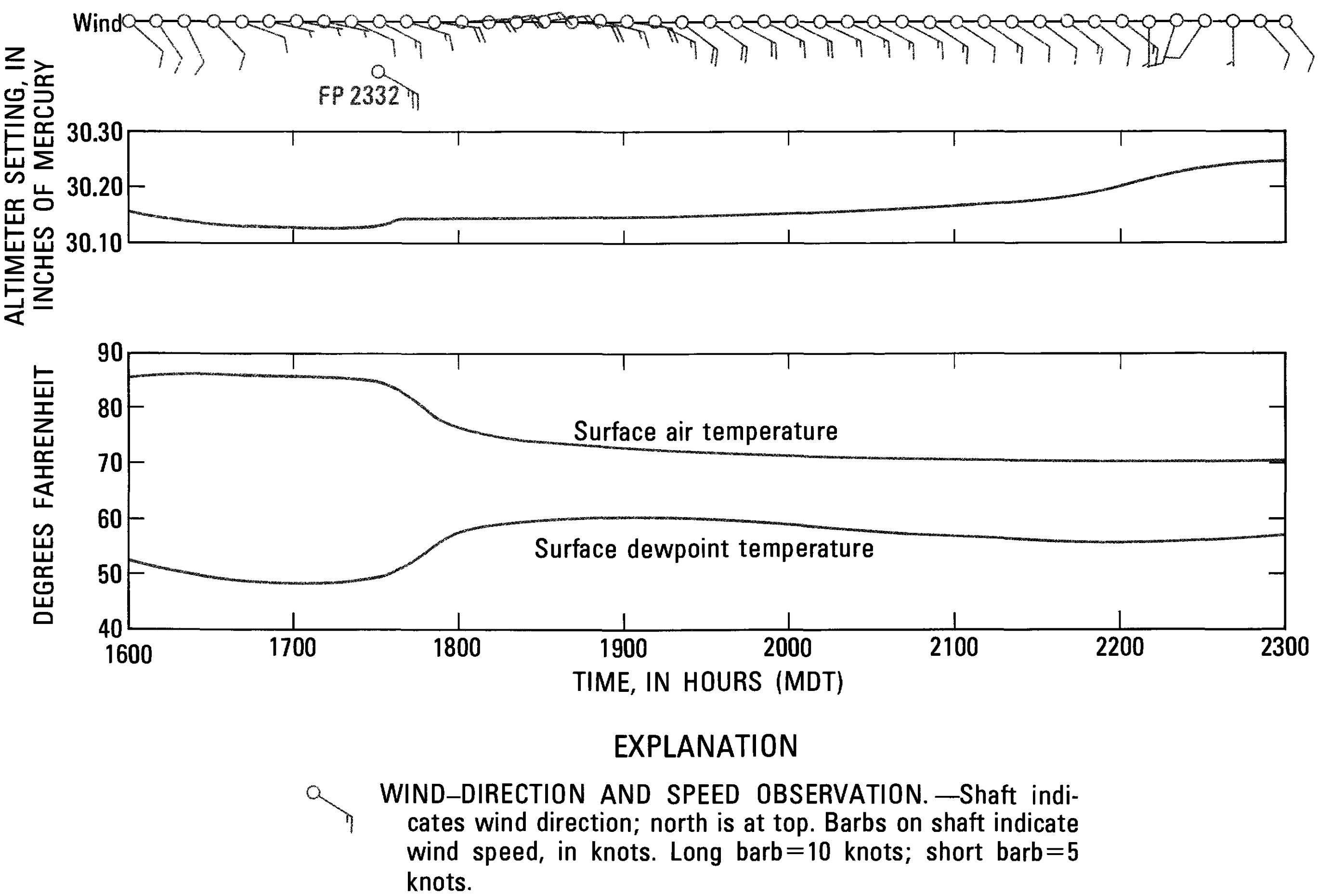


FIGURE 33.—Time series of surface winds, altimeter setting, and surface-air and dewpoint temperatures, Stapleton International Airport, Denver, Colo., 1600-2300 MDT, July 31, 1976.

thunderstorms that had formed ahead of the trailing front in the region west of Denver between 1730 and 1800 MDT. The resulting arc of thunderstorms (fig. 36*B*) moved over the Boulder, Colo., area at about 1830 MDT (fig. 36*C*). The data for the Rocky Flats plant (fig. 34) shows that the passage of the thunderstorms was marked by strong wind gusts and air and dewpoint-temperature changes similar to those occurring about 1 hour earlier at Stapleton International Airport and at Table Mountain. Eyewitness accounts and the rawinsonde data from Denver, Colo., at 1800 MDT indicated that the clouds which formed ahead of the trailing front south of Boulder had higher bases than the clouds which developed along the foothills to the north. At about 1830 MDT, a pressure increase of about 1 millibar was observed at the Rocky Flats plant and at Boulder, Colo. This pressure increase was accompanied by a wind shift to the southwest which indicated that rain showers and evaporative cooling in drier air along the foothills south of Boulder had produced a small high-pressure center in that area.

The arc of thunderstorms east of Boulder dissipated rapidly after 1830 MDT. The western part of the thunderstorms moved over the foothills southwest of Boulder, but rainfall amounts were much less than observed amounts 20-80 miles to the north. Radar echoes shown in figure 36*D* indicate the thunderstorms southwest of Boulder were not strongly affected by terrain as some of them moved westward almost to the Continental Divide. From the meager data available, it appears that the small high-pressure center developed sufficiently to cause the trailing front to become quasi-stationary between Denver and the foothills south of Boulder, thereby preventing the very moist unstable air from reaching the elevated terrain southwest of Boulder. The winds at Boulder and the Rocky Flats plant remained light southerly to westerly until about 2200 MDT on July 31.

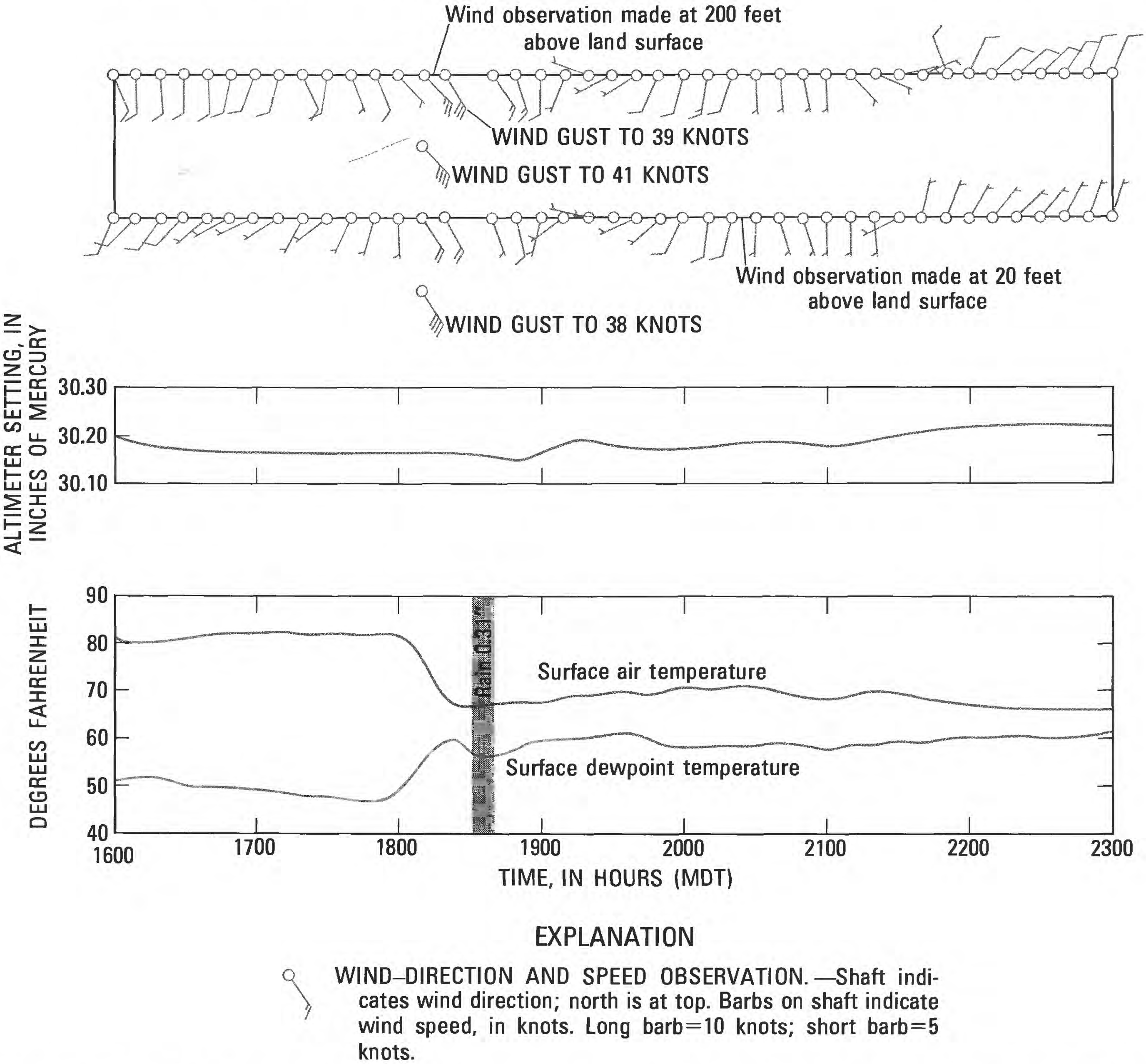


FIGURE 34.—Time series of winds, altimeter setting, and surface-air and dewpoint temperatures, Rocky Flats plant near Boulder, Colo., 1600–2300 MDT, July 31, 1976.

From Boulder northward into southern Wyoming, meterological conditions were drastically different from conditions south of Boulder. The trailing front had moved into the foothills shortly after 1730 MDT and convective clouds rapidly developed. By 1800 MDT, the growing thunderstorms were detectable by radar (fig. 36*B*), and by 1830 MDT several strong thunderstorms were orientated in a north-south line along the foothills (fig. 36*C*). Strong easterly or southeasterly winds and low clouds moving rapidly into the foothills were observed by many residents of Fort Collins, Loveland, and Longmont. Cloud bases were estimated to be 7,000–9,000 feet above mean sea level. Surface winds at Fort Collins and Greeley remained southeasterly until about 2200 MDT when the wind at Fort Collins shifted to the northwest. The time series of meteorological data at Table Mountain (fig. 35) shows that strong easterly winds persisted after

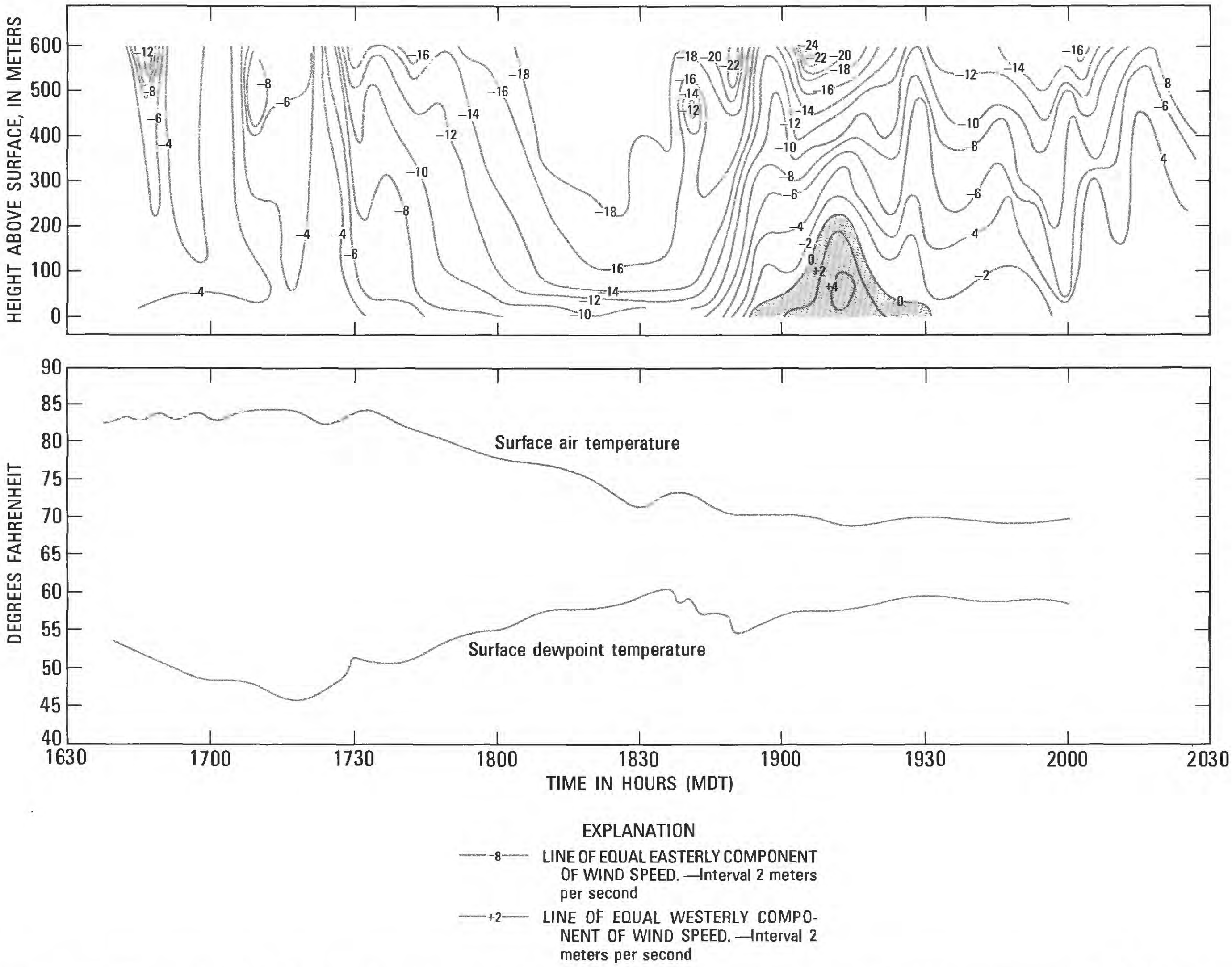


FIGURE 35.—Time series of winds, from the surface to a height of 2,000 feet, and surface-air and dewpoint temperatures, Table Mountain north of Boulder, Colo., 1630-2030 MDT, July 31, 1976.

the trailing front passed about 1730 MDT with a maximum easterly component of about 48 knots, 2,000 feet above the surface. The easterly surface wind was temporarily interrupted about 1900 MDT by a shallow region of westerly winds—probably weak outflow from a large thunderstorm cell located a few miles west of the site.

In order to provide an estimate of upper-air conditions just prior to the development of the severe thunderstorms, a sounding was interpolated for Loveland, Colo., at 1800 MDT. This sounding, shown in figure 37, was based on rawinsonde data from Sterling, Denver, and Grand Junction, Colo., surface observations, and Table Mountain wind data. The sounding data yielded a Lifted Index of −6 and a mean mixing ratio below the frontal inversion of 14.8 g/kg. The lifted condensation level was at the 730-millibar level which agrees with observed low cloud heights at Fort Collins of 7,000–9,000 feet above mean sea level. The data further indicated that the air near the surface required a lift of about 2,300 feet to reach the level of free convection.

PHYSICAL MODELS OF THUNDERSTORMS

The 10-centimeter radar at Grover, Colo., scanned the storms along the northeastern Colorado foothills until a few minutes after 1900 MDT. Storm intensity peaked about 1845 MDT and then temporarily decreased. A comparison of Limon and Grover radar echoes for this period is shown in figure 38.

Limon radar operated at 0-degree elevation angle during most of the evening with the center of the radar beam intercepting storms over the Big Thompson area

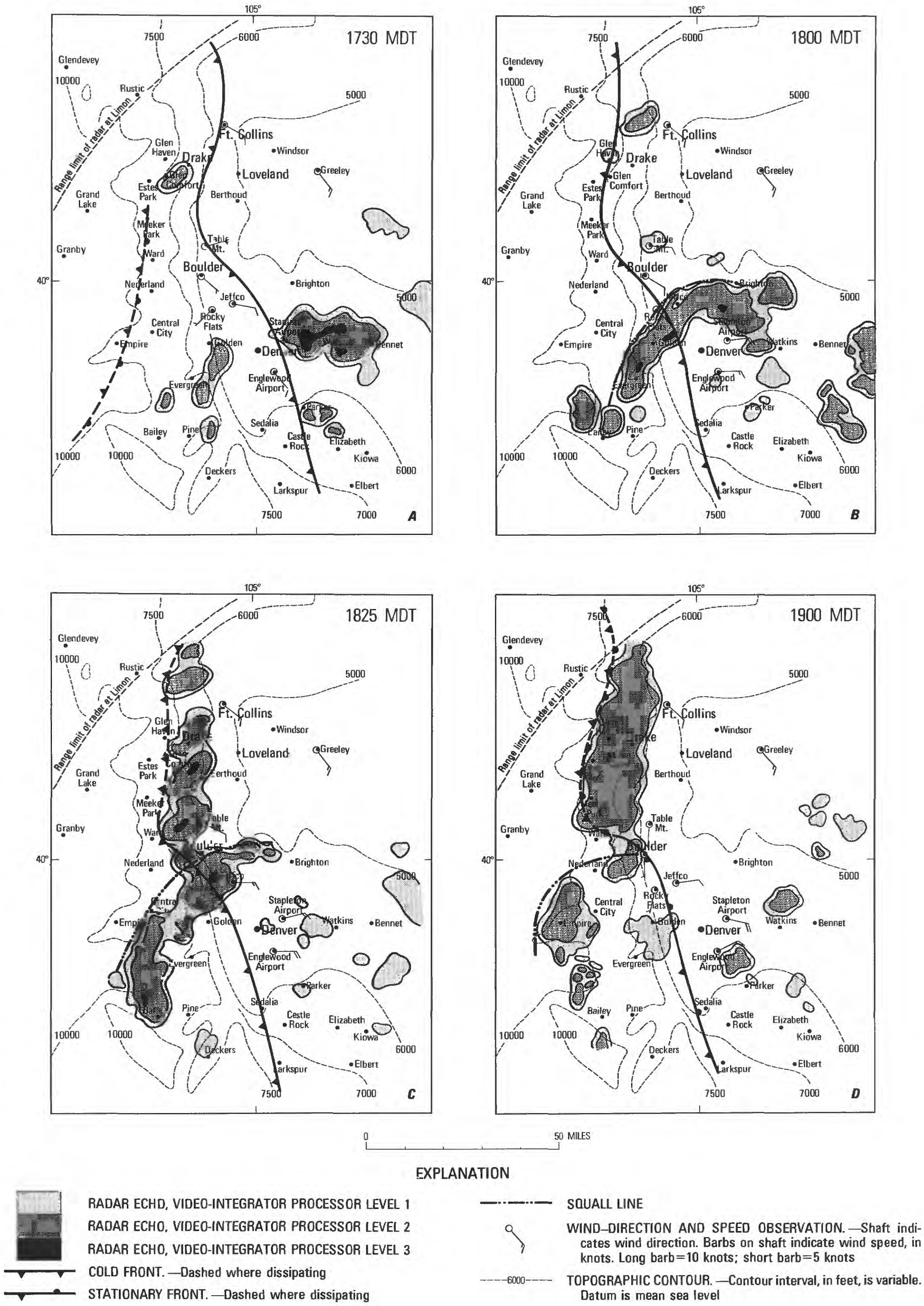
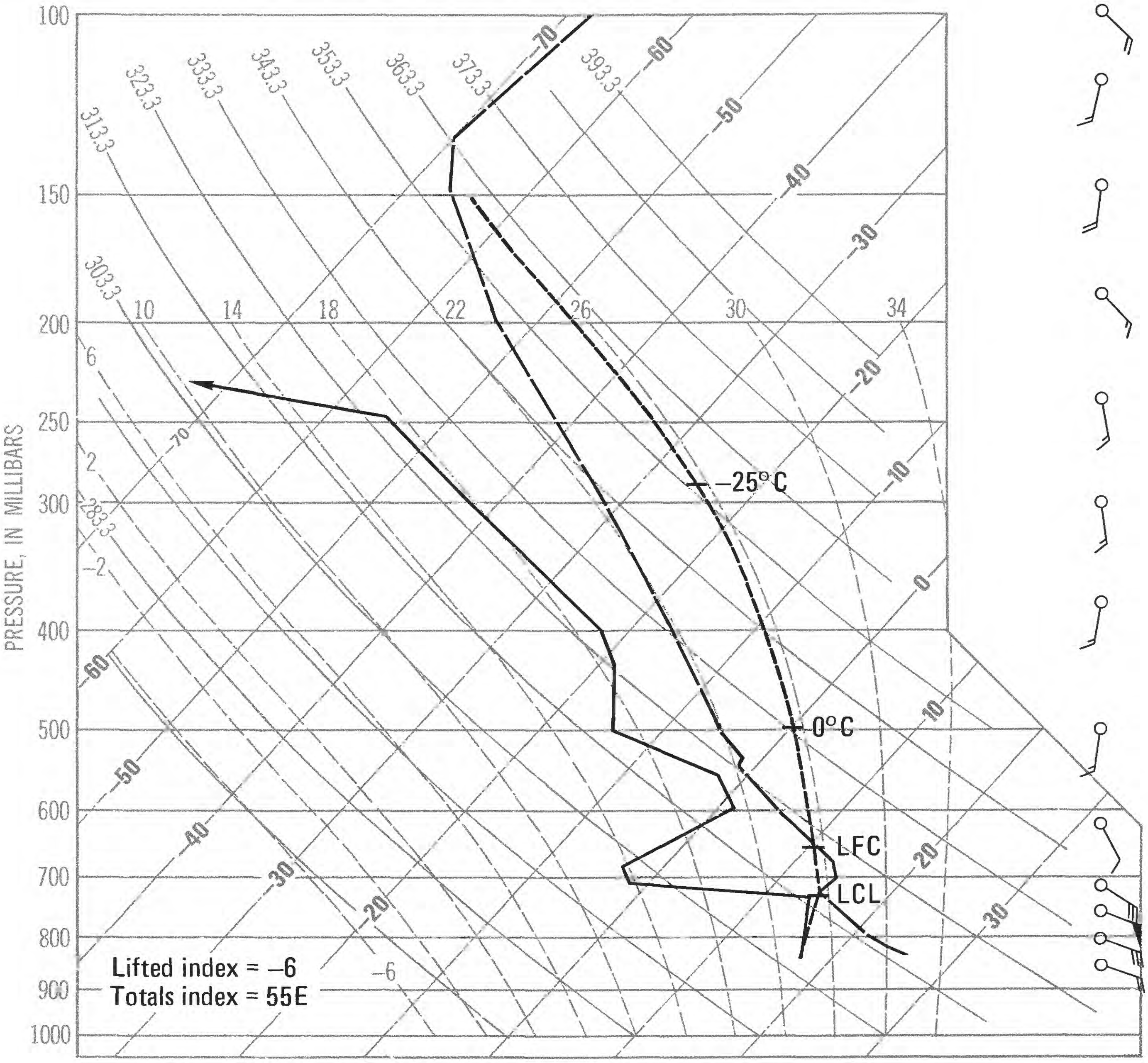


FIGURE 36.—Radar and surface analyses at about 30-minute intervals for the Denver–Fort Collins, Colo., area, 1730–1900 MDT, July 31, 1976: *A*, 1730 MDT; *B*, 1800 MDT; *C*, 1825 MDT; *D*, 1900 MDT.



EXPLANATION

- DEWPOINT TEMPERATURE
- AIR TEMPERATURE
- ASCENT CURVE FOR A PARCEL OF AIR NEAR SURFACE
- 0 — AIR-TEMPERATURE SCALE, IN DEGREES CELSIUS
- 303.3 — DRY-ADIABAT SCALE, IN DEGREES KELVIN
- 10 — MOIST-ADIABAT SCALE, IN DEGREES CELSIUS
- WIND-DIRECTION AND SPEED OBSERVATION.—Shaft indicates wind direction; north is at top. Flag and barbs on shaft indicate wind speed, in knots. Flag=50 knots; long barb=10 knots; short barb=5 knots
- LFC LEVEL OF FREE CONVECTION
- LCL LIFTED CONDENSATION LEVEL

FIGURE 37.—Interpolated plot of rawinsonde data for Loveland, Colo., 1800 MDT, July 31, 1976.

at altitudes between 15,000 and 20,000 feet above mean sea level. Grover radar operators varied the angles of their scans, effectively obtaining a three-dimensional record of the storm's reflectivities. Scans made at 1.9-degree elevation angles intercepted the foothills storms at approximately the same altitudes as the Limon radar and are shown in figure 38.

At 1845 MDT Limon radar showed Video Integrator Processor level-3 contours which corresponds to reflectivities between 41 and 46 dBZ. Brief periods of level-4 contours were observed later in the evening. Conversely, the Grover radar showed a level-5 contour (55–65 dBZ), with a maximum of 64.6 dBZ.

The Grover radar data contained more detail than the Limon data because of a 1-degree conical beam width as compared to the 2-degree conical beam width of the Limon radar, and because of a much closer location to the foothills region. The comparative readings suggest that the difference in beam width of the two radars enabled the Grover radar to detect small intense cells that were averaged out in the Limon radar signal. This difference appears to be about 15 dBZ in the center of the thunderstorms.

A two-dimensional cross section through one of the largest thunderstorms was constructed, as shown in figure 39. This thunderstorm became quasi-stationary approximately 1845 MDT near Storm Mountain, which is about 5 miles north of Drake. The cross section is positioned in a line from southeast to northwest, approximately along the direction of low-level inflow.

Grover reflectivity data, visual observation of cloud formation and movement, satellite observation of the areal extent of the cirrus anvil, and the interpolated sounding for Loveland were combined to give a schematic but fairly detailed picture of the storm structure.

The strong inflow allowed a large amount of mass to be processed by the storm. As the low-level flow approached the Front Range, a shallow layer of stratus and stratocumulus clouds formed in the layer between the lifted condensation level and the level of free convection. A surface observation at 1800 MDT at Fort Collins indicated a thin broken deck of clouds based at 4,000 feet above the surface. When the low-level air was forced above the level of free convection, explosive convective growth occurred. The radar data indicated that new cells formed in the inflow and moved north-northwestward into the storm. Over the mountains, the cloud base was effectively on the ground; the high in-cloud freezing level was at about 19,000 feet above mean sea level, and the height of the $-25\,^{\circ}C$ isotherm was at 31,500 feet above mean sea level. This indicated an unusually deep layer for warm cloud condensation and coalescence processes to act.

There was weak wind shear above the level of free convection; therefore, little entrainment of drier middle- and upper-level air into the storm. With the cloud base on or near the surface, precipitation was falling with virtually no subcloud evaporation. Neither entrainment nor evaporative processes were able to produce strong downdrafts within the storm, thus yielding a highly efficient storm. Grover radar data indicated that the storms which were moving into the foothills generally sloped to the east or southeast. Once the storm became quasi-stationary over the elevated terrain, they tended to slope to the northwest as shown in figure 39. The northwest slope of the updraft allowed large precipitation droplets to form and then to fall out of the rear of the updraft. This enabled the system to exist in a nearly steady state. Efficient unloading of the updraft in the lower half of the cloud permitted large updraft velocities to develop within the ice phase upper cloud, which, in turn, pushed the cloud top to very high levels. Indeed, radar observations indicated that the maximum tops of the thunderstorms were about 62,000 feet above mean sea level, or about 6,000 feet higher than the tops of any other similarly reported thunderstorms on the eastern slopes and plains of Colorado.

Some 20 miles to the south of the storm portrayed in figure 39, or about 5 miles southwest of Lyons, another storm of similar size and intensity developed between 1800 and 1845 MDT. A sequence of outstanding photographs of the development of this storm was taken by Mr. John Asztalos, who was located at Mitchell Lake approximately 15 miles west-southwest of the developing thunderstorm. These photographs are shown in figure 40. Note the similarities between the photographs and the cloud model in figure 39.

RAINFALL ANALYSIS

The total rainfall for July 31–August 2, 1976, is shown on the isohyetal map (fig. 41). The analysis was based on rainfall records at stations in the National Weather Service climatological network and rainfall reports from 119 miscellaneous locations in the storm area. Unfortunately, the lack of detailed rainfall-intensity data and the inaccessibility of the area over which the storm occurred resulted in data depicting

FIGURE 38.—Comparison of radar echoes observed at Limon and Grover, Colo.

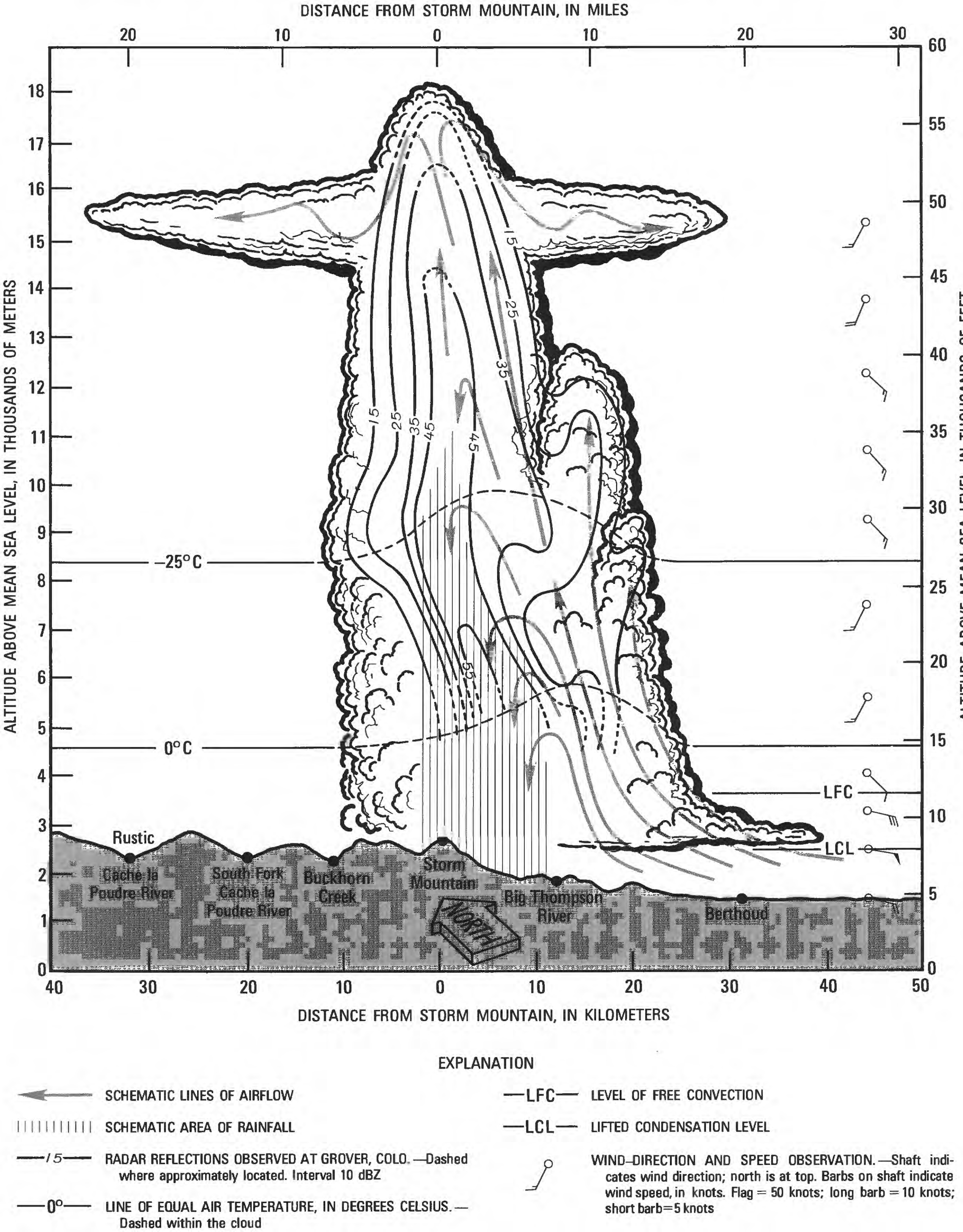


FIGURE 39.—Physical model of the thunderstorms over the Big Thompson River area at 1845 MDT, July 31, 1976.

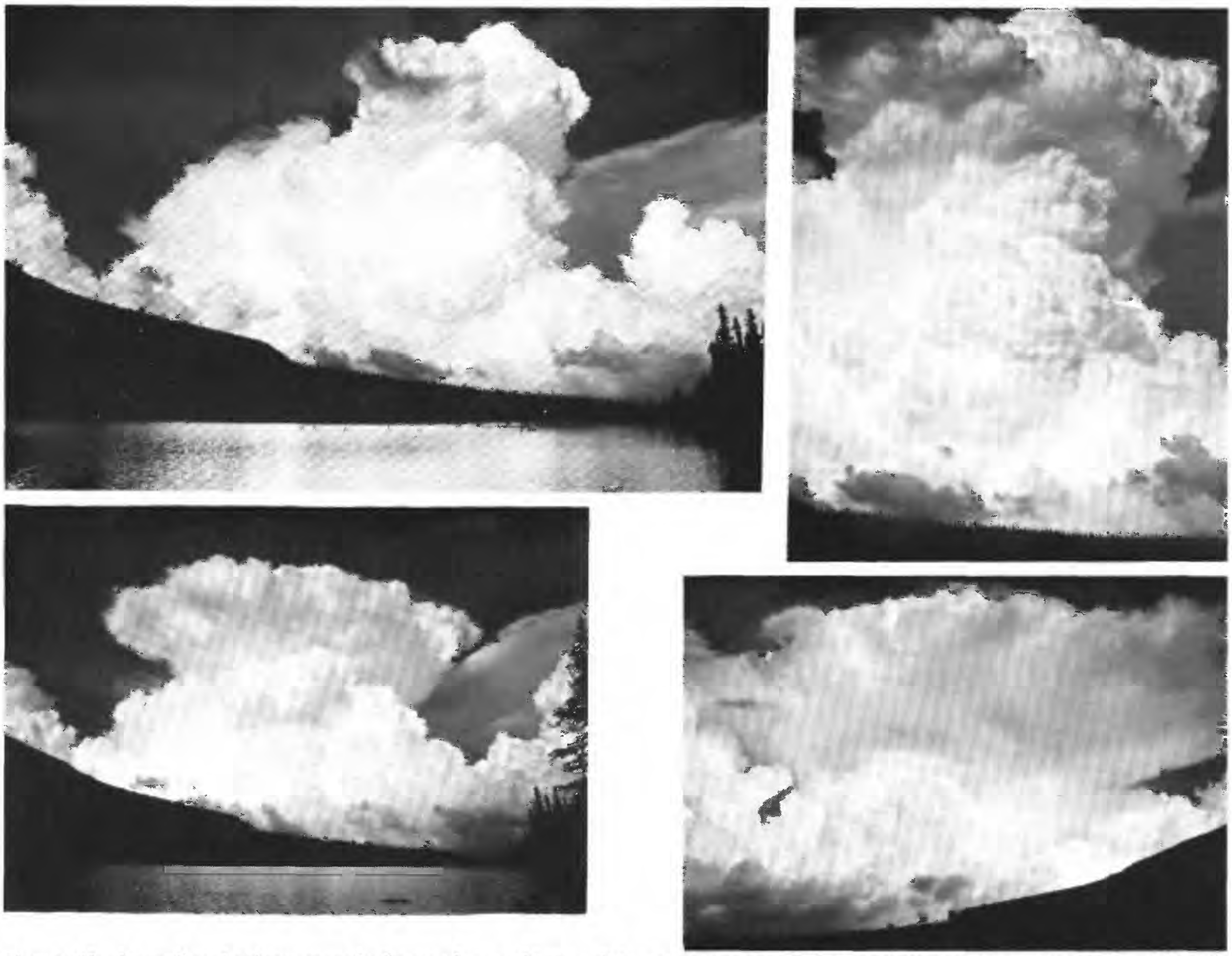


FIGURE 40.—Large thunderstorm several miles southwest of Lyons, Colo., at about 1830 MDT, July 31, 1976. Photographs taken at Mitchell Lake looking east-northeast.

only the 3-day rainfall totals. A tabulation of daily rainfalls for July 31–August 2, 1976, at 10 National Weather Service stations is shown in table 1, and total rainfall amounts for the same period at the 119 miscellaneous sites are shown in table 2. The precipitation summaries in tables 1 and 2 and the isohyetal map (fig.41) were prepared by the National Weather Service, Central Regional Headquarters, in cooperation with other Federal agencies.

For most of the area, the analysis in figure 41 provides an overestimation of the actual precipitation which produced the flash flooding. Also, the analysis offers little evidence as to rainfall intensities associated with the severe flooding during the night of July 31–August 1.

Two continuous rainfall records obtained in the Bellvue area northwest of Fort Collins and the record obtained at Allenspark (fig. 42) provide a good

TABLE 1.—*Daily precipitation, in inches, Boulder and Larimer Counties, Colorado*

[T, trace; ... leaders indicates no data available]

Station	Location		Time of observation (MDT)	1976		
				July	August	
	Latitude	Longitude		31	1	2
Allenspark	40°12′	105°32′	1700	0.02	0.50	0.90
Boulder	40°00′	105°16′	1700	T	.12	.69
Boulder 2	40°01′	105°16′	Continuous	0	0	...
Estes Park	40°23′	105°31′	1600	T	3.59	.87
Fort Collins	40°35′	105°05′	1900	.23	.11	.50
Fort Collins 9NW	40°40′	105°13′	Continuous	3.1	2.2	1.8
Longmont 6NW	40°15′	105°09′	Continuous	0	0	.7
Nederland 2NNE	39°59′	105°30′	0800	0	.19	.73
Red Feather Lakes 2SE	40°48′	105°34′	1700	1.20	.33	.12
Waterdale	40°25′	105°12′	0800	0	.33	.46

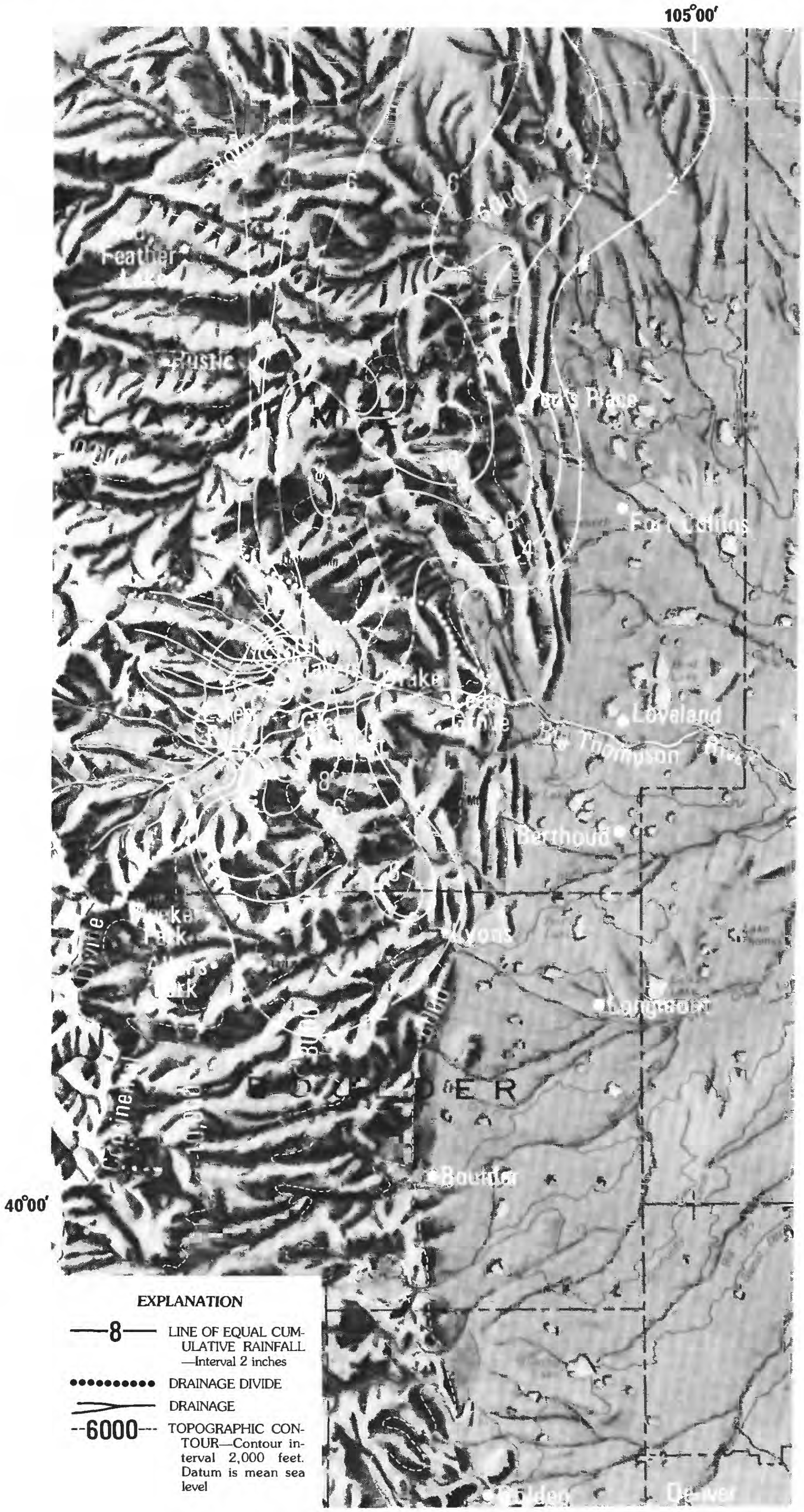


FIGURE 41.—Total rainfall in inches for July 31-August 2, 1976, along the Front Range in northeastern Colorado.

TABLE 2.—*Total rainfall, in inches, for July 31-August 2, 1976 at miscellaneous sites*

[From National Oceanic and Atmospheric Administration, August 1976]

Location				Total rainfall	Type	Rating	Observer and remarks
Township N.	Range W.	Section	Quarter				
				Boulder County			
3	71	11	C	6.8	Gage	Good	George Hircock.
3	71	12	C	[1]5.0	....	Fair	Verle Bradshaw.
3	71	13	NW	[2]3.5	Pot	Fair	C. D. Sisk—heaviest between 2100 and 2300 MDT, July 31.
3	72	4	SW	4.3	Gage	Good	Philip Trevarton.
3	72	34	S½	3.0	Bucket	Fair	Neil Turner.
3	73	12	N	2.9	....	....	Will Waite.
3	73	13	SW	1.0	....	....	Clayton Ward.
3	73	23	...	1.0	Can	Fair	Dan R. Cox.
3	73	25	...	1.12	Gage	Good	W. A. Rense.
				Larimer County			
4	71	29	SE	4.65	Gage	Good	Dottie Branum.
4	71	32	...	3.75	Gage	Fair	Lillie Olander.
4	72	2	SW	[2]9.0	Pot	....	Fred Hurt.
4	72	5	C	6.0	Tub	Fair	_____ Houck.
4	72	7	...	6.62	Bucket	....	D. A. Carvell—heaviest between 2030 and 2100 MDT, July 31.
4	72	11	C	7.0	Bucket	Fair	Byron Tudder.
4	72	35	C	4.3	....	Fair	Bob Swope.
4	73	1	NE	1.38	....	....	George Baced.
4	73	3	SE	1.33	....	....	Ken McDowell.
4	73	14	SW	4.6	....	....	Gordon Mace.
4	73	23	SW	6.0	....	....	Robert Irvin.
4	73	34	NW	.75	....	....	U.S. Forest Ranger.
5	69	34	NW	.8	Gage	Good	Darrell Fargo.
5	70	9	C	2.0	Gage	....	Clemont Young.
5	70	8	E½	.9	....	Fair	Unknown.
5	70	28	NE	[1].06	Standard	Good	Unknown.
5	71	2	NW	3.3	....	Fair	Unknown.
5	71	3	N½	3.5	Gage	Good	Unknown.
5	71	16	NE	2.0	Gage	....	Monte Christman.
5	72	4	SE	6.0	....	....	Julius Hamilton.
5	72	6	C	6.0	....	Poor	Frank McGraw.
5	72	8	SE	8.75	Bucket	....	E. L. Neuswanger.
5	72	8	NW	[1,2]6.0	Bucket	Poor	_____ Young.
5	72	10	NW	[1,2]6.0	Bucket	Poor	_____ Godesiabois.
5	72	12	SE	10.1	Can	Poor	Unknown.
5	72	18	SE	[1]4.0	Gage	Fair	O. H. Woods.
5	72	21	NE	11.0	Bucket	Fair	George Guthrie.
5	72	22	NE	[1]1.5	....	Fair	Harold Tregent.
5	72	22	NE	[2]9.7	....	Fair	Ben Federson.
5	72	23	NE	10.0	Tub	Poor	David Ruhn.
5	72	28	SW	10.75	Bucket	Poor	Harold Slapper.
5	72	29	SW	5.75	....	....	_____ Hertzler.
5	72	30	NE	5.3	....	Good	U.S. Forest Service.
5	72	30	...	4.66	....	....	Estes Power Plant.
5	72	34	NE	10.8	Gage	Good	Michael Wapprich.
5	73	15	SW	1.03	....	....	James Work.
5	73	22	SE	1.25	....	....	Les Casswell.
5	73	23	SW	[1]3.8	....	Good	Michael Marden.
5	73	26	...	2.60	Gage	Good	Howard Karp.
5	73	31	C	.38	Gage	Good	Walter Hines.
5	73	34	...	.77	....	....	National Park Service.
6	70	9	...	6.0	....	....	Ed Dion.
6	70	9	...	1.1	....	....	Kelvin Danielson.
6	71	1	NE	[2]5.0	....	....	Ray Berg.
6	71	6	...	7.5	....	....	Unkown.
6	71	27	NW	[2]5.0	Tub	....	Ray Berg.
6	71	27	...	4.1	....	....	Ed Smith.
6	71	34	SE	4.1	Gage	....	Lee Kriebaum.
6	72	16	SW	2.0	....	Poor	Don Chelley.
6	72	23	SE	12.0	Bucket	Good	Frank Faiella.
6	72	25	NW	8.0	Bucket	Fair	Unknown.
6	72	27	SW	12.0	Bucket	Fair	Clarence Nold.
6	72	27	NW	12.0	Bucket	Poor	Gordon Leonard.
6	72	27	SE	9.5	Bucket	Fair	Unknown.
6	72	27	SW	[2]7.5	Gage	Poor	Leonard Ray.
6	72	27	NW	[2]4.5	Can	Poor	Joe Bauer.
6	72	28	...	8.0	....	....	Barbara Havens.
6	72	28	SE	[2]10.5	Tub	Poor	Warren Cross.
				Larimer County—Continued			
6	72	34	SW	[2]7.2	Wheel barrow	Poor	Cliff Manson.
6	73	11	SW	[2]12.0	Can	Poor	Michael Davidson.
7	70	5	...	6.4	....	....	_____ Soderberg.
7	70	5	...	9.1	Gage	Good	Steve Cox, Colorado State University.
7	70	12	NW	7.0	Bucket	Fair	Joel Lamoreux.
7	71	14	NW	5.0	....	Fair	George Mornik.
7	71	24	SE	[1]4.5	Bucket	Fair	Jay Howlett.
7	71	14	...	4.5	....	....	G. Marwick.
7	72	12	...	10	....	....	Tom Smith.
7	72	13	...	8	....	....	Bonnie Carter.
7	72	15	SW	6	....	....	L. Rogers.
7	72	15	...	2.3	....	....	Helen Heatherington.
7	72	17	...	4.25	....	....	Helen Dickerson.
7	73	16	SW	.68	....	....	T. Noonan.
8	69	30	SW	4.6	Gage	Good	Harold Craw.
8	70	15	...	7.8	....	....	Unknown.
8	70	29	...	11.25	....	....	John Park.
8	70	29	SW	9.0	....	....	John Baker.
8	70	30	...	4.0	....	....	Mary Williams.
8	70	31	NE	10.24	Gage	....	Pete Wetzel—recording rain gage. (See fig. 1.)
8	71	1	SW	9.0	....	....	Archie Langston—heaviest between 2200 and 2400 MDT, July 31.
8	71	5	...	[2]5	....	....	Kelvin Danielson.
8	71	20	...	9.0	....	....	G. Garrison.
8	71	20	C	5.5	Can	Fair	Leon Ferguson.
8	71	23	SE	7.5	Tub	Good	_____ Wimmer.
8	71	29	...	5.0	....	....	J. Veen.
8	71	32	SE	[1]7.5	Bucket	Fair	Dan Colter—heavy intermittent rain 1600-2400 MDT, July 31.
8	71	35	...	11.25	....	....	Unknown.
8	71	36	...	7	....	....	Bill Cotton—heaviest between 2315 and 2345 MDT, July 31.
8	72	11	...	6.5	....	....	Kelvin Danielson.
8	72	25	NE	[2]7.0	Gage	Fair	Ray Vannorsdel.
8	73	14	NE	1.50	....	....	T. Williams.
8	73	25	...	1.38	....	....	James Noowan.
8	75	11	...	.30	....	....	Unknown.
9	69	11	...	[1].1	....	....	Unknown.
9	69	23	NE	[1,2]1.7	Gage	....	H. A. Simpson.
9	70	12	E½	2.7	....	Poor	Unknown
9	70	33	...	8.3	....	....	Terry Van Cleave—heaviest between 2200 MDT, July 31, to 0200 MDT, Aug. 1.
9	71	19	C	[2]7.0	Can	Poor	Unknown.
10	70	15	...	4.26	....	....	Clarence Koch—. heaviest around 2300 MDT, July 31.
10	70	32	...	4.0	....	....	Unknown.
10	70	34	...	6.25	....	....	Ed Nauta.
10	71	9	...	6.2	....	....	D. H. Webb.
10	71	36	...	6.0	....	....	Tom Thomas.
10	73	34	...	.6	....	....	U.S. Forest Service Ranger Station.
11	68	13	S½	1.9	Gage	Good	Chuck Roberts.
11	69	31	...	1.25	....	....	I. Graham.
11	69	31	...	4.25	....	....	Unknown.
11	71	15	SE	6.0	Gage	Fair	Bill Logan.
12	70	20	...	6.5	....	....	W. R. Mordah.
12	71	31	SE	5.10	....	....	F. Moin.
				Albany County, Wyoming			
13	72	24	...	4.8	....	....	Lois Bath.

[1] July 31 evening total only.
[2] Rainfall total was greater than amount indicated.

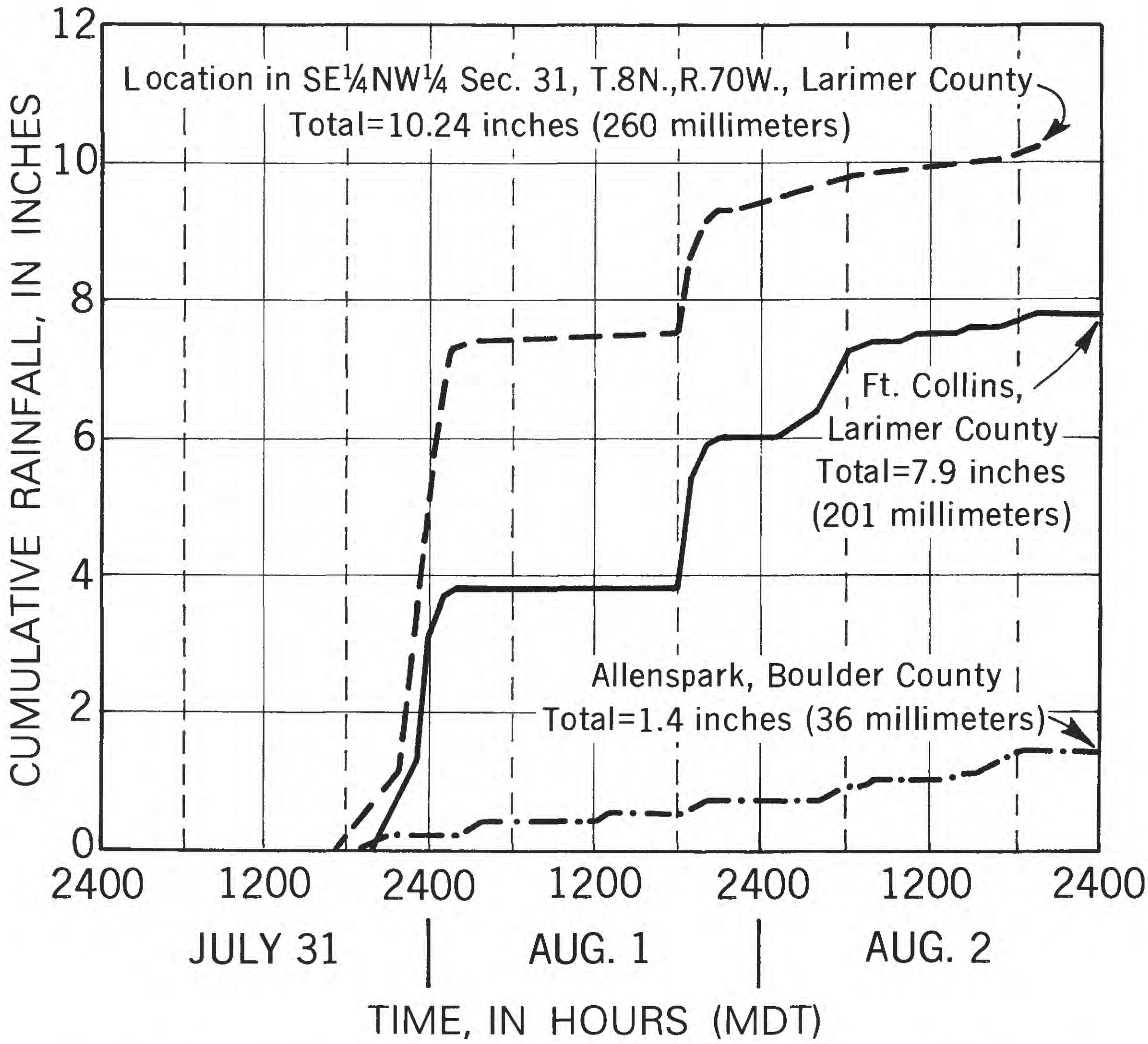


FIGURE 42.—Cumulative rainfall, at three stations in Boulder and Larimer Counties, Colo., July 31–August 2, 1976.

representation of rainfall distribution during the storm period for those areas. In the Big Thompson River basin, no continuous rainfall records were available but radar data and eyewitness accounts provide a fair description of the storm period. The North Fork Cache la Poudre River basin in the vicinity of Virginia Dale lies outside the range of the Limon radar; thus, the timing of rainfall in that area is based entirely upon eyewitness accounts.

Limon radar-image locations with relative intensities are shown in figure 43 from 1701 to 2200 MDT on July 31, 1976. The images are shown at 20-minute intervals prior to 1900 MDT and at 10-minute intervals thereafter. The first thunderstorm cells developed between 1800 and 1830 MDT several miles east of the maximum rainfall zone near Glen Comfort and Glen Haven.

The storms were moving generally north-northwestward and reached a temporary peak in intensity around 1845 MDT. Between 1900 and 1930 MDT, the individual cells tended to merge, and the rainfall pattern continued to shift slightly westward. By 1930 MDT the most intense rainfalls were southwest of Drake. From about 1930 MDT until shortly after 2100 MDT, the "cloudburst" phase of the storm occurred in the Big Thompson River basin around Glen Comfort. The storm complex continued to shift very slowly to the northwest, and after 2100 MDT, the most intense

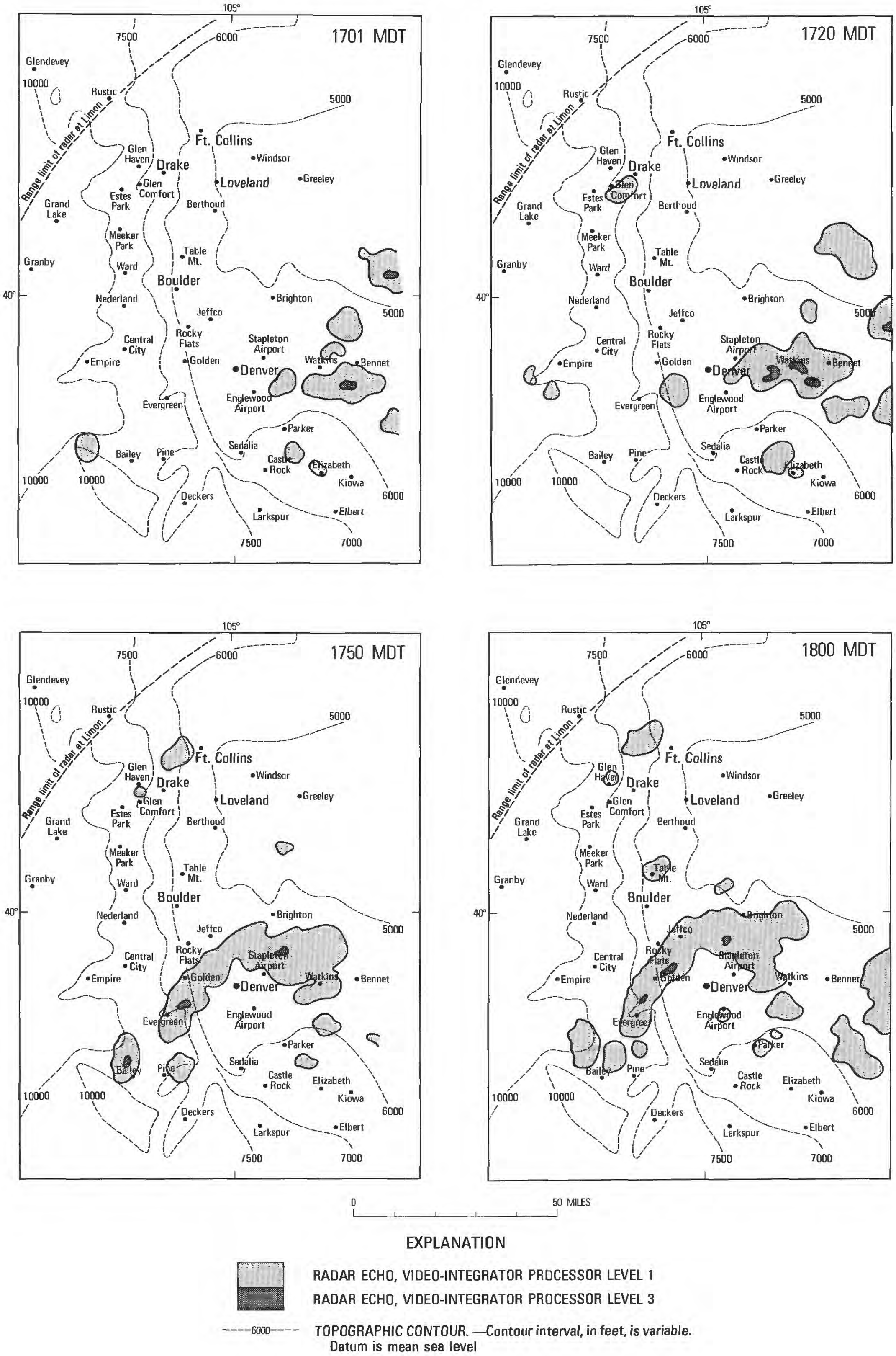


FIGURE 43.—Radar echoes in the Denver–Fort Collins, Colo., area, observed at Limon, Colo., from 1701 to 2200 MDT, July 31, 1976.

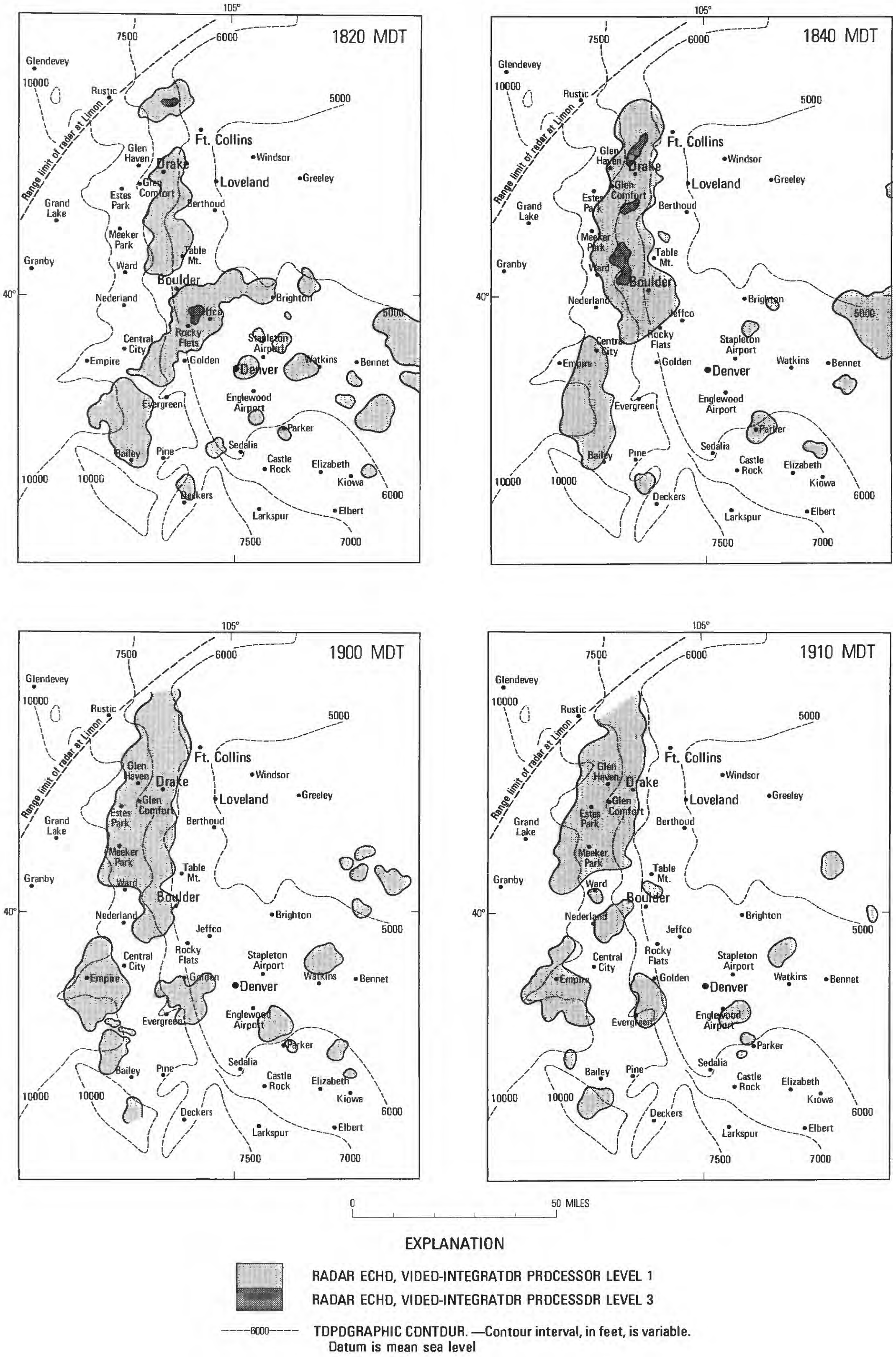


FIGURE 43.—Continued.

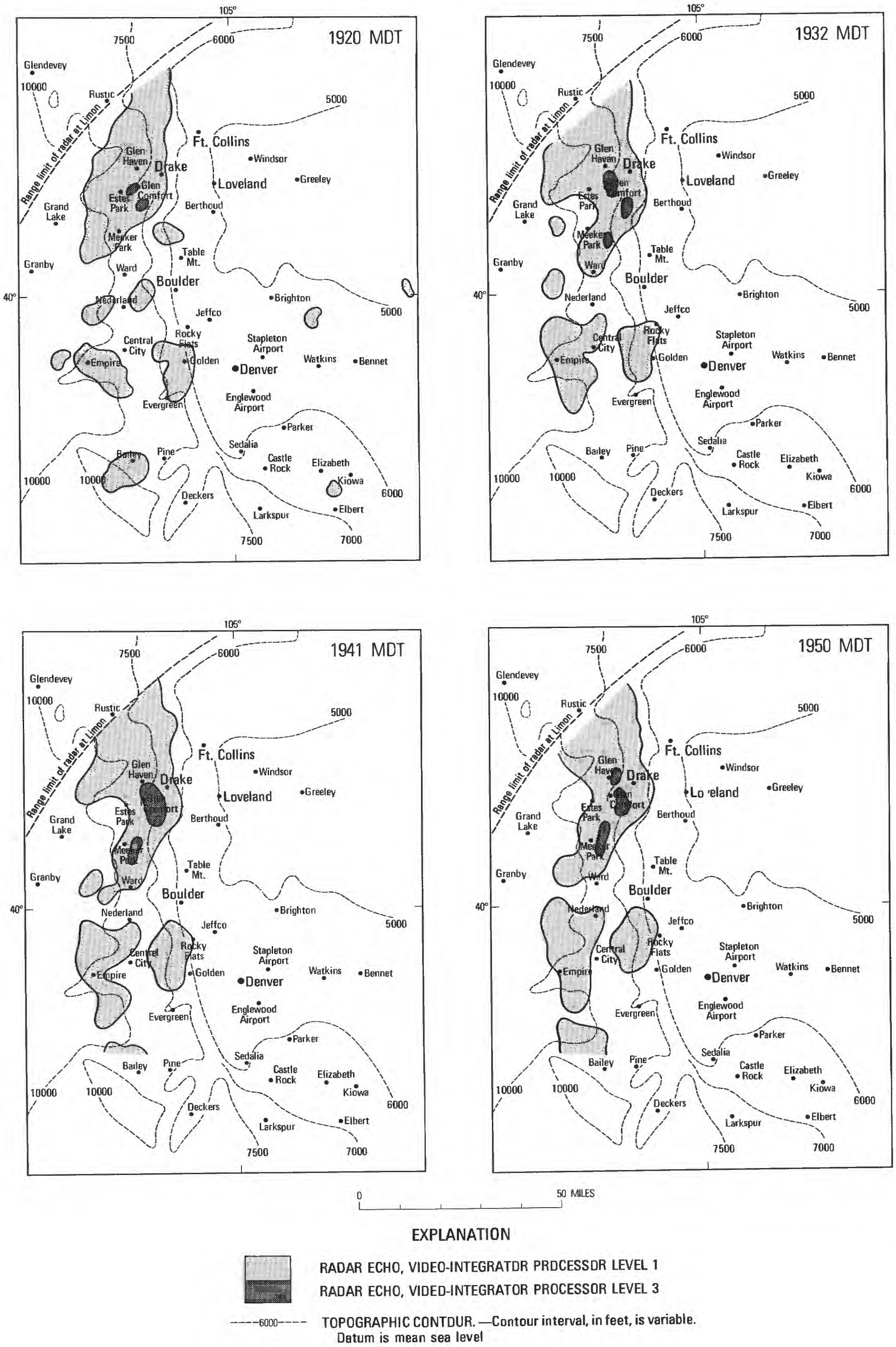


FIGURE 43.—Continued.

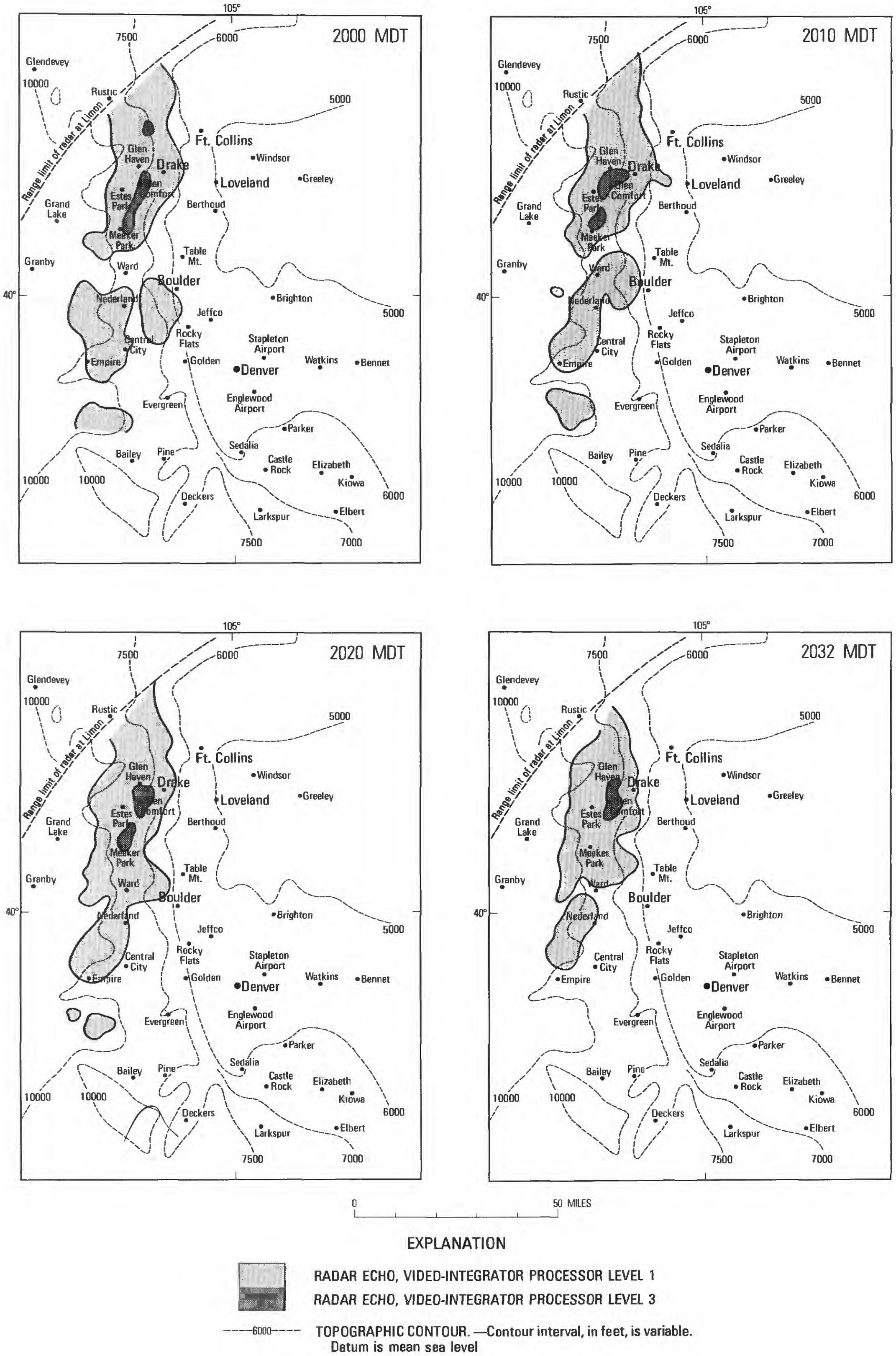


FIGURE 43.—Continued.

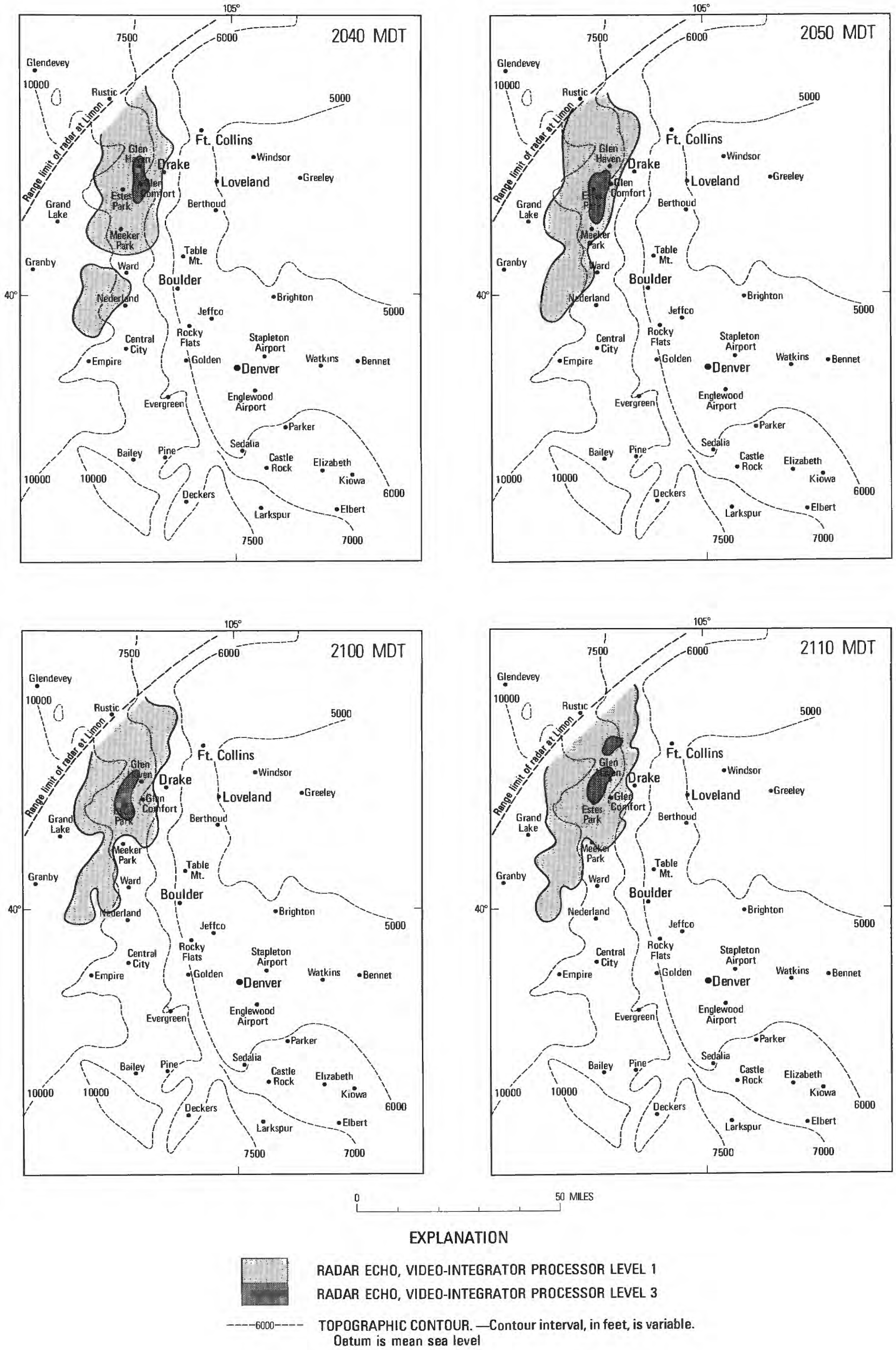


FIGURE 43.—Continued.

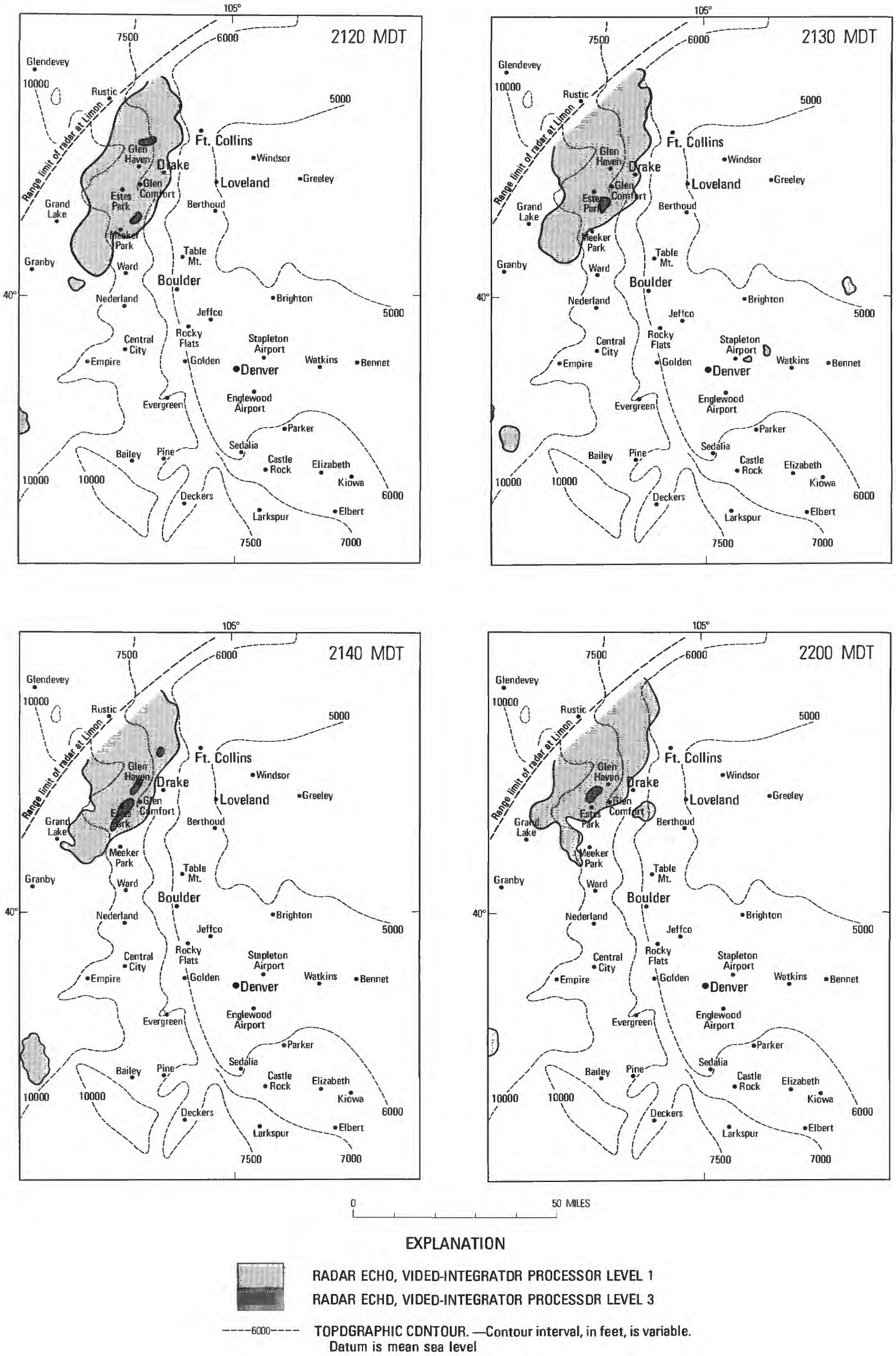


FIGURE 43.—Continued.

storms were generally over the tributaries of the North Fork Big Thompson River. Heavy rainfall reportedly continued in the Glen Haven area until about 2200 MDT with isolated bursts of rainfall near Estes Park and Glen Haven continuing into the early morning hours. Between 2200 and 2300 MDT, maximum rainfall intensities moved north-northeastward into the foothills west of Fort Collins.

During that same general time period (2000-2300 MDT), heavy rainfall occurred over the North Fork Cache la Poudre River basin between Livermore and Virginia Dale. Local residents reported the heaviest rainfall between 2100 and 2200 MDT. As shown in figure 42, moderate rainfall occurred along the southern edge of the Cache la Poudre River basin between 1800 and 2200 MDT, becoming much more intense thereafter. Heavy rainfall continued in this area until about 0100 MDT on August 1, with light showers persisting throughout the night. Rain showers continued during August 1 and 2 over most of the general storm area, with locally heavy amounts falling at times, especially near Fort Collins.

As mentioned earlier, data defining the rainfall rates in the maximum rainfall zone west of Drake were not obtained. In order to provide some estimate of the time distribution of rainfall that produced the severe flash flooding along the Big Thompson River, Limon radar reflectivity data were used to develop cumulative rainfall diagrams for Glen Comfort and Glen Haven (fig. 44). Several assumptions were required in order to make the calculations.

A total of 12 inches of rain fell at Glen Comfort during the 3-day storm period, but it is not certain how much occurred during the period of the flash flooding. On the basis of meager information from local residents, it was assumed for calculation purposes that 10 inches of rain fell between 1830 MDT and midnight on July 31. Using the comparison between Grover and Limon radar reflectivity data, it was also assumed that reflectivities within the central half of a Video Integrator Processor level-3 area were 2 dBZ higher than the level-3 threshold value.

Two generalized relationships were used along with the assumptions and the Limon radar reflectivity data to derive the cumulative rainfall totals. The two relationships are

$$z=200p^{1.6}$$

and

$$z=55p^{1.6},$$

where:

z is the reflectivity factor, in millimeters^6 (mm^6) per cubic meter, and p is the precipitation rate, in millimeters per hour.

The National Weather Service has recently found that for WSR-57 radars, such as the one at Limon, the latter relationship provides more accurate rainfall rates for convective storms.

Resulting rainfall amounts from 1830 MDT to midnight on July 31 at Glen Comfort were 0.98 inch for $z=200p^{1.6}$ and 2.22 inches for $z=55p^{1.6}$. Assuming the reflectivity data were low by a constant factor, adjustments of 16.1 dBZ and 10.6 dBZ, respectively, yield the assumed total of 10 inches of rain. These adjustments agree closely with the differences indicated by the comparison of the Grover and Limon reflectivities. Adjusted Video Integrator Processor levels 2, 3, and 3+ (level-3 threshold +2 dBZ) represent rainfall rates of 1.21, 5.91, and 7.89 inches per hour, respectively.

These modified rainfall rates were used to construct the accumulated rainfall diagrams for Glen Comfort and Glen Haven shown in figure 44. The diagram for Glen Comfort shows that about 7.5 inches of rain fell between 1930 and 2040 MDT, with rainfall rates being much lower before and after this period. The Glen Haven diagram shows that heavy rainfall began somewhat later in that area, continued for a longer period of time, but fell at slightly lower rates than in the vicinity of Glen Comfort.

HYDROLOGIC ANALYSIS OF THE FLOOD

The severe thunderstorms of July 31 produced flooding in Larimer County along a band several miles wide extending from just southeast of Estes Park northward to the Wyoming border. The Big Thompson River basin between Estes Park and Drake was especially hard hit by the storm which resulted in devastating flooding along the Big Thompson River from Estes Park to Loveland and along the North Fork Big Thompson River from the Glen Haven area to its mouth at Drake. The flood in the Cache la Poudre River basin originated mainly in sparsely populated areas along the North Fork Cache la Poudre River between Livermore and Virginia Dale; consequently, flood damage was much less extensive and, fortunately, no deaths occurred.

FLOOD DATA

STATION DESCRIPTIONS AND STREAMFLOW DATA

Flood data obtained at 10 gaging stations and 27 miscellaneous sites in the affected area are tabulated in downstream order on pages 72-81. Station descriptions give the location of each site, size of the drainage area upstream from the site, the method of discharge determination, and peak discharge or peak stage dur-

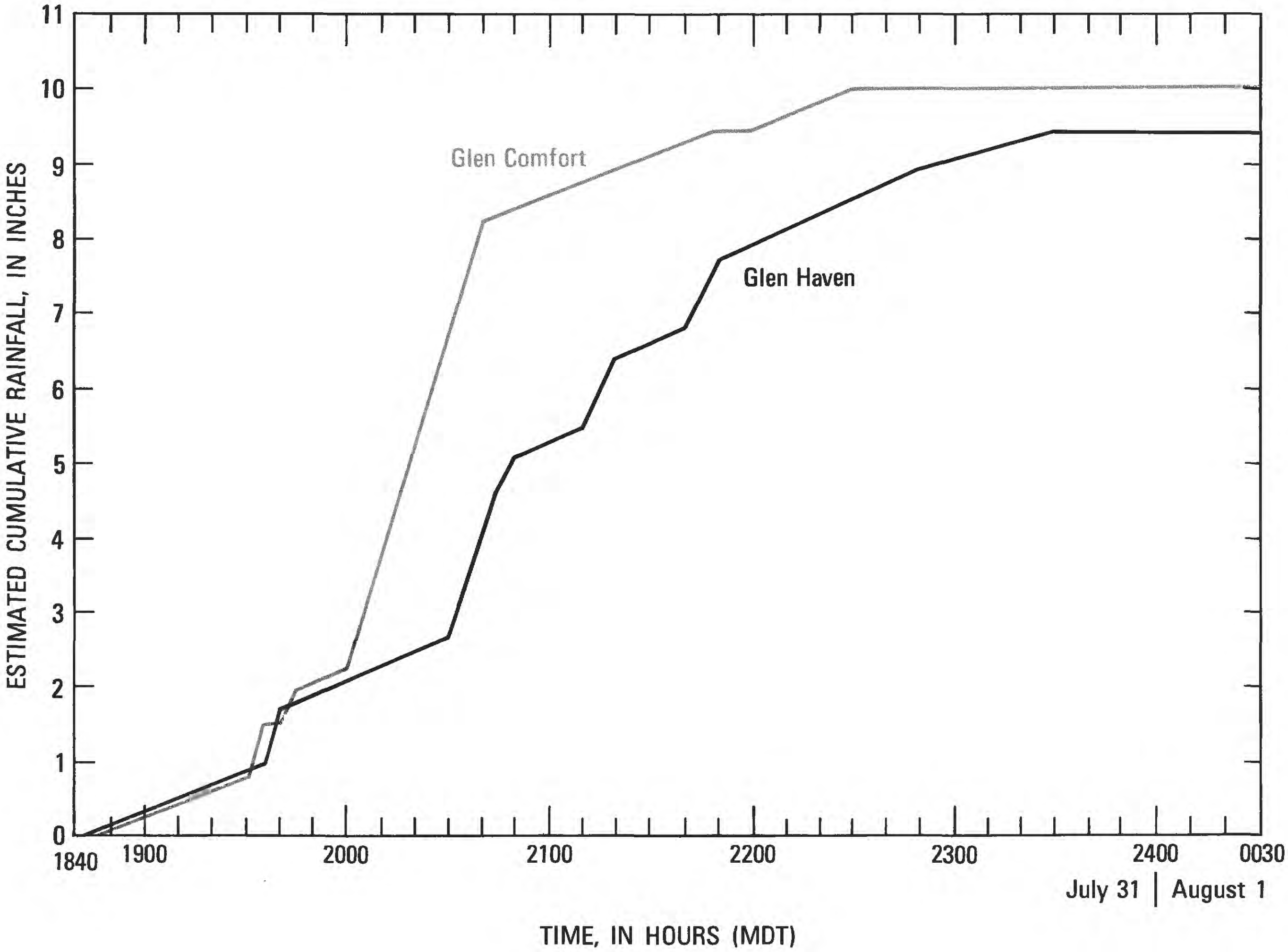


FIGURE 44.—Estimated cumulative rainfall at Glen Comfort and Glen Haven, Colo., July 31–August 1, 1976.

ing July–August 1976. Where available, information also is given on gage datum, nature of gage-height record obtained during the flood period, and maximum stage and discharge known prior to this flood.

PEAK STAGES AND DISCHARGES

Peak stages and discharges for the 10 gaging stations and 27 miscellaneous sites in the flood area are listed in downstream order in table 3 and site locations are shown in figure 45. The drainage areas listed for sites on the Big Thompson River downstream from Lake Estes include both total drainage area and the intervening area between Lake Estes and the respective site. As subsequently explained, the gates at Lake Estes were closed at the beginning of the flood; thus, the upstream part of the basin did not contribute to the flood. Drainage area for several other sites are footnoted in table 3 to indicate that only a small, undetermined part of the basin contributed to the flood. Also listed for some sites in table 3 are the previously recorded maximum stages and discharges.

VELOCITIES AND DEPTHS

Probably the most destructive element during the flood period was the extremely high velocities of the floodwater. These high velocities greatly increased stream competence resulting in severe channel erosion and transport of debris and large streambed material. Average velocities of 20–25 feet per second were common on the steep tributaries near the center of the rainstorm. In general, average cross-sectional depths were small with most depths being less than 6 feet except on the main streams where depths as much as 10 feet occurred. Average velocities and depths for 29 sites where slope-area measurements were made are listed in table 4.

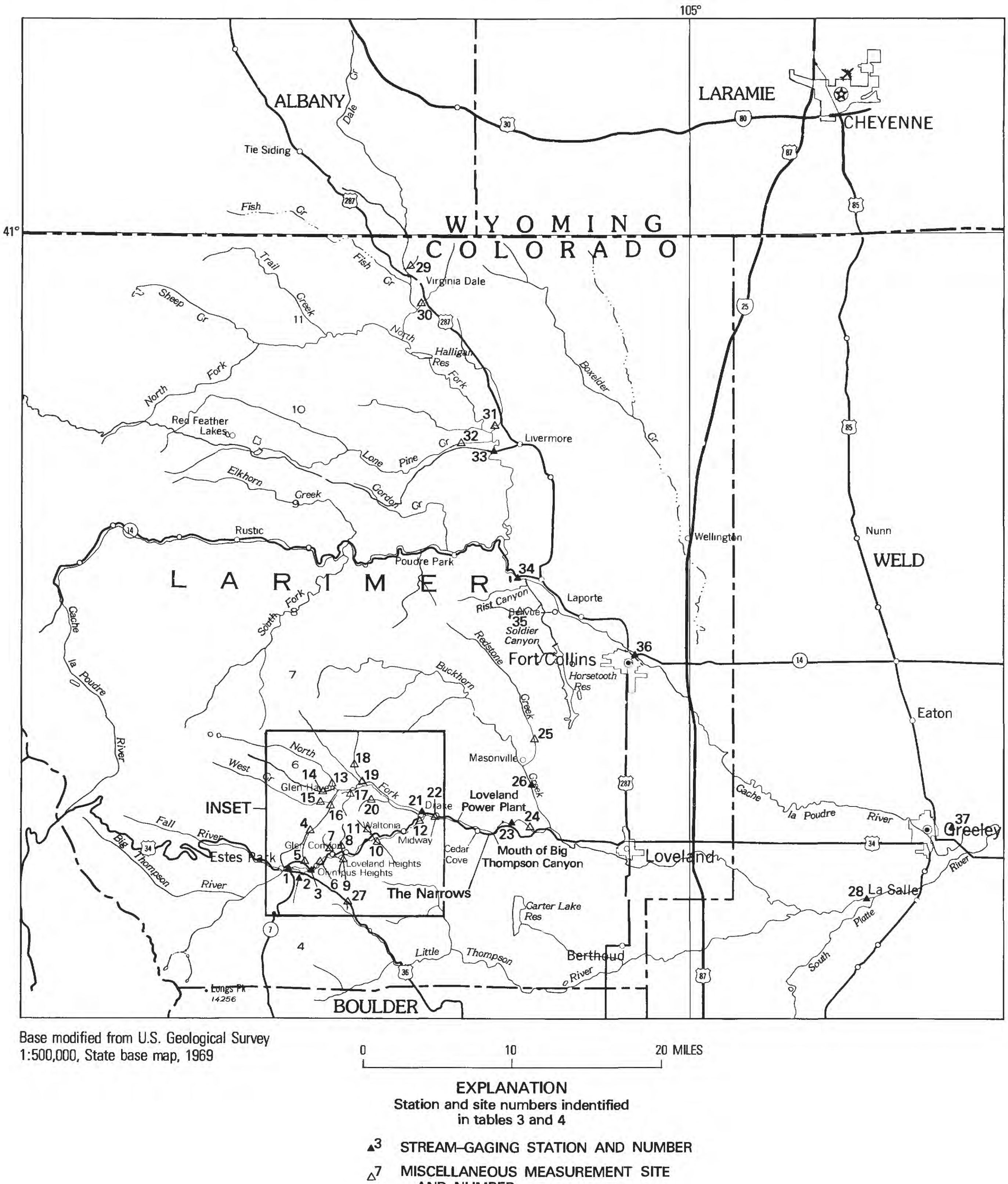


FIGURE 45.—Stream-gaging stations and miscellaneous measurement sites in flood area in Larimer and Weld Counties.

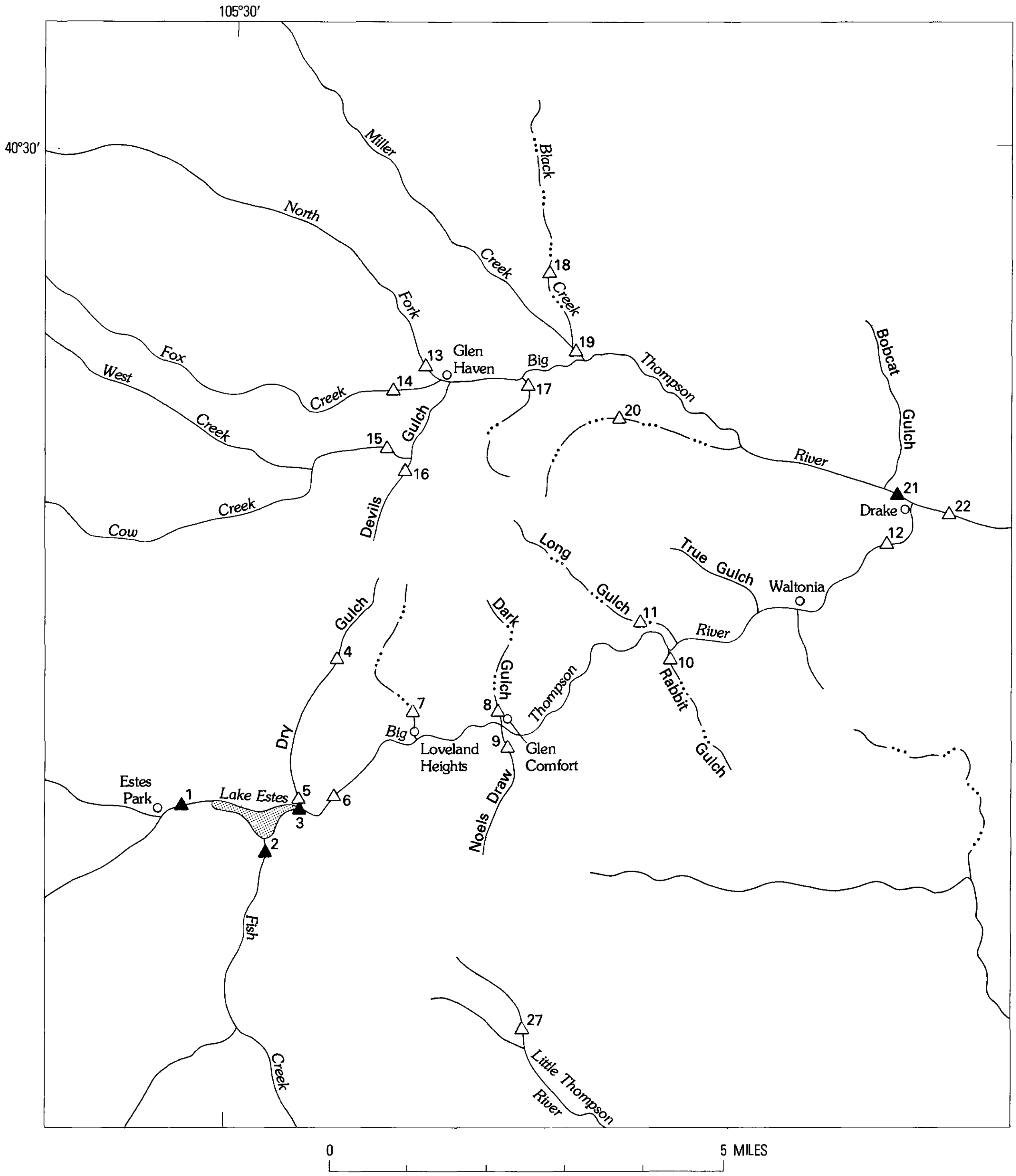


FIGURE 45.—Continued.

TABLE 3.—*Flood stages and discharges in Larimer and Weld Counties for the flood of July 31–August 1, 1976, and during previous maximum floods*

Site No.	Station No.	Stream and place of determination	Drainage area (mi²)	Maximum floods previously known: Prior to July–August 1976: Period	Maximum floods previously known: Prior to July–August 1976: Year	Maximum floods previously known: Gage height (ft)	Maximum floods previously known: Discharge (ft³/s)	Maximum floods previously known: Recurence interval (yrs)	Maximum July 31–August 1, 1976: Discharge day	Maximum July 31–August 1, 1976: Hour (MDT)	Maximum July 31–August 1, 1976: Gage height (ft)	Maximum July 31–August 1, 1976: Discharge (ft³/s)	Maximum July 31–August 1, 1976: Recurence interval (yrs)
1	06733000	Big Thompson River at Estes Park	[a]137	1946-76	1949	[b]3.16	1,660	13	31	2130	3.64	457	<2
2	06734500	Fish Creek near Estes Park	[a]16.0	1947-55, 1976	1951	7.32	[c]1,480	[d]3.7	31	2150	4.02	182	3
3	06735500	Big Thompson River nearEstes Park	155 [e](0)	1930-76	1933	[b]4.0	2,800	[d]1.1	31	2230	[f]5.51	([g])	…
4	…	Dry Gulch near Estes Park	2.00	…	…	…	…	…	31	[h]2215	…	3,210	…
5	…	Dry Gulch at Estes Park	6.12	…	…	…	…	…	31	[h]2230	…	4,460	…
6	…	Big Thompson River below Estes Park	164 [e](9)	…	…	…	…	…	31	[h]2300	…	4,330	75
7	…	Big Thompson River tributary below Loveland Heights	1.37	…	…	…	…	…	31	…	…	8,700	…
8	…	Dark Gulch at Glen Comfort	1.00	…	…	…	…	…	31	…	…	7,210	…
9	…	Noels Draw at Glen Comfort	3.37	…	…	…	…	…	31	…	…	6,910	…
10	…	Rabbit Gulch near Drake	3.41	…	…	…	…	…	31	…	…	3,540	…
11	…	Long Gulch near Drake	1.99	…	…	…	…	…	31	…	…	5,500	…
12	…	Big Thompson River above Drake	189 [e](34)	…	…	…	…	…	31	[h]2100	…	28,200	[d]3.8
13	…	North Fork Big Thompson River at Glen Haven	[a]18.5	…	…	…	…	…	31	…	…	888	…
14	…	Fox Creek at Glen Haven	[a]7.18	…	…	…	…	…	31	…	…	1,300	…
15	…	West Creek near Glen Haven	[a]23.1	…	…	…	…	…	31	…	…	2,320	…
16	…	Devils Gulch near Glen Haven	.91	…	…	…	…	…	31	…	…	2,810	…
17	…	North Fork Big Thompson River tributary near Glen Haven	1.38	…	…	…	…	…	31	…	…	9,670	…
18	…	Black Creek near Glen Haven	3.17	…	…	…	…	…	31	[h]2300	…	1,990	…
19	…	Miller Fork near Glen Haven	[a]13.9	…	…	…	…	…	31	[h]2300	…	2,060	…
20	…	North Fork Big Thompson River tributary near Drake	1.26	…	…	…	…	…	31	…	…	3,240	…
21	06736000	North Fork Big Thompson River at Drake	[a]85.1	[i]1947-76	1965	5.66	1,290	8	31	2140	9.21	8,710	[d]1.4
22	…	Big Thompson River below Drake	[a]276 [e](121)	…	…	…	…	…	31	…	…	30,100	[d]2.9
23	06738000	Big Thompson River at mouth of canyon, near Drake	305 [e](150)	1887-92, 1895-1903, 1926-33, 1948-49, 1951-76	1919	…	[j]8,000	26	31	[h]2140	19.7	31,200	[d]1.8
24	…	Big Thompson River below Green Ridge Glade, near Loveland	[a]311 [e](150)	…	…	…	…	…	31	…	…	27,000	[d]1.7
25	…	Redstone Creek near Masonville	[a]29.1	…	…	…	…	…	1	…	…	2,640	5
26	06739500	Buckhorn Creek near Masionville	[a]131	1923, 1938, 1947-55	1951	13.40	14,000	50	1	…	8.1	3,400	4
27	…	Little Thompson River near Estes Park	2.77	…	…	…	…	…	31	[h]2130	…	1,940	…
28	06744000	Big Thompson River at mouth, near LaSalle	828 [e](673)	1914-15, 1927-76	1951	[b]7.80	6,100	77	1	2235	7.82	2,470	11
29	…	Dale Creek tributary near Virginia Dale	.68	…	…	…	…	…	31	…	…	727	17
30	…	Deadman Creek near Virginia Dale	[a]23.7	…	…	…	…	…	31	[h]2230	…	7,400	100
31	…	Stonewall Creek near Livermore	[a]31.9	…	…	…	…	…	31	[h]2200	…	3,470	6
32	…	Lone Pine Creek near Livermore	[a]86.3	…	…	…	…	…	31	[h]2230	…	2,590	6

TABLE 3.—*Flood stages and discharges in Larimer and Weld Counties for the flood of July 31–August 1, 1976, and during previous maximum floods* —Continued

Site No.	Station No.	Stream and place of determination	Drainage area (mi²)	Maximum floods previously known: Prior to July–August 1976: Period	Prior to July–August 1976: Year	Gage height (ft)	Discharge (ft³/s)	Recurence interval (yrs)	Maximum July 31–August 1, 1976: Discharge day	Hour (MDT)	Gage height (ft)	Discharge (ft³/s)	Recurence interval (yrs)
33	....	North Fork Cache la Poudre River at Livermore........	[a]539	1904, 1929-31	1904	....	20,000	33	31	....	....	9,460	16
34	06752000	Cache la Poudre River at mouth of canyon, near Fort Collins...........	[a]1,056	1882-1976	1904	....	([k])	....	1	0130	7.86	7,340	16
35	....	Rist Canyon near Bellvue..........	5.27	....	....	....	....	....	1	[h]0030	....	2,710	16
36	06752260	Cache la Poudre River at Fort Collins...........	[a]1,129	1976	....	....	....	....	1	0430	8.84	5,700	....
37	06752500	Cache la Poudre River near Greeley	[a]1,877	1903-04	1917	....	[l]4,220	....	2	0030	5.62	1,600	....

[a] Contributing drainage area for flood of July 31–August 1, 1976, unknown.
[b] Site and datum then in use.
[c] Caused by dam failure at Lilly Lake.
[d] Ratio of peak discharge to that of 100-year flood discharge.
[e] Approximate contributing area during flood of July 31–August 1, 1976.
[f] Backwater from Dry Gulch.
[g] Gates at Lake Estes closed at 2055 MDT; no outflow during remainder of flood period.
[h] Approximate time based on information from local resident.
[i] Record unpublished 1956-76; availiable from State Engineer's office.
[j] Recorded at site 5 miles upstream.
[k] Greater than 21,000 cubic feet per second.
[l] Daily discharge.

TABLE 4.—*Hydrologic data for selected flood-data sites*

Site No.	Station No.	Stream and Location	Drainage area (mi²)	Discharge (ft³/s)	Unit discharge ((ft³/s)/mi²)	Average velocity (ft/s)	Average depth (ft)
4	....	Dry Gulch near Estes Park, Colo........	2.00	3,210	1,600	12	3.3
6	....	Big Thompson River below Estes Park, Colo	[a] 9	4,330	481	8	4.6
7	....	Big Thompson River tributary below Loveland Heights, Colo	1.37	8,700	6,350	26	5.5
8	....	Dark Gulch at Glen Comfort, Colo	1.00	7,210	7,210	28	5.1
9	....	Noels Draw at Glen Comfort, Colo	3.37	6,910	2,050	21	5.7
10	....	Rabbit Gulch near Drake, Colo	3.41	3,540	1,040	13	4.7
11	....	Long Gulch near Drake, Colo	1.99	5,500	2,760	19	5.8
12	....	Big Thompson River above Drake, Colo.	189 [a]34	28,200	829	22	8.3
13	....	North Fork Big Thompson River at Glen Haven, Colo .	[b]18.5	888	.....	8	2.2
14	....	Fox Creek at Glen Haven, Colo .	[b]7.18	1,300	.....	9	2.8
15	....	West Creek near Glen Haven, Colo .	[b]23.1	2,320	.....	7	3.0
16	....	Devils Gulch near Glen Haven, Colo .	.91	2,810	3,090	12	2.1
17	....	North Fork Big Thompson River tributary near Glen Haven, Colo	1.38	9,670	7,010	29	5.6
18	....	Black Creek near Glen Haven, Colo .	3.17	1,990	628	11	4.5
19	....	Miller Fork near Glen Haven, Colo	[b]13.9	2,060	.....	12	3.6
20	....	North Fork Big Thompson River tributary near Drake, Colo	1.26	3,240	2,570	18	3.0
21	06736000	North Fork Big Thompson River at Drake, Colo	[b]85.1	8,710	.....	12	5.2
22	....	Big Thompson River below Drake, Colo.	[b]276	30,100	.....	16	10.3
23	06738000	Big Thompson River at mouth of canyon, near Drake, Colo	[b]305	31,200	.....	26	10.6
24	....	Big Thompson River below Green Ridge Glade, near Loveland, Colo ...	[b]311	27,000	.....	12	6.7
25	....	Redstone Creek near Masonville, Colo .	[b]29.1	2,640	.....	10	4.2
27	....	Little Thompson River near Estes Park, Colo	2.77	1,940	700	10	1.6
30	....	Deadman Creek near Virginia Dale, Colo	[b]23.7	7,400	.....	10	4.0
31	....	Stonewall Creek near Livermore, Colo ...	[b]31.9	3,470	.....	12	3.7
32	....	Lone Pine Creek near Livermore, Colo ...	[b]86.3	2,590	.....	7	3.5
33	....	North Fork Cache la Poudre River at Livermore, Colo ..	[b]539	9,460	.....	9	5.3
34	06752000	Cache la Poudre River at mouth of canyon, near Fort Collins, Colo	[b]1,056	7,340	.....	9	6.2
35	....	Rist Canyon near Bellvue, Colo	5.27	2,710	514	12	3.4
36	06752260	Cache la Poudre River at Fort Collins, Colo	[b]1,129	5,700	.....	8	6.7

[a] Approximate contributing drainage area during flood of July 31–August 1, 1976.
[b] Contributing drainage area for flood of July 31–August 1, 1976, unknown.

FLOOD MARKS AND PROFILES

Soon after the flood, the U.S. Geological Survey, the U.S. Army Corps of Engineers, Omaha District, and the U.S. Bureau of Reclamation referenced high-water marks at numerous locations along the Big Thompson and the North Fork Big Thompson Rivers. The Colorado Water Conservation Board conducted a study to develop flood profiles from the high-water marks and stream cross-section data at selected locations in the flood area. Flood profiles, cross-section data, and preliminary streamflow data are contained in a report published by the Colorado Water Conservation Board (Grozier and others, 1976).

DETAILED DESCRIPTION OF FLOOD AREAS

BIG THOMPSON RIVER BASIN: UPSTREAM FROM OLYMPUS DAM

After the flood, a field inspection made upstream from Olympus Dam indicated that streams west of Estes Park received no appreciable flood runoff. The gaging station on the Big Thompson River upstream from Lake Estes (Site 1) recorded a peak discharge of 457 cubic feet per second at 2130 MDT as shown in figure 46, but all this floodwater reportedly was stored in Lake Estes and did not contribute to the downstream flooding. Earlier, at 1930 MDT, a much smaller peak had occurred, and an intermediate-sized peak was recorded at 0300 MDT on August 1.

Minor flooding also occurred on Fish Creek (Site 2) which enters Lake Estes from the south, just upstream from Olympus Dam. The discharge hydrograph for Fish Creek (fig. 47) shows that the stream rose slightly at 1920 MDT with a lull until 2000 MDT, followed by a sharp rise which peaked at 2150 MDT at a discharge of 182 cubic feet per second. A smaller peak occurred on Fish Creek at 0400 MDT on August 1.

The gates at Olympus Dam were closed at 2055 MDT on July 31 at which time the river discharge was about 200 cubic feet per second. This discharge is a small percentage of the peak discharges at downstream sites; thus, the basin upstream from Olympus Dam was considered as a noncontributing area for the purpose of these analyses.

BIG THOMPSON RIVER BASIN: OLYMPUS DAM TO LOVELAND HEIGHTS

This part of the flooded area consists of approximately 9 square miles beginning at Olympus Dam (Site 3) and ending at Site 6 on the Big Thompson River 0.5 mile southwest of Loveland Heights.

Dry Gulch, which drains 6.12 square miles northeast of Estes Park, flows southwestward to join the Big

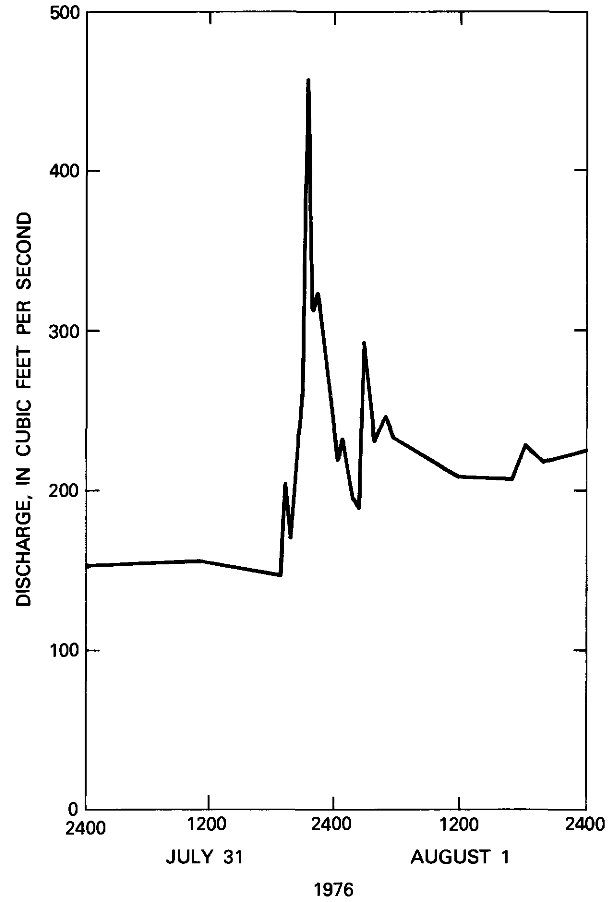


FIGURE 46.—Discharge hydrograph for the Big Thompson River at Estes Park (Site 1).

Thompson River just downstream from Olympus Dam. A peak discharge of 3,210 cubic feet per second occurred at Site 4 on Dry Gulch about 2.4 miles upstream from the mouth. According to a local resident, the peak stage occurred at 2215 MDT. Downstream at U.S. Highway 34, Dry Gulch (Site 5) had a peak discharge of 4,460 cubic feet per second. The peak stage occurred about 2230 MDT at Site 5 according to the gaging-station record on the Big Thompson River downstream from Olympus Dam (fig. 48). As shown in figure 49, the floodwater from Dry Gulch impinged on the base of Olympus Dam just downstream from U.S. Highway 34, eroding part of the base material. Fortunately, the erosion did not create a dangerous situation.

The largest rainfall amounts in Dry Gulch basin occurred upstream from Site 4 resulting in a unit discharge of 1,600 cubic feet per second per square mile, from the 2.0-square-mile basin. Much of the Dry Gulch basin between the two sites lies to the west of the area of heaviest rainfall; thus, the unit discharge

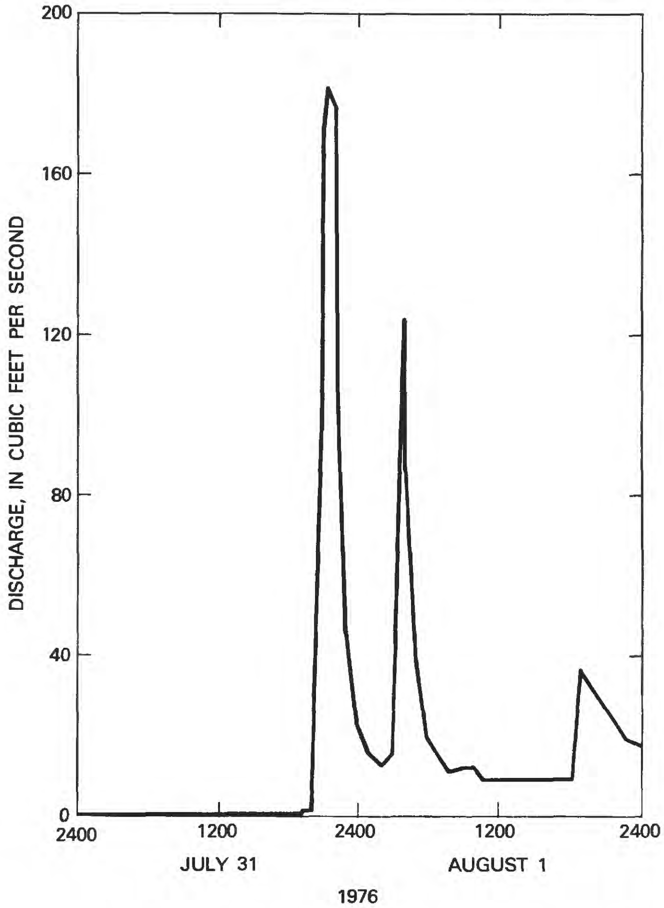


FIGURE 47.—Discharge hydrograph for Fish Creek near Estes Park (Site 2).

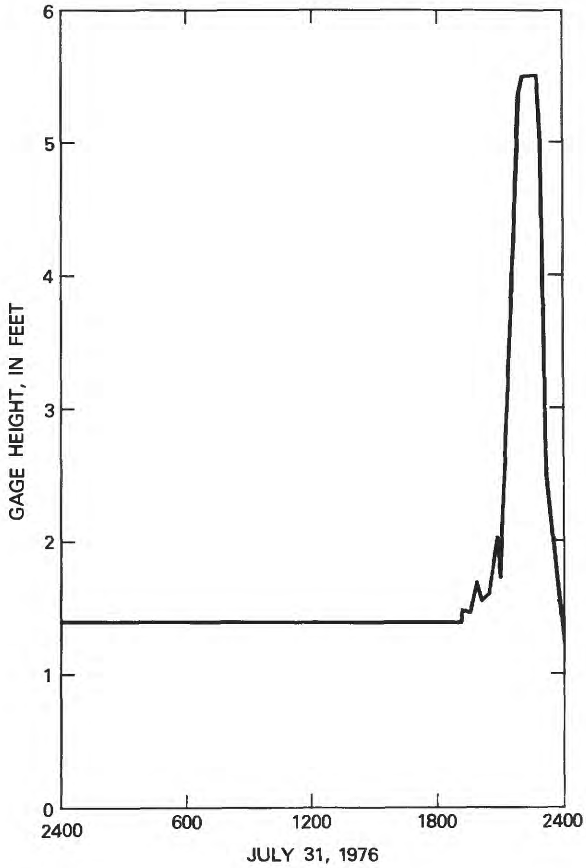


FIGURE 48.—Stage graph for the Big Thompson River near Estes Park (Site 3).

was much less for the downstream site, being 729 cubic feet per second per square mile.

The peak discharge on the Big Thompson River upstream from Loveland Heights (Site 6) was 4,330 cubic feet per second. Residents of the area reported that the highest river stage occurred about 2300 MDT which indicates that this rise was derived primarily from Dry Gulch discharge. They also mentioned a smaller rise after midnight, but none prior to the 2300-MDT peak. Considering the above information, the basin upstream from Site 6 probably contributed very little runoff to the initial, and most destructive, flood crest.

BIG THOMPSON RIVER BASIN: LOVELAND HEIGHTS TO DRAKE

The tributaries of the Big Thompson River in the upstream part of this reach received the brunt of the July 31 storm. From Loveland Heights to a point about 1 mile west of Waltonia, all tributaries produced extremely high runoff rates and consequent high velocities with accompanying streambed and bank erosion. In contrast, tributaries east of Waltonia exhibited little evidence of flooding.

The most severe flooding occurred on north bank tributaries between Loveland Heights and Glen Comfort. An unnamed tributary (Site 7) near Loveland Heights had a peak discharge of 8,700 cubic feet per second while Dark Gulch at Glen Comfort (Site 8) had a peak discharge of 7,210 cubic feet per second. A peak discharge of 6,910 cubic feet per second occurred on Noels Draw (Site 9) which enters the Big Thompson River from the south about 0.25 mile downstream from the mouth of Dark Gulch.

Both the unnamed tributary (Site 7) and Dark Gulch (Site 8) exceeded previously recorded maximum unit-discharge rates for basins of less than 4 square miles in Colorado. The unnamed tributary which drains 1.37 square miles had a unit discharge of 6,350 cubic feet per second per square mile. The unit discharge for Dark Gulch which drains 1.00 square mile was 7,210 cubic feet per second per square mile. Although Noels Draw (Site 9) lies just south of Dark Gulch, the unit

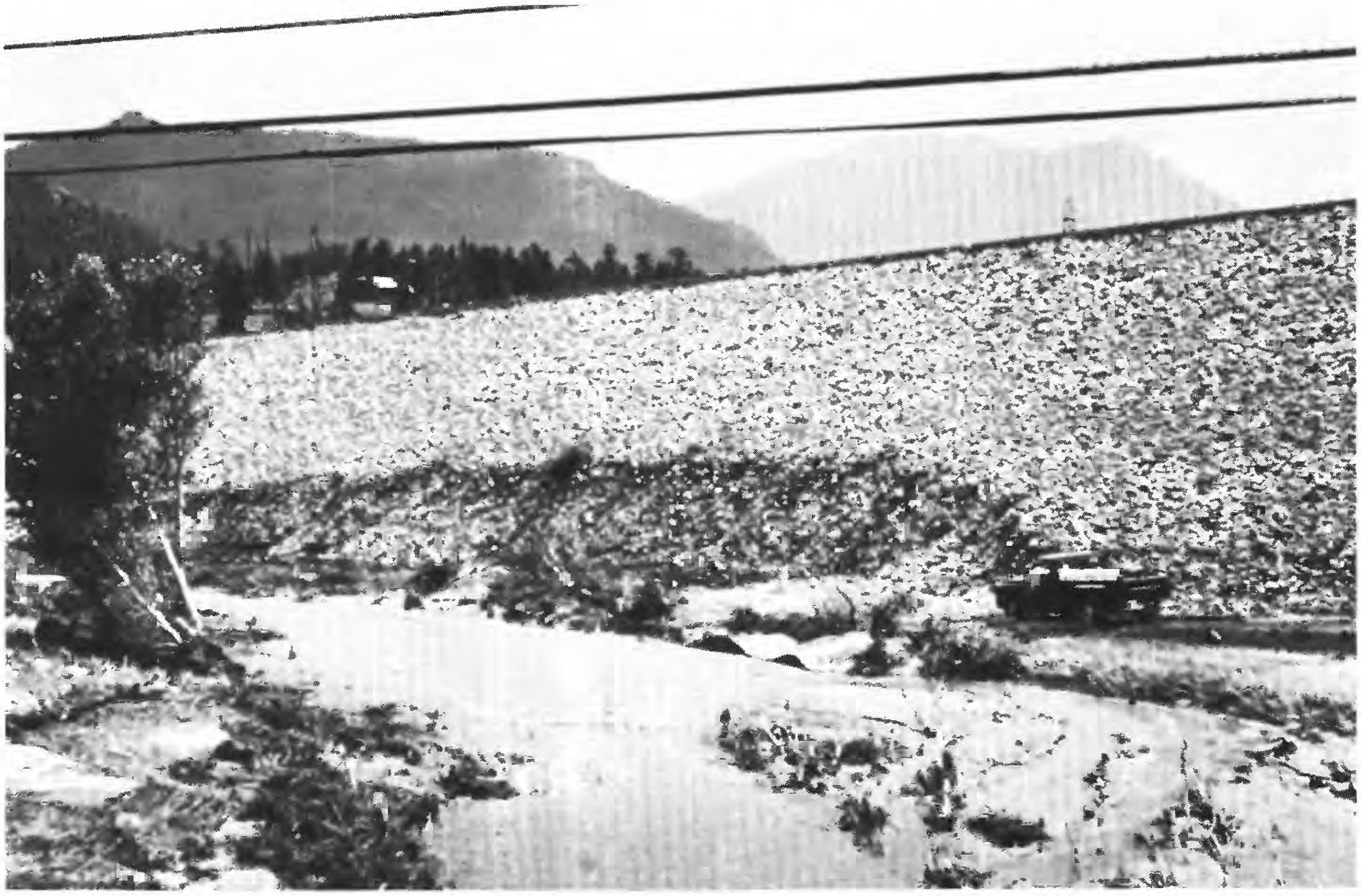


FIGURE 49.—Erosion along base of Olympus Dam caused by Dry Gulch floodwater.

discharge was much less, being 2.050 cubic feet per second per square mile from the 3.37-square-mile basin. The reason for this large difference in unit discharges is uncertain, but it probably is related to velocity and direction of storm movement past the opposite-facing valley slopes.

The peak discharge for Rabbit Gulch (Site 10), a south bank tributary which enters the river 2.5 miles downstream from Noels Draw, was 3,540 cubic feet per second. Both an aerial reconnaissance and aerial-photograph interpretation indicated little flood runoff in Rabbit Gulch upstream from a point about 1.5 miles above the mouth. Farther east, Long Gulch (Site 11), which enters the river from the north, had a peak discharge of 5,500 cubic feet per second. Although Long Gulch heads near the same point as Dark Gulch, probably only the downstream part of the basin received extremely heavy rainfall. The only stream east of Long Gulch that discharged significant floodwater was True Gulch which enters the Big Thompson River 0.5 mile west of Waltonia. Because smaller streams near Waltonia were relatively unaffected by the storm, it appears that the flood on True Gulch originated near the upper end of its basin and that little contribution came from the downstream part of the basin.

The Big Thompson River at Site 12, about 0.5 mile upstream from Drake, had a peak discharge of 28,200 cubic feet per second at about 2100 MDT on July 31. As mentioned previously, the part of the basin upstream from Olympus Dam did not significantly contribute to the flood-peak discharge; therefore, the contributing drainage area for Site 12 is 34 square miles. On this basis, the unit discharge for Site 12 is 829 cubic feet per second per square mile.

NORTH FORK BIG THOMPSON RIVER BASIN: GLEN HAVEN VICINITY TO DRAKE

Extremely heavy rainfall over an area of approximately 20 square miles centered slightly east of Glen Haven produced severe flooding on the North Fork Big Thompson River and several of its tributaries. Heavy rainfall reportedly began about 1930 MDT in Glen Haven, but the first account of extreme flooding came from Fox Creek, which reached a peak stage at about 2100 MDT. Another burst of rainfall at approximately

2300 MDT produced rises on several streams with resultant crests almost as high as the earlier ones. The major damage occurred in Glen Haven from West Creek which enters the town from the southwest. Downstream from Glen Haven, damage was limited mainly to the highway, which generally parallels the river to Drake.

The peak discharge of 888 cubic feet per second, which occurred on North Fork Big Thompson River about 0.1 mile upstream from Fox Creek (Site 13), indicates the small contribution to downstream floodflows from that part of the basin west of Glen Haven. Similar results were obtained for Fox Creek where a peak discharge of 1,300 cubic feet per second occurred at Site 14, 0.2 mile above the mouth. Peak discharges on West Creek (Site 15) and Devils Gulch (Site 16) were 2,320 cubic feet per second and 2,810 cubic feet per second, respectively. Again, only a small part of the West Creek basin was hit by the heavy rainfall. Conversely, the entire basin of Devils Gulch received extremely heavy rainfall resulting in the high unit runoff of 3,090 cubic feet per second per square mile from the 0.91-square-mile basin.

Downstream from Glen Haven, the unnamed tributary which enters the river from the south at Glen Haven picnic ground (Site 17) had a peak discharge of 9,670 cubic feet per second from a drainage area of 1.38 square miles. This peak-runoff rate of 7,010 cubic feet per second per square mile is the second highest unit-runoff rate for the flood, being exceeded only by Dark Gulch (Site 8) which heads due south of this stream. Peak discharges for Black Creek (Site 18) and Miller Fork (Site 19) were 1,990 cubic feet per second and 2,060 cubic feet per second, respectively. The peak stages occurred on these two streams about 2300 MDT; both streams were reported as being dry during the 2100-MDT flood period. A peak discharge of 3,240 cubic feet per second occurred on the unnamed tributary (Site 20) which enters North Fork from the south about 3.2 miles west of Drake. The unit discharge of 2,570 cubic feet per second per square mile is less than that of other streams which head in the same general area, but much of this basin lies near the eastern edge of the storm area. Flood runoff in streams east of this point rapidly decreased with no evidence of flood runoff on North Fork tributaries at Drake.

At Drake, the North Fork Big Thompson River (Site 21) had a peak discharge of 8,710 cubic feet per second. This peak discharge greatly exceeds the previous maximum discharge of 1,290 cubic feet per second which occurred on June 16, 1965. The hydrograph from the gaging station (operated by the Colorado Division of Water Resources) on the North Fork at Drake (fig. 50) shows that one peak occurred at 2110 MDT, possibly caused by backwater from the Big Thompson River. The stream then receded until 2135 MDT and rose again to a peak stage of 9.21 feet at 2140 MDT. The second peak which occurred in the vicinity of Glen Haven about 2300 MDT was not recorded at this site because of the plugged gage intakes.

BIG THOMPSON RIVER BASIN: DRAKE TO MOUTH OF CANYON

The peak discharge of the Big Thompson River about 0.4 mile east of Drake (Site 22) was 30,100 cubic feet per second. The flood crest at this location occurred a few minutes after 2100 MDT or approximately 30 minutes prior to the flood crest on the North Fork at Drake. At 2100 MDT, the approximate time of the Big Thompson River crest stage at Drake,the discharge of the North Fork was about 4,500 cubic feet per second. By adding this discharge to the peak discharge of the Big Thompson River at Site 12, a discharge of 32,700 cubic feet per second is obtained, which is only about 9 percent greater than the measured peak discharge of 30,100 cubic feet per second. Fortunately, the flood

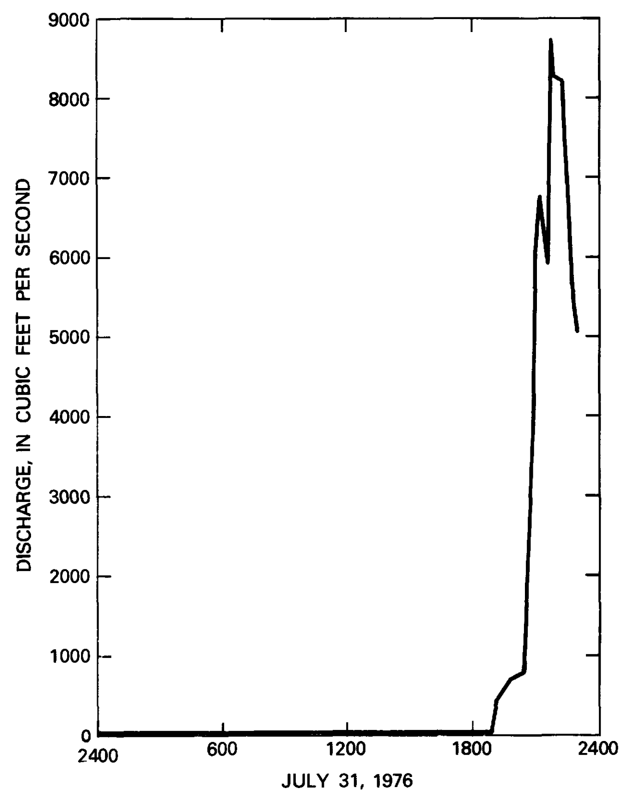


FIGURE 50.—Discharge hydrograph for the North Fork Big Thompson River at Drake (Site 21) until 2300 MDT on July 31, 1976.

crests on the main stem and the North Fork did not occur simultaneously at Drake; otherwise, the downstream peak discharge would have been larger and damages even more severe.

The flood crest moved through the 7.7-mile reach between Drake and the canyon mouth in about 30 minutes for an average travel rate of 15 miles per hour, or about 23 feet per second. The peak discharge occurred at the gaging station at the mouth of the Big Thompson Canyon (Site 23) about 2140 MDT on July 31 at 31,200 cubic feet per second, as shown in figure 51. Because the gage was destroyed during the sharp rise, river stages were based on observer readings and high-water marks left by the flood, the times were based on information from observers of the flood. The U.S. Bureau of Reclamation's calculation of peak discharge at the canyon mouth yielded 30,000 cubic feet per second, a percentage difference of less than 4 percent from that determined by the U.S. Geological Survey.

The peak discharge of 31,200 cubic feet per second is almost four times that of the previously known maximum discharge of 8,000 cubic feet per second which occurred on July 31, 1919. The gaging station at the mouth of the canyon was not in operation during 1919, but the flood was recorded at a gaging station about 5 miles upstream. The 1976 peak discharge is more than four times the previous recorded maximum discharge of 7,600 cubic feet per second which occurred on July 19, 1945, at the mouth of canyon gage. The peak stage of 19.7 feet on July 31, 1976, exceeded the previous recorded peak stage by more than 10 feet.

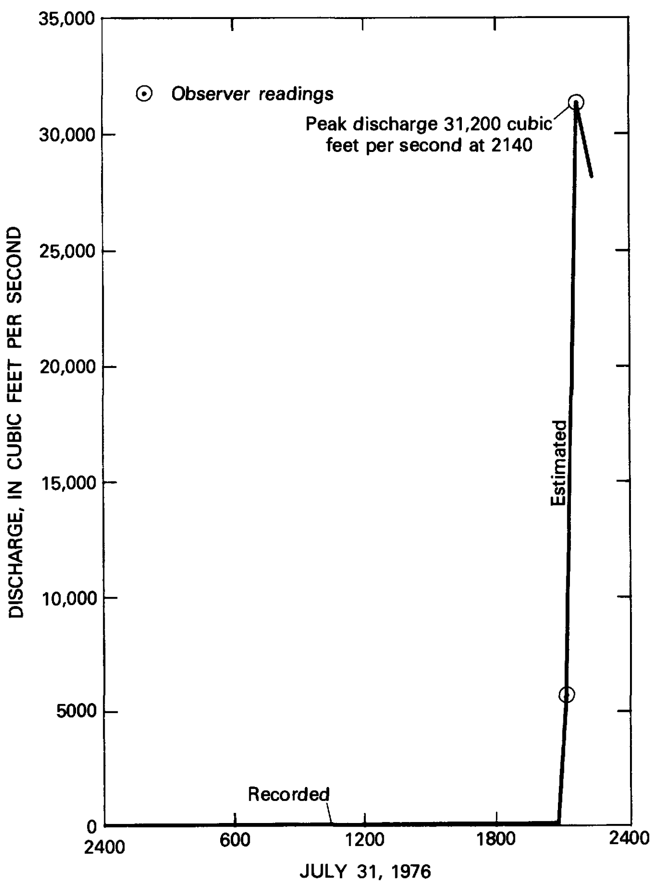


FIGURE 51.—Discharge hydrograph for rising stage at the Big Thompson River at mouth of canyon, near Drake (Site 23).

BIG THOMPSON RIVER BASIN: MOUTH OF CANYON TO SOUTH PLATTE RIVER

As it leaves the canyon, the Big Thompson River valley widens rapidly. The flood crest attenuated quickly because of valley storage and overflow into numerous reservoirs near the river. The peak discharge of 27,000 cubic feet per second for the Big Thompson River just downstream from Green Ridge Glade (Site 24) indicates the effects of peak-discharge attenuation (nearly 14 percent) although Site 24 is only about 2 miles downstream from the canyon mouth.

Buckhorn Creek experienced only minor flooding upstream from Redstone Creek. At Site 25 on Redstone Creek near Masonville, a peak discharge of 2,640 cubic feet per second occurred some time after midnight as the storm system moved northeastward out of the Estes Park-Glen Haven area. Downstream from Redstone Creek, a peak discharge of about 3,400 cubic feet per second occurred at the discontinued gaging station on Buckhorn Creek (Site 26) south of Masonville. This peak discharge occurred between 0300-0330 MDT based on a stage record furnished by the Colorado Division of Water Resources for Buckhorn Creek (fig. 52) at a site 1.7 miles downstream.

As the flood crest on the Big Thompson River moved eastward into the wider and flatter valley, the resultant reduced velocity caused massive amounts of debris and sediment to be deposited. In Loveland, flooding was limited to low-lying areas along the river and overtopping of several streets. U.S. Highway 287 south of Loveland was overtopped for a distance of about 0.6 mile at the time of the flood crest.

The Little Thompson River, which enters the Big Thompson River about 5 miles upstream from the mouth, experienced severe flooding in the headwaters southeast of Estes Park. The affected area which lies on the south-facing slope opposite Noels Draw was subjected to extremely high runoff rates near the basin divide, as evidenced by numerous small areas of severe sheet erosion. A peak discharge of 1,940 cubic feet per second occurred on the Little Thompson River at Site 27 southeast of Estes Park at about 2130 MDT. The

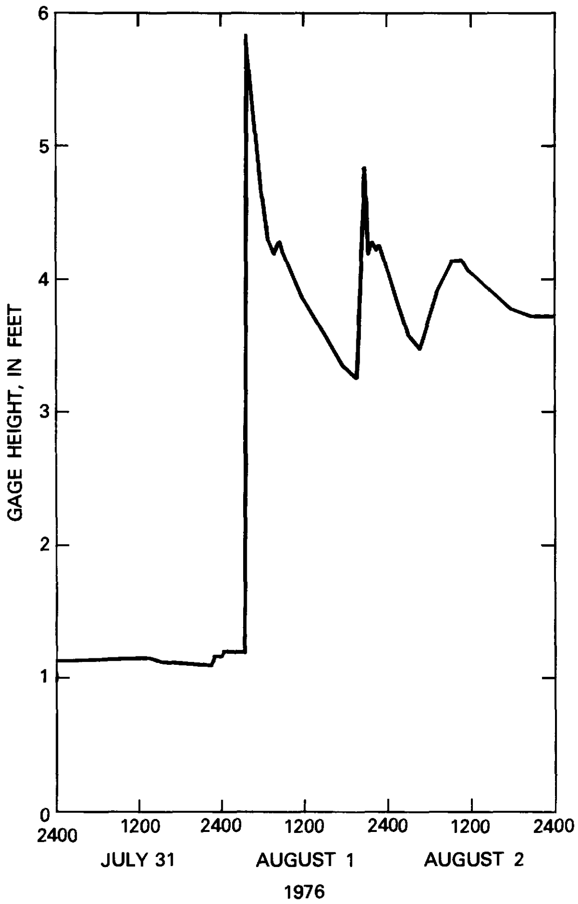


FIGURE 52.—Stage graph for Buckhorn Creek near Masonville (downstream site).

unit discharge of 700 cubic feet per second per square mile from 2.77 square miles of the basin does not indicate a high runoff rate; thus, apparently only the extreme northwest part of the basin received heavy rainfall. Farther east, at U.S. Highway 287 south of Berthoud, the Little Thompson River did not overtop the main channel banks.

The peak discharge of the Big Thompson River at its mouth near LaSalle (Site 28) was 2,470 cubic feet per second at 2235 MDT on August 1 (fig. 53). This small discharge is further evidence of the flood-reduction effects of valley and reservoir storage. The flood crest slowed considerably and traveled through the 35-mile reach between the canyon mouth and the mouth of the river in about 25 hours, an average rate of 1.4 miles per hour.

CACHE LA POUDRE RIVER BASIN

Flood runoff originated from an area about 10 miles wide extending from north to south across the Cache la Poudre River basin. Generally, U.S. Highway 287 traverses the area from northwest to southeast (fig. 2). The two heaviest areas of flood runoff appeared to be on tributaries of the North Fork Cache la Poudre River north of Livermore and on streams in the vicinity of Bellvue, northwest of Fort Collins. The rainfall that produced the flooding on the North Fork tributaries near Virginia Dale began about 2000 MDT and was reported as being most intense between 2100 and 2200 MDT. Between 2200 on July 31 and 0100 MDT on August 1, the part of the storm system that caused the Big Thompson River flooding moved over the Bellvue area and produced flooding in Rist Canyon, on several Cache la Poudre tributaries near Bellvue, and on the downstream tributaries of the North Fork Cache la Poudre River. The western limit of the flood on the Cache la Poudre River was in the vicinity of Poudre Park, while on the North Fork Cache la Poudre River no significant flooding occurred upstream from the mouth of Dale Creek just southwest of Virginia Dale. There was minor flooding along the headwaters of Boxelder Creek east of Virginia Dale, but data were not obtained for this basin.

According to information from local residents, tributaries of the North Fork Cache la Poudre River basin near Virginia Dale crested between 2200 and 2300 MDT on July 31. Deadman Creek at U.S. Highway 287 (Site 30) crested about 2230 MDT at a peak discharge of 7,400 cubic feet per second. The floodwater at this location eroded the highway fill behind one bridge abutment and temporarily halted traffic, but the bridge was not overtopped or structurally damaged. A peak discharge of 727 cubic feet per second, or 1,070 cubic feet per second per square mile, was determined for Dale Creek tributary (Site 29) about 1 mile northwest of Virginia Dale. Stonewall Creek (Site 31) near the mouth experienced a peak discharge of 3,470 cubic feet per second about 2200 MDT. Much of Stonewall Creek basin east of U.S. Highway 287 did not contribute significant flood runoff. Lone Pine Creek west of Livermore (Site 32) crested about 2230 MDT at a peak discharge of 2,590 cubic feet per second. On the basis of field inspection and rainfall data, only the eastern edge of the Lone Pine Creek basin contributed to flood runoff.

The flood crest on North Fork Cache la Poudre River at Red Feather Lakes road (Site 33) occurred about 0100 MDT on August 1 at a peak discharge of 9,460 cubic feet per second. According to a local resident, the river at this location was higher than at any time since May 20, 1904, when a peak discharge of 20,000 cubic feet per second occurred. The North Fork reportedly crested at its mouth about 0200 MDT on August 1.

Flooding on the main stem of the Cache la Poudre River downstream from the mouth of the North Fork resulted from a combination of flood runoff from the

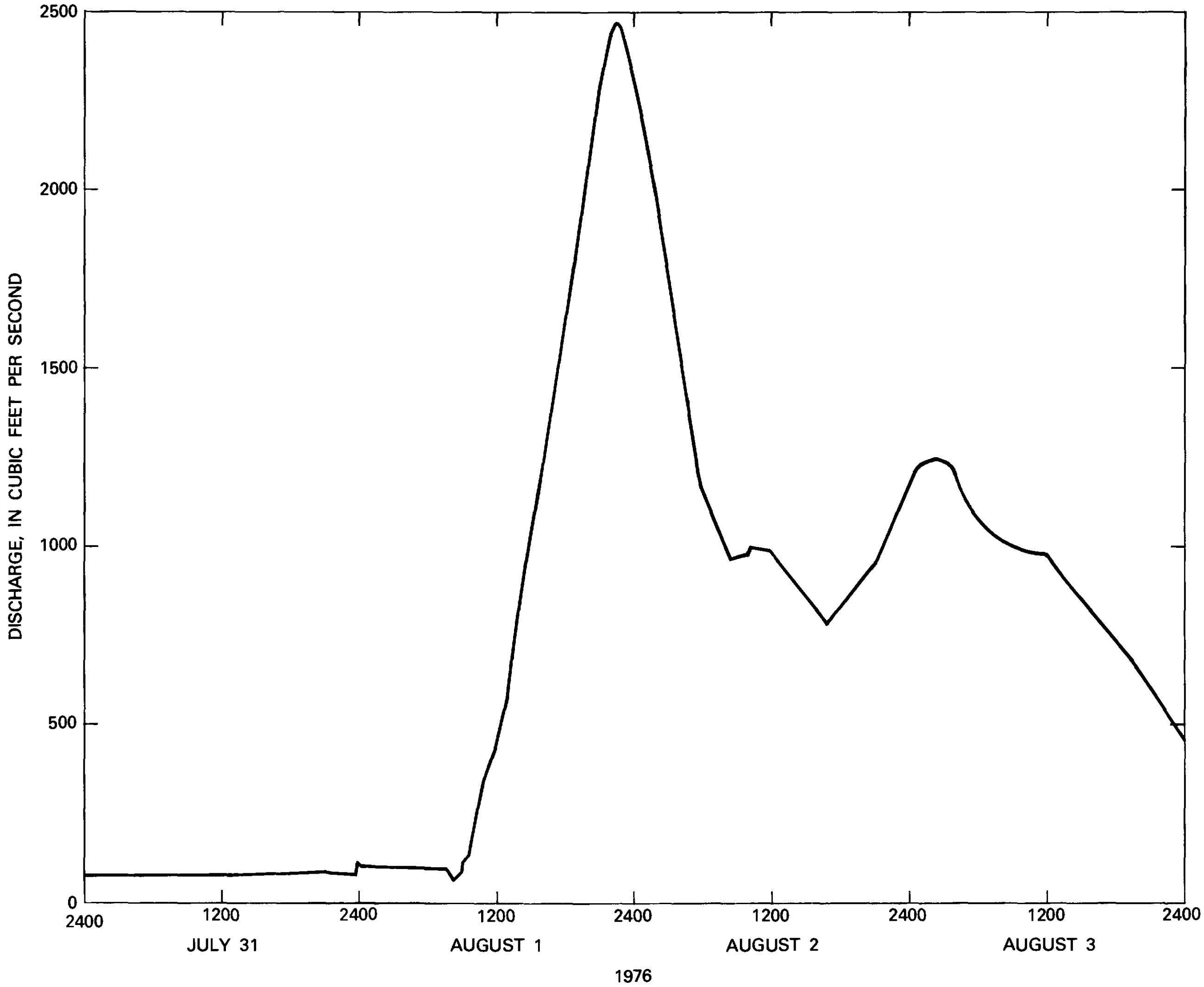


FIGURE 53.—Discharge hydrograph for the Big Thompson River at mouth, near LaSalle (Site 28).

two periods of intense rainfall. The discharge hydrograph (fig. 54) for the gaging station on the Cache la Poudre River at the canyon mouth near Fort Collins (Site 34) shows that the river rose only slightly until about midnight on July 31. After midnight, the river rose sharply to a peak discharge of 7,340 cubic feet per second at 0135 MDT on August 1, about 30 minutes prior to the flood peak on North Fork at its mouth about 4 miles upstream. Because the hydrograph shows only a single peak, it appears that the peak rates of flood runoff from the two intense bursts of rainfall arrived almost simultaneously at the gaging station.

Several south bank tributaries of the Cache la Poudre River between Laporte and Poudre Park yielded high flood-runoff rates. Rist Canyon, which enters the Cache la Poudre River just upstream from Bellvue, reached a peak discharge of 2,710 cubic feet per second about 0015 MDT on August 1 at Site 35. The unit discharge for this 5.27-square-mile basin was 514 cubic feet per second per square mile. The period of most intense rainfall in this basin reportedly occurred between 2315 and 2345 MDT on July 31.

A peak discharge of 5,700 cubic feet per second occurred at the gaging station on the Cache la Poudre River at Fort Collins (Site 36). The discharge hydrograph for the station (fig. 55) shows that the river started to rise sharply at 0200 MDT and crested at 0430 MDT on August 1. Farther downstream, the Cache la Poudre River at the gaging station near Greeley (Site 37) reached a peak discharge of 1,600 cubic feet per second at 0030 MDT on August 2 (fig. 56). As in the Big Thompson River basin, the sharp reduction in peak discharge between the upstream station and the mouth of the river indicates the attenuating effects of valley and off-channel storage.

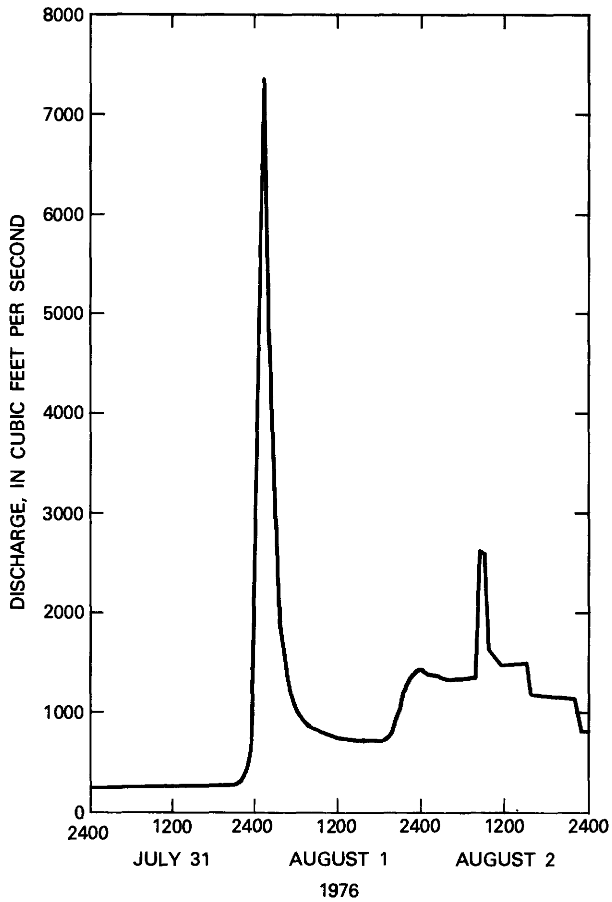


FIGURE 54.—Discharge hydrograph for the Cache la Poudre River at mouth of canyon, near Fort Collins (Site 34).

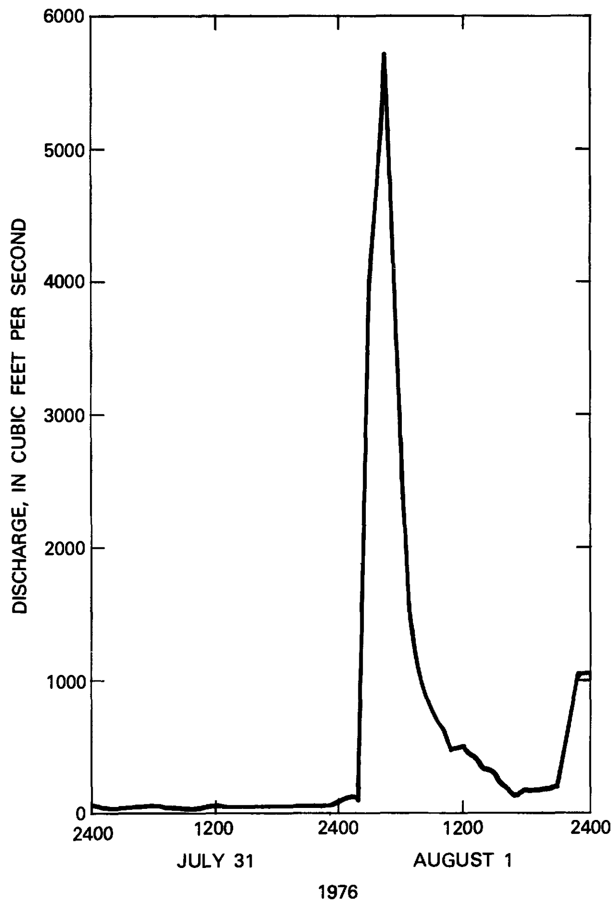


FIGURE 55.—Discharge hydrograph for the Cache la Poudre River at Fort Collins (Site 36).

FLOOD FREQUENCY

In some parts of the flooded area, the peak discharges of the July 31-August 1, 1976 flood are extremely rare, but, in other parts, they have been exceeded several times. Along the Big Thompson River from Estes Park to the canyon mouth, this flood far exceeded the previous maximum flood recorded during almost a century of documented observation. Conversely, the flood on the Cache la Poudre River has been exceeded several times during that same period of time. To provide an estimate of the probability of occurrence of the flood, a frequency analysis was made for gaging-station records, and regional regression equations (McCain and Jarrett, 1976) were used for ungaged sites, where applicable. The flood-frequency results are listed in table 3 for sites where estimates could be made.

The 1976 flood discharge at the canyon mouth (Site 23) of the Big Thompson River was 1.8 times the 100-year flood for that site. Upstream in the Big Thompson River basin near the flood source, the flood was even more rare than at the canyon mouth. For some sites in this area, the ratio of the 1976 peak discharge to that of the 100-year flood discharge was computed as listed in table 3. At the Big Thompson River above Drake (Site 12) the 1976 peak discharge was 3.8 times the estimated 100-year flood discharge for the site. For several small basins in the Estes Park-Glen Haven vicinity, no estimates of the 100-year floods could be made because existing methods are not applicable, but on the basis of field data and information from local residents, the floods in these basins probably were much greater than the 100-year flood.

In the Cache la Poudre River basin, the floods on Deadman Creek near Virginia Dale and in Rist Canyon near Bellvue had recurrence intervals of 100 years and 16 years, respectively. At the gaging station on the Cache la Poudre River at the canyon mouth near Fort Collins (Site 34), the recurrence interval of the flood was computed to be 16 years.

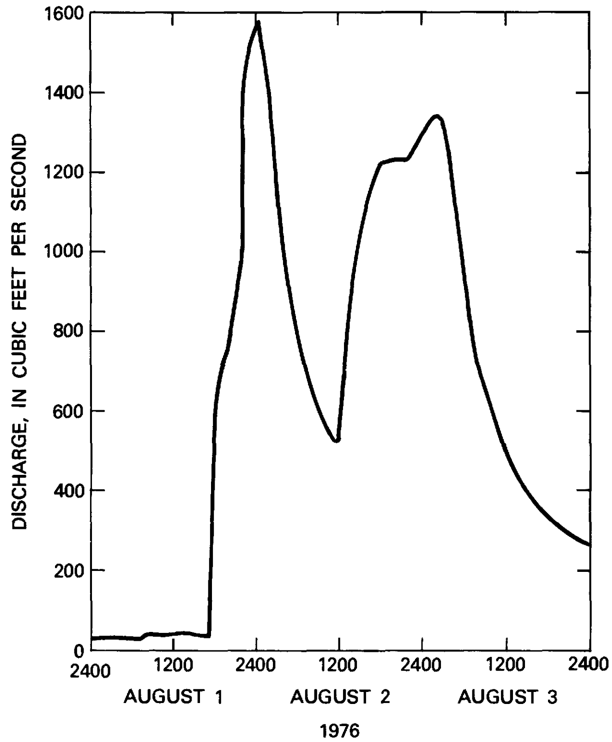


FIGURE 56.—Discharge hydrograph for the Cache la Poudre River at mouth, near Greeley (Site 37).

THE AFTERMATH

The major brunt of the flood lasted only a few hours but during that short period of time an appalling amount of death and destruction occurred. Search and rescue operations were quickly begun and on August 2 Larimer County was declared a disaster area by the President of the United States. On the same day, a 6-month moratorium on construction in the flooded area along the Big Thompson River was declared by the county commissioners. This moratorium was effected to restrict new construction or repairs to structures damaged 50 percent or more until completion of a study to delineate the limits of the 100-year flood plain (Gingery Associates, Inc., 1976).

THE HUMAN ELEMENT

There were 139 fatalities, with 5 persons remaining on the list of missing. The ages of the victims ranged from 2 years to 94 years, with about 40 percent of them under 30 years of age and 28 percent over 60 years old. About two-thirds of the victims were residents of Colorado; the other one-third were from 17 other States and the Philippine Islands.

THE DAMAGE

The dawn of Centennial Sunday unveiled an almost incomprehensible scene of destruction in many parts of the flooded area. Eastward along the Big Thompson River from Estes Park to Loveland Heights there was evidence of flooding but damage was not severe. At Loveland Heights, conditions changed dramatically, for, from this point downstream to Loveland, the scene was one of almost total devastation. As one observer described it, "* * * The scene was one to rival a combination tornado, flood, and earthquake * * *." Conditions were similar along the North Fork Big Thompson River in the vicinity of Glen Haven. Downstream from Glen Haven, the major damage occurred to the county highway which generally parallels the river to Drake but several buildings located close to the river were severely damaged. Damage in Weld County along the downstream reach of the Big Thompson River was not severe, consisting mainly of bridge damage and debris accumulation. In the Cache la Poudre River basin, damage also was light, being mostly related to irrigation structures and partially completed flood-detention structures on Boxelder Creek.

Although the estimates are far from complete, the total damage to date (1977) is estimated at $35.5 million. A summary of damage estimates compiled by the U.S. Army Corps of Engineers is given in table 5. Almost one-half of the total damage was related to rebuilding a major portion of U.S. Highway 34 which parallels the Big Thompson River from Loveland to Estes Park. As illustrated in figure 57, the highway embankment was completely destroyed in some reaches, leaving the canyon in a natural-appearing condition. Structural damages totaling almost $9 million included more than 50 percent damage to 252 structures and less than 50 percent damage to 242 structures. The aerial photographs shown in figure 58 vividly illustrate structure damage at Drake. Figure 58*A*, made on August 29, 1973, represents approximate conditions of development at Drake before the flood. Figure 58*B* was made on August 3, 1976, after the flood, and figure 58*C* was made on October 29, 1976, after the Drake area was cleared of debris and condemned structures.

The damage estimate also included $2.5 million for the Big Thompson dam, pipeline, and powerplant. The flood destroyed 438 automobiles and caused nearly $1 million in additional damages to house trailers. Several views of destroyed automobiles, some battered into almost unrecognizable shapes by debris and boulders while others almost buried by sediment are shown in

TABLE 5.—*Damage estimates for the July 31-August 1, 1976 flood*

[Adapted from U.S. Army Corps of Engineers data]

Breakdown	Dollar Estimate
LARIMER COUNTY	
Governmental clean-up operations	$ 1,611,000
Emergency efforts	656,700
Transportation damages	17,420,000
Land-erosion damages	No dollar estimate
Structural damages	8,928,500
Personal property damages	5,036,000
Employment losses	115,500
Damages to public facilities not listed elsewhere	1,634,000
Indirect damages	No dollar estimate
Emergency social assistance	96,400
Total estimated economic and financial loses, Larimer County	$ [1]35,498,100
WELD COUNTY	
Damage (preliminary—all public)	$ 45,000
Total estimated damage	$ 35,543,100

[1]Of the total losses, public damage is estimated at $23,671,600, and private damage is estimated at $11,826,500.

figure 59. Another significant item was the $1.6 million expenditure for removal of more than 400,000 cubic yards of debris from the flooded area. No estimates were available for items, such as business losses from reduced tourist trade, loss of tax receipts, damage to wells and septic systems, and property devaluation because of location in a designated flood plain.

COMPARISON WITH PREVIOUS RAINSTORMS AND FLOODS

The rainfall and flood discharges that occurred on July 31-August 1, 1976, were unusually large, but they are not unprecedented for areas along the eastern foothills and plains of Colorado. A comparison between rainfalls for the 1976 storm and some previously recorded amounts in the area is shown in figure 60. Although many of the plotted points represent observed measurements for the May 1935 and June 1965 storms, several other storms have produced rainfalls larger than those for the storm of July 31-August 1, 1976.

Peak discharges for the July 31-August 1 flood at selected sites are plotted in figure 61 along with previously recorded peak discharges at other locations. The 1976 peak discharges were greatly exceeded by the May 1935 and June 1965 floods which occurred along the eastern plains and have been approximately equalled by several other floods some of which occurred in the eastern foothills. Only for drainage areas less than 4 square miles do the 1976 values exceed previously observed floods in eastern Colorado, and this may be largely attributed to failure to obtain flood data for small basins during previous extreme floods. Also shown in figure 61 is a plot of maximum observed flood discharges in the United States as developed by Matthai (1969). Again, the comparison shows that larger floods have been experienced at other locations in the United States.

SOURCES OF DATA

Sources of data, including both data in this report and supplementary or auxiliary data, are listed below. These sources were identified and listed in this report through the suggestions and efforts of the U.S. Water Resources Council, Hydrology Committee.

1. U.S. Geological Survey, Water Resources Division, Box 25046, Mail Stop 415, Denver Federal Center, Lakewood, Colorado 80225. Flood stages, discharges, volumes, travel times, flood profiles, hydrographs, and cross sections.
2. Colorado Water Conservation Board, 1313 Sherman Street, Denver, Colorado 80203. Flood stages, flood areas, discharges, volumes, travel times, flood profiles, hydrographs, and cross sections.
3. Colorado Division of Water Resources, Room 802, Building A, New State Building, 1313 Sherman Street, Denver, Colorado 80203. Flood stages, discharges, volumes, travel times, flood areas, flood profiles, hydrographs, and cross sections.
4. Board of County Commissioners, Larimer County, Colorado. P.O. Box 1190, Fort Collins, Colorado 80522. General hydrologic information and specific information on flood fatalities, flood damage, and rescue operations.
5. National Climatic Center, Federal Building, Asheville, North Carolina 28801. Archives of all meteorological and hydrological data gathered by National Oceanic and Atmospheric Administration.
6. National Weather Service, Office of Hydrology, Silver Spring, Maryland 20910. Original bucket-survey data of rainfall.

FIGURE 57.—Erosion damage to U.S. Highway 34 and to irrigation siphon at the gaging station on the Big Thompson River at mouth of canyon, near Drake (Site 23).

7. National Oceanic and Atmospheric Administration, Environmental Research Laboratory, Boulder, Colorado 80302. Report by R. A. Maddox and others, "Meteorological Aspects of Big Thompson Flash Flood of July 31, 1976."
8. National Hail Research Experiment, National Center for Atmospheric Research, Boulder, Colorado 80302. Radar data from NHRE Radar at Grover, Colo., and upper-air sounding data at Sterling, Colo.
9. National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Wave Propagation Laboratory, Boulder, Colorado 80302. Acoustic echo-sounder data at Table Mountain, Colo., on July 31, 1976.
10. Omaha District, U.S. Army Corps of Engineers, 6014 U.S. Post Office and Courthouse, 215 North 17th Street, Omaha, Nebraska 68102. Flood-damage data.
11. Colorado Water Conservation Board, 1313 Sherman Street, Denver, Colorado 80203. "Big Thompson River Flood of July 31–August 1, 1976, Larimer County, Colorado, Report of 1976."
12. Bureau of Reclamation, Lower Missouri Region, P.O. Box 25247, Denver Federal Center, Denver, Colorado 80225. Contact Regional Director's Office for specific information that is available.

GAGING-STATION AND MISCELLANEOUS-SITE DATA

PLATTE RIVER BASIN

SITE 1: 06733000 BIG THOMPSON RIVER AT ESTES PARK, COLO.

Location.—Lat 40°22'42", long 105°30'48", in NW¼NW¼ sec. 30, T. 5 N., R. 72 W., Larimer County, on right bank in Estes Park, 600 ft downstream from bridge on State Highways 7 and 66, 900 ft downstream from Black Canyon Creek, and 0.3 mi northeast of Estes Powerplant. Station is upstream from Lake Estes.

Drainage area.—137 mi^2.

Gage-height record.—Water-stage recorder graph furnished by Colorado Division of Water Resources. Datum of gage is 7,492.5 ft above mean sea level (levels by U.S. Bureau of Reclamation).

Discharge record.—Stage-discharge relation defined by current-meter measurement below 1,500 ft^3/s.

Maxima.—July-August 1976: Discharge, 457 ft^3/s 2130 MDT July 31 (gage height, 3.64 ft).

1946 to June 1976: Discharge, 1,660 ft^3/s June 18, 1949 (gage height, 3.16 ft site and datum then in use); gage height, 6.89 ft June 17, 1965.

Gage height and discharge at indicated time, 1976

Time	Gage height (ft)	Discharge (ft^3/s)	Time	Gage height (ft)	Discharge (ft^3/s)
July 30			*August 1*		
2400	1.84	153	0030	2.31	221
July 31			0100	2.38	232
0600	1.86	156	0200	2.14	195
1200	1.85	155	0230	2.10	190
1800	1.80	148	0300	2.75	292
1900	1.79	147			
1930	2.20	204	0400	2.38	232
			0500	2.47	246
2000	1.97	171	0600	2.39	233
2100	2.56	260	1200	2.23	209
2130	3.64	457	1700	2.22	207
2200	2.88	314			
			1800	2.30	219
2230	2.93	323	1820	2.36	228
2300	2.83	305	2000	2.29	218
2400	2.46	244	2400	2.34	225

SITE 2: 06734500 FISH CREEK NEAR ESTES PARK, COLO.

Location.—Lat 40°22'10", long 105°29'40", in SW¼ sec. 29, T. 5 N., R. 72 W., Larimer County, on right bank 100 ft upstream from highwater line of Lake Estes, 0.4 mi upstream from bridge on U.S. Highway 36, and 2 mi southeast of Estes Park.

Drainage area.—16.0 mi^2.

Gage-height record.—Water-stage recorder graph furnished by Colorado Division of Water Resources. Datum of gage is 7,475.80 ft above mean sea level (levels by U.S. Bureau of Reclamation).

Discharge record.—Stage-discharge relation defined by standard Parshall flume rating and by slope-area measurement at 1,480 ft^3/s.

Maxima.—July-August 1976: Discharge, 182 ft^3/s 2150 MDT July 31 (gage height, 4.02 ft).

1947 to June 1976: Discharge, 1,480 ft^3/s May 25, 1951 (gage height, 7.32 ft from floodmark) caused by dam failure at Lily Lake.

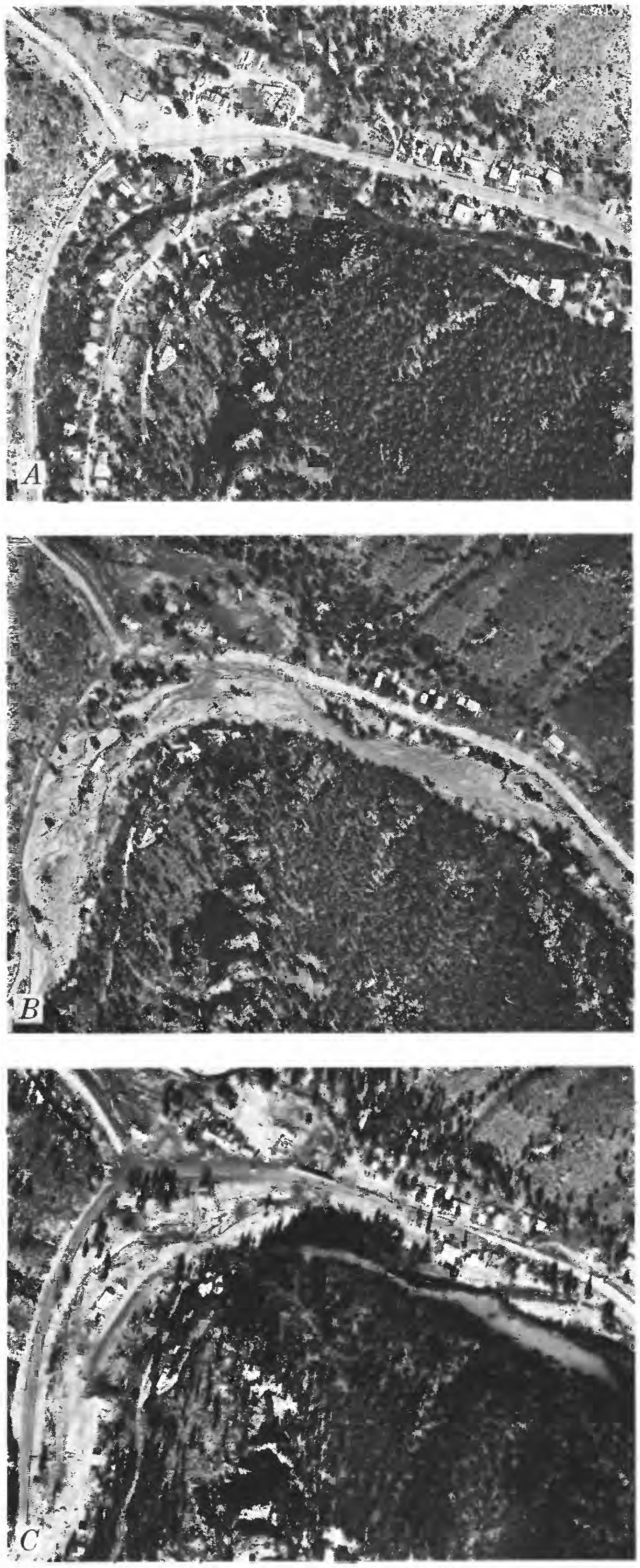


FIGURE 58.—Photographs showing aerial views of Drake: *A*, pre-flood conditions, August 29, 1973; *B*, immediately after the flood, August 3, 1976; *C*, after cleanup operations, October 29, 1976.

FIGURE 59.—Views of destroyed automobiles.

Gage height and discharge at indicated time, 1976

Time	Gage height (ft)	Discharge (ft³/s)	Time	Gage height (ft)	Discharge (ft³/s)
July 30			*August 1*		
2400	0.10	0.44	0100	0.88	16
July 31			0220	.78	13
0600	0.10	.44	0300	.85	15
1200	0.11	.52	0400	3.16	123
1800	0.10	.44	0415	2.57	88
1920	0.10	.44			
1930	.21	1.6	0430	2.50	84
			0500	1.58	40
2000	.19	1.3	0600	1.02	20
2030	.74	12	0800	.71	11
2100	2.68	95	0900	.74	12
2120	3.87	170			
2130	3.89	172	1000	.74	12
			1100	.63	9.1
2150	4.02	182	1820	.63	9.1
2200	3.97	178	1900	1.47	36
2220	2.96	111	2000	1.37	32
2230	2.86	105	2300	1.00	19
2300	1.75	48	2400	.95	18
2400	1.10	23			

SITE 3: 06735500 BIG THOMPSON RIVER NEAR ESTES PARK, COLO.

Location.—Lat 40°22'35", long 105°29'06", in NE¼NE¼ sec. 29, T. 5 N., R. 72 W., Larimer County, on right bank 100 ft upstream from Dry Gulch, 600 ft downstream from Olympus Dam, and 2.0 mi east of Estes Park.

Drainage area.—155 mi².

Gage-height record.—Water-stage recorder graph until midnight July 31 at which time intakes were plugged. Record furnished by Colorado Division of Water Resources. Datum of gage is 7,422.5 ft above mean sea level (levels by U.S. Bureau of Reclamation).

Discharge record.—Gates at Olympus Dam were closed at 2055 MDT July 31. Subsequent stream discharge which derived from Dry Gulch caused the Parshall flume to be covered by sediment making the stage-discharge relation indefinite.

Maxima.—July–August 1976: Discharge, undetermined; gage height (5.51 ft) 2230 MDT July 31 (backwater from Dry Gulch).

1930 to June 1976: Discharge, 2,800 ft³/s June 20, 1933 (gage height, 4.0 ft, site and datum then in use).

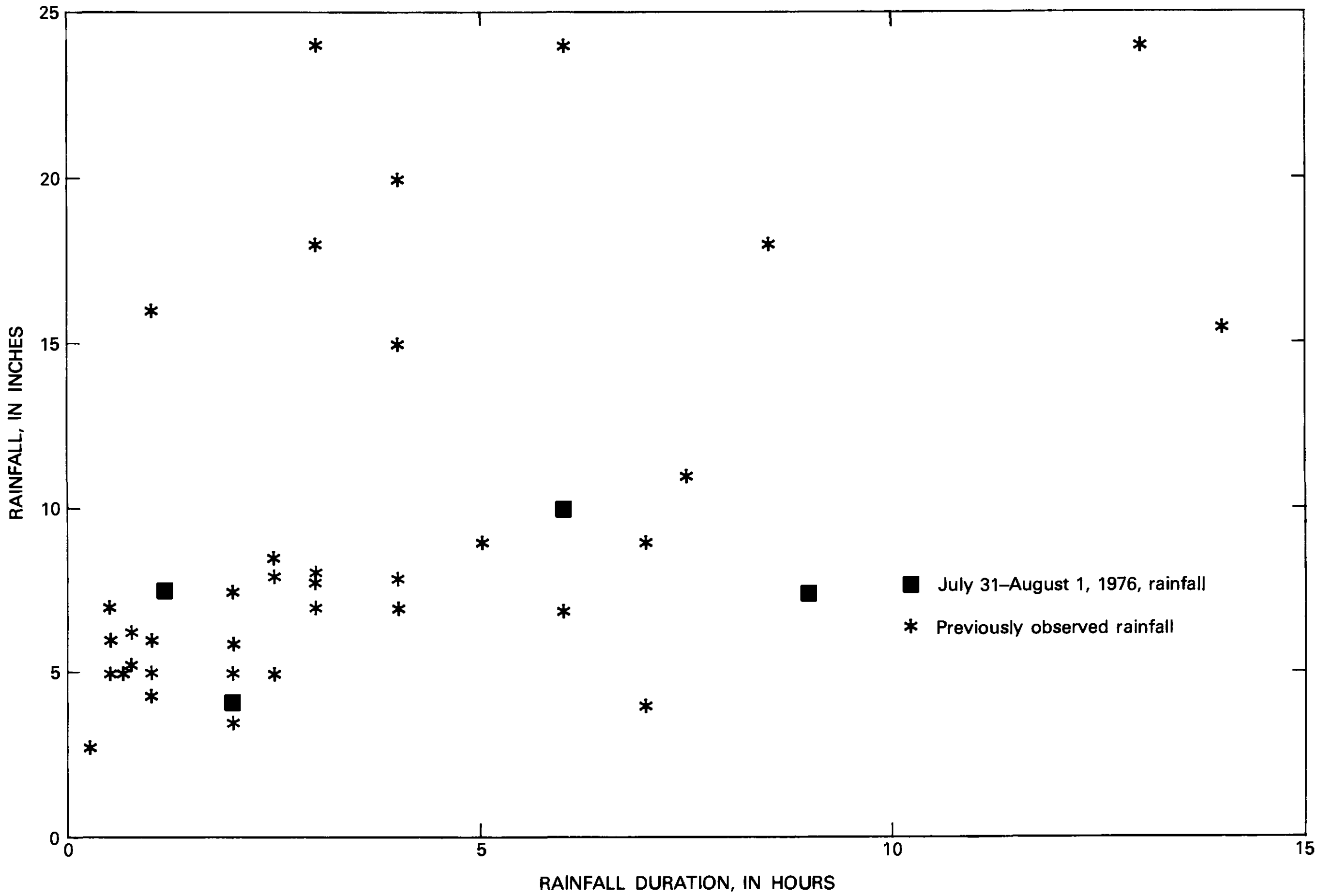


FIGURE 60.—Comparison between July 31-August 1, 1976, rainfalls and previously observed rainfalls in eastern Colorado.

Gage height at indicated time, 1976

Time	Gage height (ft)	Time	Gage height (ft)
July 30		*July 31*—Continued	
2400	1.40	2105	1.73
July 31		2130	3.45
0600	1.40	2150	4.95
1200	1.39	2200	5.40
1800	1.39	2210	5.50
1905	1.39		
1915	1.48	2245	5.51
		2300	4.95
1935	1.46	2315	2.55
1955	1.69	2400	1.34
2010	1.56	*August 1*	
2030	1.60	Gage intakes	
2055	2.02	plugged	

SITE 4: DRY GULCH NEAR ESTES PARK, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°24'22", long 105°28'37", in NE¼NE¼ sec. 17, T. 5 N., R. 72 W., Larimer County, 2.2 mi upstream from U.S. Highway 34, and 2.2 mi northeast of Estes Park.

Drainage area.—2.00 mi^2.

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July-August 1976: Discharge, 3,210 ft^3/s about 2215 MDT July 31.

SITE 5: DRY GULCH AT ESTES PARK, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°22'42", long 105°29'15", in NE¼NW¼ sec. 29, T. 5 N., R. 72 W., Larimer County, 1,000 ft upstream from mouth, 0.9 mi east of Estes Park, at U.S. Highway 34 bridge over Dry Gulch.

Drainage area.—6.12 mi^2.

Discharge record.—Peak discharge by computation of flow through culvert.

Maximum.—July-August 1976: Discharge, 4,460 ft^3/s about 2230 MDT July 31.

SITE 6: BIG THOMPSON RIVER BELOW ESTES PARK, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°22'59", long 105°28'11", in NE¼SW¼ sec. 21, T. 5 N., R. 72 W., Larimer County, 0.4 mi upstream from Loveland Heights, 1.2 mi downstream from Olympus Dam, and 2 mi east of Estes Park.

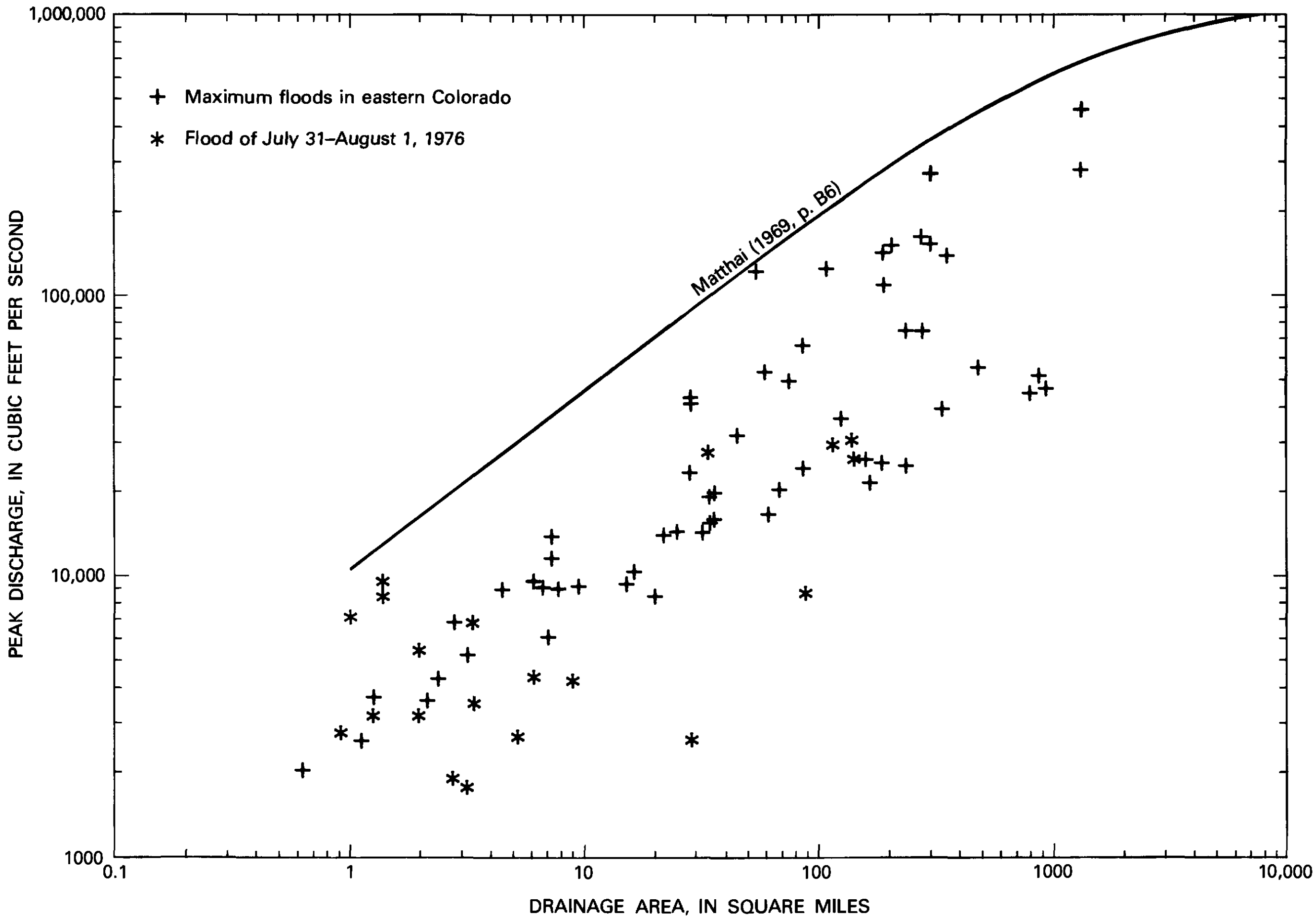


FIGURE 61.—Relation of peak discharge to drainage area for flood of July 31-August 1, 1976, and previous maximum floods.

Drainage area.—164 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 4,330 ft³/s about 2300 MDT July 31.

SITE 7: BIG THOMPSON RIVER TRIBUTARY BELOW LOVELAND HEIGHTS, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°23'44", long 105°27'34", in SE¼SE¼ sec. 16, T. 5 N., R. 72 W., Larimer County, 0.4 mi upstream from mouth, 0.5 mi northeast of Loveland Heights, and 2.5 mi east of Estes Park.
Drainage area.—1.37 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 8,700 ft³/s July 31.

SITE 8: DARK GULCH AT GLEN COMFORT, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°23'44", long 105°26'17", in SW¼ sec. 14, T. 5 N., R. 72 W. (unsurveyed), Larimer County, 800 ft upstream from mouth, 800 ft north of Glen Comfort, and 3.5 mi east of Estes Park.
Drainage area.—1.00 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 7,210 ft³/s July 31.

SITE 9: NOELS DRAW AT GLEN COMFORT, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°23'25", long 105°26'00", in NE¼NW¼ sec. 23, T. 5 N., R. 72 W., Larimer County, 1,100 ft upstream from mouth, 0.3 mi south of Glen Comfort, and 3.8 mi east of Estes Park.
Drainage area.—3.37 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 6,910 ft³/s July 31.

SITE 10: RABBIT GULCH NEAR DRAKE, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°24'23", long 105°24'17", in NE¼NE¼ sec. 13, T. 5 N., R. 72 W. (unsurveyed), Larimer County, 300 ft upstream from mouth, 5.5 mi northeast of Estes Park, and 4.0 mi southwest of Drake.
Drainage area.—3.41 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 3,540 ft³/s July 31.

SITE 11: LONG GULCH NEAR DRAKE, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°24'46", long 105°24'04", in SW¼ sec. 7, T. 5 N., R. 71 W., Larimer County, 1,200 ft upstream from mouth, 5.8 mi northeast of Estes Park, and 3.7 mi southwest of Drake.
Drainage area.—1.99 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 5,500 ft³/s July 31.

SITE 12: BIG THOMPSON RIVER ABOVE DRAKE, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°25'39", long 105°20'37", in SW¼ sec. 3, T. 5 N., R. 71 W., Larimer County, 0.66 mi upstream of confluence with North Fork Big Thompson River in Drake, and 9 mi northeast of Estes Park.
Drainage area.—189 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 28,200 ft³/s about 2100 MDT July 31.

SITE 13: NORTH FORK BIG THOMPSON RIVER AT GLEN HAVEN, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°27'17", long 105°27'05", in NE¼SW¼ sec. 27, T. 6 N., R. 72 W., Larimer County, 0.1 mi upstream from Fox Creek, 0.2 mi northwest of Glen Haven, and 5.7 mi northeast of Estes Park.
Drainage area.—18.5 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 888 ft³/s July 31.

SITE 14: FOX CREEK AT GLEN HAVEN, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°27'17", long 105°27'13", in NE¼SW¼ sec. 27, T. 6 N., R. 72 W., Larimer County, 0.2 mi upstream from mouth, 0.3 mi west of Glen Haven, and 5.7 mi northeast of Estes Park.
Drainage area.—7.18 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 1,300 ft³/s July 31.

SITE 15: WEST CREEK NEAR GLEN HAVEN, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°26'32", long 105°27'40", in SE¼ sec. 33, T. 6 N., R. 72 W. (unsurveyed), Larimer County, 0.2 mi upstream from mouth, 1.0 mi southwest of Glen Haven, and 4.6 mi northeast of Estes Park.
Drainage area.—23.1 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge 2,320 ft³/s July 31.

SITE 16: DEVILS GULCH NEAR GLEN HAVEN, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°26'24", long 105°27'31", in SE¼ sec. 33, T. 6 N., R. 72 W. (unsurveyed), Larimer County, 600 ft upstream from mouth, 1.1 mi south of Glen Haven, and 4.5 mi northeast of Estes Park.
Drainage area.—0.91 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 2,810 ft³/s July 31.

SITE 17: NORTH FORK BIG THOMPSON RIVER TRIBUTARY NEAR GLEN HAVEN, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°27'14", long 105°26'04", in NW¼SE¼ sec. 26, T. 6 N., R. 72 W., Larimer County, 300 ft upstream from mouth, 0.8 mi east of Glen Haven, and 5.7 mi northeast of Estes Park.
Drainage area.—1.38 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 9,670 ft³/s July 31.

SITE 18: BLACK CREEK NEAR GLEN HAVEN, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°28'04", long 105°25'28", in SE¼ sec. 23, T. 6 N., R. 72 W. (unsurveyed), Larimer County, 0.2 mi upstream from mouth, 1.6 mi northeast of Glen Haven, and 7 mi northeast of Estes Park.
Drainage area.—3.17 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 1,990 ft³/s about 2300 MDT July 31.

SITE 19: MILLER FORK NEAR GLEN HAVEN, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°27'47", long 105°25'13", in NW¼NW¼ sec. 25, T. 6 N., R. 72 W., Larimer County, 0.3 mi downstream from Black Creek, 0.4 mi upstream from mouth, 1.6 mi east of Glen Haven, and 7.0 mi northeast of Estes Park.
Drainage area.—13.9 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 2,060 ft³/s about 2300 MDT on July 31.

SITE 20: NORTH FORK BIG THOMPSON RIVER TRIBUTARY NEAR DRAKE, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°26'55", long 105°24'11", in NW¼ sec. 31, T. 6 N., R. 71 W. (unsurveyed), Larimer County, 0.8 mi upstream from mouth, 2.4 mi east of Glen Haven, and 3.5 mi northwest of Drake.
Drainage area.—1.26 mi².
Discharge record.—Peak discharge by slope-area measurement.
Maximum.—July-August 1976: Discharge, 3,240 ft³/s July 31.

SITE 21: 06736000 NORTH FORK BIG THOMPSON RIVER AT DRAKE, COLO.

Location.—Lat 40°26'00", long 105°20'18", in NW¼ sec. 3, T. 5 N., R. 71 W., Larimer County, 400 ft upstream from mouth at Drake.
Drainage area.—85.1 mi².
Gage-height record.—Water-stage recorder graph furnished by Colorado Division of Water Resources. Stage record unusable after 2300 MDT, July 31, because gage intakes were plugged by sediment. Altitude of gage is 6,170 ft from topographic map.
Discharge record.—Stage-discharge relation extended above 1,580 ft³/s on basis of slope-area measurement made at site 1.6 mi upstream.

Maxima.—July-August 1976: Discharge, 8,710 ft³/s 2140 MDT July 31 (gage height, 9.21 ft).

1947 to June 1976: Discharge, 1,290 ft³/s June 16, 1965 (gage height, 5.66 ft).

Gage height and discharge at indicated time, 1976

Time	Gage height (ft)	Discharge (ft³/s)	Time	Gage height (ft)	Discharge (ft³/s)
July 30			*July 31*—Continued		
2400	3.78	42	2030	5.30	925
July 31			2050	7.00	3,000
0600	3.74	38	2100	8.40	6,000
1200	3.72	36	2110	8.66	6,780
1600	3.71	35	2135	8.38	5,940
1700	3.72	36			
1745	3.77	41	2140	9.21	8,710
			2150	9.09	8,260
1820	3.76	40	2210	9.08	8,230
1855	3.80	44	2245	8.24	5,520
1900	4.17	132	2300	8.05	5,100
1910	4.65	440	Gage intakes plugged about 2300 on July 31.		
1950	5.03	704			
2025	5.14	792			

SITE 22: BIG THOMPSON RIVER BELOW DRAKE, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°25'52", long 105°19'37", in NE¼ sec. 3, T. 5 N., R. 71 W. (unsurveyed), 0.6 mi downstream from North Fork Big Thompson River, 0.6 mi east of Drake, and 3.4 mi northwest of Cedar Cove.

Drainage area.—276 mi².

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July-August 1976: Discharge, 30,100 ft³/s July 31.

SITE 23: 06738000 BIG THOMPSON RIVER AT MOUTH OF CANYON, NEAR DRAKE, COLO.

Location.—Lat 40°25'18", long 105°13'34", in SW¼SW¼ sec. 3, T. 5 N., R. 70 W., Larimer County, on right bank at mouth of canyon, 400 ft upstream from Handy Ditch diversion dam, and 6.0 mi east of Drake.

Drainage area.—305 mi².

Gage-height record.—Water-stage recorder graph furnished by Colorado Division of Water Resources. Gage was destroyed by flood; but one observed stage was obtained at 2110 MDT, and the peak stage which occurred at 2140 MDT was obtained by leveling to high-water marks. Datum of gage is 5,297.47 ft above mean sea level (levels by U.S. Bureau of Reclamation).

Discharge record.—Stage-discharge relation extended above 2,310 ft³/s on basis of slope-area measurement.

Maxima.—July-August 1976: Discharge, 31,200 ft³/s 2140 MDT July 31 (gage height, 19.7 ft from floodmarks).

1887-92, 1895-1903, 1926-33, 1938-49, 1951 to June 1976: Discharge, 7,600 ft³/s July 19, 1945 (gage height, 7.55 ft, site and datum then in use). A peak discharge of 8,000 ft³/s was recorded at a site 5 mi up stream on July 31, 1919.

Gage height and discharge at indicated time, 1976

Time	Gage height (ft)	Discharge (ft³/s)	Time	Gage height (ft)	Discharge (ft³/s)
July 30			*July 31*—Continued		
2400	1.76	104	2015	1.74	99
July 31			2050	1.76	104
0600	1.72	95	2110	9.0	5,500
1200	1.69	89	2140	19.7	31,200
1800	1.68	87	Gage destroyed		
1930	1.68	87			

SITE 24: BIG THOMPSON RIVER BELOW GREEN RIDGE GLADE, NEAR LOVELAND, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°25'05", long 105°12'02", in NW¼NE¼ sec. 11, T. 5 N., R. 70 W., Larimer County, 2,300 ft downstream from mouth of Green Ridge Glade, 2,200 ft upstream from bridge on U.S. Highway 34, and 6.5 mi west of Loveland.

Drainage area.—311 mi².

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July-August 1976: Discharge, 27,000 ft³/s July 31.

SITE 25: REDSTONE CREEK NEAR MASONVILLE, COLO.
(MISCELLANEOUS SITE)

Location.—Lat 40°30'19", long 105°11'49", in NW¼NE¼ sec. 11, T. 6 N., R. 70 W., Larimer County, 50 ft downstream from Hansen Canal crossing, 3.4 mi southwest of Spring Canyon Dam, and 1.5 mi northeast of Masonville.

Drainage area.—29.1 mi².

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July-August 1976: Discharge, 2,640 ft³/s August 1.

SITE 26: 06739500 BUCKHORN CREEK NEAR MASONVILLE, COLO.
(DISCONTINUED GAGING-STATION SITE)

Location.—Lat 40°27'15", long 105°11'50", in SE¼ sec. 26, T. 6 N., R. 70 W., Larimer County, on right bank 1.5 mi upstream from Buckhorn Reservoir Dam and 2.5 mi south of Masonville.

Drainage area.—131 mi².

Gage-height record.—Station at site discontinued but water-stage recorder graph for site 1.7 mi downstream furnished by Colorado Division of Water Resources.

Discharge record.—Stage-discharge relation defined by current-meter measurements below 1,300 ft³/s and extended on basis of two slope-area measurements.

Maxima.—July-August 1976: Discharge, 3,400 ft³/s August 1 (gage height, 8.1 ft from floodmarks).

1923, 1938, 1947-June 1976: Discharge, 14,000 ft³/s August 3, 1951 (gage height, 13.40 ft).

SITE 27: LITTLE THOMPSON RIVER NEAR ESTES PARK, COLO.

(MISCELLANEOUS SITE)

Location.—Lat 40°20′06″, long 105°25′48″, in SW¼SW¼ sec. 2, T. 4 N., R. 72 W., Larimer County, 900 ft upstream from mouth of Big Gulch, 0.35 mi south of Meadowdale Ranch, and 5.1 mi southeast of Estes Park.

Drainage area.—2.77 mi².

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July–August 1976: Discharge, 1,940 ft³/s 2130 MDT July 31.

SITE 28: 06744000 BIG THOMPSON RIVER AT MOUTH, NEAR LASALLE, COLO.

Location.—Lat 40°21′00″, long 104°47′04″, in SW¼SE¼ sec. 33, T. 5 N., R. 66 W., Weld County, on left bank just southeast of gage on Evans Town ditch, 0.7 mi upstream from highway bridge, 1.6 mi upstream from mouth, and 4.2 mi west of LaSalle.

Drainage area.—828 mi².

Gage-height record.—Water-stage recorder graph furnished by Colorado Division of Water Resources. Altitude of gage is 4,680 ft from topographic map.

Discharge record.—Stage-discharge relation defined by current-meter measurements.

Maxima.—July–August 1976: Discharge, 2,470 ft³/s 2235 MDT August 1 (gage height, 7.82 ft).

1914–15, 1927 to June 1976: Discharge, 6,100 ft³/s August 4, 1951 (gage height, 7.80 ft at site 0.7 mi downstream at different datum); gage height, 8.70 ft May 9, 1957, present datum.

Gage height and discharge at indicated time, 1976

Time	Gage height (ft)	Discharge (ft³/s)
July 30		
2400	1.61	77
July 31		
0600	1.62	78
1200	1.62	78
1800	1.66	85
2340	1.62	78
2400	1.79	109
August 1		
0030	1.75	102
0600	1.72	96
0735	1.71	94
0820	1.55	67
0900	1.66	85
0920	1.85	120
0940	1.93	135
1000	2.17	184
1100	2.79	344
1200	3.08	430
August 1—Continued		
1300	3.45	559
1400	4.03	798
1500	4.50	1,000
1600	4.93	1,180
1700	5.50	1,410
1800	5.99	1,620
1900	6.42	1,790
2000	7.03	2,030
2100	7.45	2,240
2200	7.74	2,410
2235	7.82	2,470
2300	7.80	2,460
2400	7.66	2,360
August 2		
0100	7.34	2,180
0200	6.99	2,010
0600	4.89	1,170
0800	4.52	1,010
0840	4.43	965

Gage height and discharge at indicated time, 1976—Continued

Time	Gage height (ft)	Discharge (ft³/s)
August 2—Continued		
1000	4.45	975
1020	4.49	995
1100	4.49	995
1200	4.48	990
1700	4.01	789
1800	4.09	825
2100	4.38	946
2400	4.86	1,160
August 3		
0100	5.00	1,220
0200	5.06	1,240
0300	5.05	1,240
0400	4.99	1,210
0600	4.67	1,080
0800	4.50	1,020
1200	4.29	980
1800	3.77	740
2000	3.60	667
2400	3.12	472

SITE 29: DALE CREEK TRIBUTARY NEAR VIRGINIA DALE, COLO.

(MISCELLANEOUS SITE)

Location.—Lat 40°57′36″, long 105°21′39″, in NW¼NW¼ sec. 4, T. 11 N., R. 71 W., Larimer County, 300 ft upstream from mouth, at culvert on U.S. Highway 287, and 0.75 mi northwest of Virginia Dale.

Drainage area.—0.68 mi².

Discharge record.—Peak discharge by computation of flow through culvert.

Maximum.—July–August 1976: Discharge, 727 ft³/s July 31.

SITE 30: DEADMAN CREEK NEAR VIRGINIA DALE, COLO.

(MISCELLANEOUS SITE)

Location.—Lat 40°55′50″, long 105°20′57″, in NE¼NE¼ sec. 16, T. 11 N., R. 71 W., Larimer County, 1,700 ft upstream from mouth, 0.65 mi downstream from U.S. Highway 287, and 1.6 mi south of Virginia Dale.

Drainage area.—23.7 mi².

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July–August 1976: Discharge, 7,400 ft³/s July 31.

SITE 31: STONEWALL CREEK NEAR LIVERMORE, COLO.

(MISCELLANEOUS SITE)

Location.—Lat 40°48′37″, long 105°15′04″, in NE¼NE¼ sec. 29, T. 10 N., R. 70 W., Larimer County, 0.65 mi upstream from mouth, 1.6 mi downstream from North Poudre Ditch crossing, and 2.2 mi northwest of Livermore.

Drainage area.—31.9 mi².

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July–August 1976: Discharge, 3,470 ft³/s July 31.

SITE 32: LONE PINE CREEK NEAR LIVERMORE, COLO.

(MISCELLANEOUS SITE)

Location.—Lat 40°47′44″, long 105°17′24″, in NW¼NE¼ sec. 36, T. 10 N., R. 71 W., Larimer County, 50 ft downstream from irrigation ditch diversion, 2.2 mi upstream from mouth, and 3.9 mi west of Livermore.

Drainage area.—86.3 mi^2.

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July-August 1976: Discharge, 2,590 ft^3/s July 31.

SITE 33: NORTH FORK CACHE LA POUDRE RIVER AT LIVERMORE, COLO.

(DISCONTINUED GAGING-STATION SITE)

Location.—Lat 40°47′15″, long 105°15′08″, in SW¼SE¼ sec. 32, T. 10 N., R. 70 W., Larimer County, 1,000 ft upstream from bridge on State Highway 200, and 2.0 mi west of Livermore.

Drainage area.—539 mi^2.

Discharge record.—Peak discharge by slope-area measurement.

Maxima.—July-August 1976: Discharge, 9,460 ft^3/s July 31.

1904, 1929-31: Discharge, 20,000 ft^3/s May 20, 1904.

SITE 34: 06752000 CACHE LA POUDRE RIVER AT MOUTH OF CANYON, NEAR FORT COLLINS, COLO.

Location.—Lat 40°39′52″, long 105°13′26″, in NW¼ sec. 15, T. 8 N., R. 70 W., Larimer County, on left bank at mouth of canyon, 0.5 mi downstream from headgate of Poudre Valley Canal, 1.2 mi upstream from Lewstone Creek, and 9.3 mi northwest of courthouse in Fort Collins.

Drainage area.—1,056 mi^2.

Gage-height record.—Water-stage recorder graph furnished by Colorado Division of Water Resources. Altitude of gage is 5,220 ft from topographic map.

Discharge record.—Stage-discharge relation defined by current-meter measurements to 3,800 ft^3/s and extended on basis of slope-area measurement.

Maxima.—July-August 1976: Discharge, 7,340 ft^3/s 0130 MDT August 1 (gage height, 7.86 ft).

1882 to June 1976: Maximum discharge not determined, occurred May 20, 1904; maximum discharge determined, 21,000 ft^3/s June 9, 1891, caused by failure of Chambers Lake Dam.

Gage height and discharge at indicated time, 1976

Time	Gage height (ft)	Discharge (ft^3/s)
July 30		
2400	2.35	252
July 31		
0500	2.34	248
1000	2.35	252
1200	2.38	266
1800	2.40	275
2030	2.40	275
2150	2.45	300
2210	2.45	300
2300	2.68	428
2400	3.34	912
August 1		
0100	7.02	5,820
0130	7.86	7,340
0200	6.77	5,380
0300	5.58	3,480
0400	4.27	1,790
0600	3.53	1,070
0800	3.29	872
1000	3.21	808
1200	3.15	760
1400	3.12	736

Gage height and discharge at indicated time, 1976—Continued

Time	Gage height (ft)	Discharge (ft3/s)
August 1—Continued		
1600	3.10	720
1830	3.09	712
1900	3.10	720
2000	3.20	800
2200	3.75	1,260
2330	3.91	1,410
2400	3.92	1,420
August 2		
0200	3.87	1,370
0400	3.82	1,330
0500	3.82	1,330
0700	3.83	1,340
0800	3.83	1,340
August 2—Continued		
0840	4.95	2,620
0920	4.93	2,590
1000	4.13	1,630
1200	3.98	1,480
1400	4.00	1,500
1520	4.00	1,500
1600	3.65	1,180
1800	3.63	1,160
2000	3.62	1,150
2200	3.61	1,140
2315	3.22	816
2400	3.21	808

SITE 35: RIST CANYON NEAR BELLVUE, COLO.

(MISCELLANEOUS SITE)

Location.—Lat 40°37′43″, long 105°12′44″, in SE¼SE¼ sec. 27, T. 8 N., R. 70 W., Larimer County, 1,000 ft upstream from bridge on county road, and 2.0 mi west of Bellvue.

Drainage area.—5.27 mi^2.

Discharge record.—Peak discharge by slope-area measurement.

Maximum.—July-August 1976: Discharge, 2,710 ft^3/s 0030 MDT August 1.

SITE 36: 06752260 CACHE LA POUDRE RIVER AT FORT COLLINS, COLO.

Location.—Lat 40°35′17″, long 105°04′08″, in NE¼SW¼ sec. 12, T. 7 N., R. 69 W., Larimer County, on left bank 150 ft downstream from Lincoln Avenue Bridge, and 2,200 ft east of intersection of College Avenue (U.S. Highway 287) and Mountain Avenue in Fort Collins.

Drainage area.—1,129 mi^2.

Gage-height record.—Water-stage recorder graph. Altitude of gage is 4,940 ft from topographic map.

Discharge record.—Stage-discharge relation defined to 1,250 ft^3/s by current-meter measurements and extended on basis of slope-area measurement.

Maxima.—July-August 1976: Discharge, 5,700 ft^3/s 0430 MDT August 1 (gage height, 8.84 ft).

April 1975 to June 1976: Discharge, 2,200 ft^3/s June 19, 1975 (gage height, 5.93 ft).

Gage height and discharge at indicated time, 1976

Time	Gage height (ft)	Discharge (ft^3/s)
July 30		
2400	2.11	62
July 31		
0100	2.00	46
0200	1.91	31
0300	1.90	30
0400	2.00	44
0500	2.00	44
July 31—Continued		
0600	2.00	44
0700	1.96	38
0800	1.94	35
0900	1.95	36
1000	1.95	36
1100	1.96	38
1200	2.04	50

Gage height and discharge at indicated time, 1976—Continued

Time	Gage height (ft)	Discharge (ft3/s)
July 31—Continued		
1300	2.02	47
1400	2.02	47
1500	2.02	47
1600	2.01	45
1700	2.03	48
1800	2.07	55
1900	2.08	57
2000	2.09	59
2100	2.10	61
2200	2.11	62
2300	2.11	62
2400	2.19	79
August 1		
0100	2.38	126
0200	2.30	105
0300	7.67	3,940
0400	8.35	4,920
0430	8.84	5,700
0500	8.32	4,870
0600	6.77	2,920
0700	5.13	1,440
0800	4.54	1,020
0900	4.14	790
1000	3.87	665
1100	3.47	485
1200	3.53	510
1300	3.35	434
1400	3.10	346
1500	3.00	310
1600	2.66	206
1700	2.45	141
1800	2.59	185
1900	2.58	182

Time	Gage height (ft)	Discharge (ft3/s)
August 1—Continued		
2000	2.58	182
2100	2.69	213
2200	3.75	610
2300	4.59	1,050
2400	4.61	1,060
August 2		
0100	4.51	1,000
0200	4.43	956
0300	4.37	920
0400	4.26	854
0500	4.23	836
0600	4.22	836
0700	4.38	926
0800	4.49	992
0900	4.55	1,030
1000	4.39	932
1100	5.22	1,510
1200	4.65	1,130
1300	4.19	878
1400	4.11	836
1500	3.87	735
1600	3.92	755
1700	3.63	630
1800	3.49	580
1900	3.07	426
2000	2.91	374
2100	2.82	346
2200	2.59	280
2300	2.13	164
2400	2.00	135

SITE 37: 06752500 CACHE LA POUDRE RIVER NEAR GREELEY, COLO.

Location.—Lat 40°25'04", long 104°38'22", in NW¼ sec. 11, T. 5 N., R. 65 W., Weld County, on right bank 25 ft downstream from highway bridge, 2.9 mi east of courthouse in Greeley, and 3.0 mi upstream from mouth.

Drainage area.—1,877 mi^2.

Gage-height record.—Water-stage recorder graph furnished by Colorado Division of Water Resources. Altitude of gage is 4,610 ft from topographic map.

Discharge record.—Stage-discharge relation defined by current-meter measurements.

Maxima.—July-August 1976: Discharge, 1,600 ft^3/s 0030 MDT August 2 (gage height, 5.62 ft).

1903-4, 1914-19, 1924 to June 1976: Daily discharge, 4,220 ft^3/s June 24, 26, 1917.

Gage height and discharge at indicated time, 1976

Time	Gage height (ft)	Discharge (ft^3/s)
July 31		
2400	1.95	28

Time	Gage height (ft)	Discharge (ft^3/s)
August 1		
0135	1.98	31
0715	1.93	27

Gage height and discharge at indicated time, 1976—Continued

Time	Gage height (ft)	Discharge (ft3/s)
August 1—Continued		
0800	2.05	38
0900	2.02	35
1230	2.09	42
1345	2.07	40
1410	2.08	41
1540	2.02	35
1700	2.01	34
1800	4.02	560
1830	4.27	676
1900	4.33	709
2000	4.44	764
2100	4.64	872
2200	4.82	980
2215	5.40	1,400
2300	5.52	1,500
2400	5.58	1,550
August 2		
0030	5.62	1,580
0200	5.39	1,400
0400	4.83	986
0600	4.49	786

Time	Gage height (ft)	Discharge (ft3/s)
August 2—Continued		
0800	4.26	660
1000	4.07	565
1130	3.99	529
1200	4.00	534
1400	4.66	926
1600	5.03	1,120
1800	5.17	1,220
2000	5.18	1,230
2200	5.18	1,230
2400	5.26	1,290
August 3		
0200	5.32	1,340
0300	5.31	1,330
0400	5.21	1,250
0600	4.77	950
0800	4.38	726
1200	3.92	502
1600	3.62	380
2000	3.42	311
2400	3.30	272

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Part B.
Geologic and Geomorphic Effects in the Big Thompson Canyon Area, Larimer County

By RALPH R. SHROBA, PAUL W. SCHMIDT, ELEANOR J. CROSBY,
and WALLACE R. HANSEN
of the U.S. GEOLOGICAL SURVEY

With a section on

DAMAGE CAUSED BY GEOLOGICAL PROCESSES DURING FLOOD PRODUCING STORMS

By JAMES M. SOULE *of the* COLORADO GEOLOGICAL SURVEY

STORM AND FLOOD OF JULY 31-AUGUST 1, 1976, IN THE BIG THOMPSON RIVER AND CACHE LA POUDRE RIVER BASINS, LARIMER AND WELD COUNTIES, COLORADO

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GEOLOGIC AND GEOMORPHIC EFFECTS IN THE BIG THOMPSON CANYON AREA, LARIMER COUNTY

By RALPH R. SHROBA, PAUL W. SCHMIDT, ELEANOR J. CROSBY, *and* WALLACE R. HANSEN,
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ABSTRACT

Intense rainfall from the Big Thompson thunderstorm complex on the evening of July 31, 1976, and the ensuing floods that evening and the following day led to widespread erosive and depositional effects along the Big Thompson River and its tributaries. Because of the intensity of the rainfall and the steepness of the terrain, runoff quickly reached flood stage.

The storm was centered over rugged country. Mountain tops are as much as 3,000 ft (feet) above stream level, and the canyon walls are commonly as steep as 80 percent (40°). Cliffs are common. The canyon is cut mostly into Precambrian metamorphic and igneous rocks, and stream gradients are closely related to the erosive resistance of the rocks. The steepest reaches are across resistant pegmatite; the flattest are across broad fault zones. Fault zones, in places, also control the trend of drainage. On the Great Plains the Big Thompson River crosses rocks of Paleozoic and Mesozoic age mantled with Quaternary deposits, and the gradient flattens accordingly. In general, the river is at grade on the plains but not in the mountains.

The flood responded markedly to changes in gradient. Reaches steeper than 2 percent generally were scoured, especially on the outsides of bends and where the channel was constricted. Basically, the main channel was scoured throughout its length, but outside the main channel deposition took place where the gradient flattened to less than 2 percent, especially at wide places on the flood plain and on the insides of bends, where point bars formed. Large boulder-gravel bars diverted the river from its preflood channel, notably at the community of Drake, and deposition was intensified where the flow was impeded by bridges, buildings, or vegetation. Boulders as large as 7 ft in intermediate diameter were deposited in bars. The largest boulder apparently moved by the flood measured about 12×12×23 ft and weighed an estimated 275 tons.

Lateral scour was most pronounced at the outsides of bends; in general, highway damage was greatest at such places. At The Narrows at the mouth of Big Thompson Canyon, scouring floodwater rose 14 ft above the preflood level, and obliterated 1.9 miles of highway.

Downstream from the mouth of the canyon, overbank deposition was the chief geologic effect of the flood, although scour was appreciable at the outsides of bends and in the main channel. Overbank deposits of sand and silt decreased in thickness and grain size from the canyon mouth to the South Platte River. Local deposits of gravel and cobbles were reworked from the preflood riverbed and banks. Buoyant debris was abundant. Croplands were damaged by deposits of silt and sand.

Along the tributaries, geologic effects were confined largely to the zone of intense downpour, chiefly to places within the 6-in. (inch) isohyet and, foremost, within the 10-in. isohyet. Sheetflooding on hillslopes locally removed as much as a foot of soil and left pebbly to bouldery lag deposits. Locally, boulders were transported down slopes by sheetflooding and were redeposited on gentler slopes. Thickly grassed open slopes resisted sheet erosion rather well, but gullying quickly cut through the soil where the grass had been worn thin along dirt roads and trails. Sparsely covered slopes in pine forests were vulnerable to sheetflooding.

Along minor drainageways, channelized runoff commonly scoured down to bedrock, then deposited debris flows or debris fans where reduced gradients lowered the competence of the floodwater. Some major tributaries dumped their loads into the main stem where the load was either deposited as an obstructing bar or was carried off by the flood. In places the Big Thompson River and the North Fork were forced laterally out of their preflood channels by swollen tributaries.

Debris slides, debris flows, debris avalanches, rock slides, and rock falls were set off in the intense-downpour area. Saturation of the soil was the chief cause, but some landslides were caused by lateral undercutting.

Many homes and other buildings were lifted off their foundations and were carried away by the flood. Some of these collapsed with nearly explosive force. Some buildings that remained in place were partly filled with sediment and were damaged by impact from floating and saltating debris. Massive piles of buoyant debris accumulated against trees and buildings. Trees, bushes, and even grasses acted as natural sediment traps.

Historic, climatologic, hydrologic, and geologic evidence indicates that other drainage basins along the east slope of the Front Range are no less vulnerable than the Big Thompson River basin to catastrophic flooding in the future.

INTRODUCTION

Mountain flooding is not uncommon in the Front Range of Colorado, and previous floods have also produced marked geologic and geomorphic changes. No previous historic Front Range flood, however, has involved so much erosion and material transport, and never before has a Front Range storm of such magnitude afforded such an opportunity for study and documentation. Centered over Big Thompson Canyon and its North Fork between Estes Park and Drake (pl. 1), uncommonly heavy rains falling on steep slopes led to very rapid runoff, high flow velocities and flood peaks, widespread geologic and geomorphic changes, heavy property damages, and high mortality among canyon residents and visitors. Maximum rainfall intensity was about 10 in. in less than 4 hours (hrs). An estimated 6 in. fell at Glen Haven in about 45 minutes (min), and a total of 12 in. fell in 48 hrs. (See Part A, fig. 44.) Hydrologic measurements at the canyon mouth indicate a recurrence interval of about 200 yrs. Small tributary basins had discharges unequalled in the records of Colorado flood history, and flow velocities reached about 10-30 ft/s (Part A, table 4). With such intensities of rainfall and runoff, widespread geologic-geomorphic effects were inevitable.

Coming on a weekend during the peak of the summer vacation season—with an estimated 2,500 people in the canyon—the Big Thompson flood caught hundreds of residents, campers, and tourists with virtually no warning. It left 139 known dead and, at this writing, 5 persons unaccounted for.

Although a detailed discussion of the socioeconomic impact of the Big Thompson storm is outside the scope of this report, it was of great concern to many people, and we would be remiss not to note briefly some of the costs. The economic losses were severe, amounting to an estimated \$35.5+ million.[1] Tables prepared by the U.S. Army Corps of Engineers, Omaha District (James W. Ray, letter dated Dec. 30, 1976), list financial losses caused by the Big Thompson storm in various categories.

Most of the damage in the public sector was to highways, roads, and bridges; whereas most of the private damage befell individuals and small businesses. A damage survey by Larimer County indicated that 252 structures, mostly dwelling units, were damaged beyond repair (damaged more than 50 percent—condemned and demolished); 242 structures were damaged to the extent of less than 50 percent and, therefore, were declared eligible for repair. The U.S. Army Corps of Engineers awarded contracts for the removal of 319,863 yd^3 of debris, 93 propane tanks, and 197 automobiles. Debris included flotsam as well as structures that were damaged beyond salvage and had to be demolished.

[1]Even so, property damages from the Big Thompson flood were far less than from some previous floods. The storm of June 14-17, 1965, over the South Platte River basin cost an estimated \$508.2 million in damages, about 75 percent of which occurred in the Greater Denver Area (Matthai, 1969, p. B31). The storm of May 5-6, 1973, in the Greater Denver Area (Hansen, 1973; Ducret and Hansen, 1973) cost an estimated \$50 million.

GRAIN SIZES OF SEDIMENTS

Grain sizes of sand, gravel, and so forth noted in this report are based mostly on visual estimates or field measurements rather than on laboratory measurements. Because of the extreme heterogeneity of most of the flood deposits, precise laboratory measurements of small samples, in fact, could yield misleading results. Our field nomenclature for these materials is modified from the widely used United Soil Classification System adopted by the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers as follows:

<table>
<tr><th colspan="9">SIEVE NO. (OPENINGS PER INCH)</th><th colspan="5">INCHES</th></tr>
<tr><td></td><td colspan="2">200</td><td colspan="2">40</td><td colspan="2">10</td><td colspan="2">4</td><td colspan="2">3</td><td colspan="2">12</td><td></td></tr>
<tr><td colspan="2">clay and silt</td><td colspan="2">fine sand</td><td colspan="2">medium sand</td><td colspan="2">coarse sand</td><td colspan="2">pebble gravel</td><td colspan="2">cobble gravel</td><td colspan="2">boulder gravel</td></tr>
</table>

CONVERTING ENGLISH UNITS TO METRIC

With the passage by Congress of the Metric Conversion Act of 1975, agencies of the United States Government, nearly all scientific and research organizations, and many private industrial organizations are rapidly converting measurements from the Customary System of Units (English) to the International System of Units (metric). The Geological Survey has been in the forefront, but inasmuch as many readers of this report probably are not yet comfortable with the International System, customary units are used here.

ACKNOWLEDGMENTS

This report is based on information and assistance from many sources. Local residents and other private individuals, and county, State, and Federal agencies all contributed data and cooperation in the field. We thank the many landowners who permitted access to or through their properties. Sheriff Bob Watson and his staff in Larimer County extended their cooperation, eased access to the devastated areas, and provided much basic information. Helicopter support was provided by the Colorado National Guard, the U.S. Air Force, and private firms. The Colorado Geological Survey cooperated in many ways, both in the field and in the office.

Larry W. Anderson, H. Kit Fuller, William Markovic, and Roderic A. Parnell, Jr., assisted in the field on numerous occasions.

PHYSICAL SETTING OF THE BIG THOMPSON RIVER BASIN AND ITS RELATION TO THE FLOOD

TOPOGRAPHY AND DRAINAGE

The Big Thompson River arises near timberline just below the Continental Divide at an altitude of about 11,000 ft in Rocky Mountain National Park, north-central Colorado (fig. 62). Some of its tributaries arise even higher from small glaciers. The headwaters are rimmed on the west, north, and south by many peaks that stand more than 12,000 ft above mean sea level, including Longs Peak, which at 14,255 ft is the highest summit in the watershed. The Big Thompson River descends about 6,330 ft in 55 mi—as a crow flies—from its sources to its confluence with the South Platte River on the Great Plains at an altitude of about 4,670 ft. The Big Thompson River descends about 3,500 ft in 17 mi as it flows eastward from its source to the town of Estes Park at the west edge of the downpour area of the Big Thompson River flood. Estes Park is about 7,500 ft above sea level and is about 50 mi northwest of Denver (pl. 1). Estes Park is named for a broad grassy mountain valley (or "park") of the same name surrounded by crags and forested mountains. Just downstream from Estes Park the Big Thompson River enters the narrow Big Thompson Canyon. Most of the severe flooding took place in the canyon and its tributary gulches. The east edge of Estes Park and the head of Big Thompson Canyon about coincide with the west edge of the heavy rainstorm that caused the July 31–August 1, 1976, Big Thompson flood (pl. 2*A*).

Three permanent streams, Fish Creek from the south and Fall River and Black Canyon Creek from the northwest, join the Big Thompson just above Estes Lake, which is impounded by Olympus Dam at the east edge of the park. These three streams were not involved in the flood. Dry Gulch, which was heavily involved in the flood, drains into the Big Thompson from the north just below the dam.

Olympus Dam is about 1¾ mi downstream from Estes Park. The dam serves chiefly as a power structure, and its modest reservoir capacity (Lake Estes) was not designed for flood control, especially since the water level must be kept high for power production. Nevertheless, the outlet from the reservoir to the Big Thompson River was closed by the U.S. Bureau of Reclamation at 2055 MDT after the first reports of flooding, and the inflow from the river to the reservoir—about 400 ft^3/s—was diverted to the Olympus tunnel, which bypasses the canyon. Ultimately this inflow was stored east of the mountains at Carter Lake reservoir. The entire inflow of the Big Thompson River above the dam was so diverted during salvage and cleanup operations.

Just east of Lake Estes at Olympus Heights, the river enters Big Thompson Canyon. It emerges from the canyon 20 mi downstream at the mountain front. The North Fork Big Thompson River, the largest tributary within the canyon, arises among the high peaks of the Mummy Range to the northwest (also within Rocky Mountain National Park) and joins the main stem at Drake, about two-thirds of the distance down the canyon. Many smaller gulches and draws join the Big Thompson River and the North Fork in the canyon section, and many of them released exceptional discharges of water during the 1976 flood.

The storm of July 31, 1976, centered over rugged country, and the steepness of the terrain helped promote the rapid runoff that led to the catastrophic flooding. Mountain tops are as much as 2,000–3,000 ft above stream level, and the steep canyon walls commonly have slopes of 40–80 percent (20°–40°); locally, the slopes are much steeper. Slopes of 10 percent or less (about 5°) are exceptional. Along much of Big Thompson Canyon the canyon walls rise directly from the water's edge. Along discontinuous flood plains and at the mouths of large tributaries, the canyon floor is as much as 500 ft wide in some places, but it generally is considerably less. U.S. Highway 34 through Big Thompson Canyon utilized flood-plain surfaces and low terraces where they provided a practical base, but much of the road was constructed on manmade embankments built against the canyon walls. Since the flood the road has been rebuilt in much the same fashion.

From Olympus Dam to the canyon mouth, the Big Thompson River descends more than 2,100 ft in 20 mi (pl. 4). The average gradient in this distance is about 2 percent, or a little more than 100 ft/mi. In the upper third of the canyon, above Waltonia, the gradient is about 1 percent. Downstream from Waltonia it varies locally from as much as 7 percent, to as little as 0.75 percent. On the North Fork, from Devils Gulch near Glen Haven to the main river at Drake, the channel gradient averages about 2 percent. Major tributary gulches that drained the heavy precipitation of July 31, 1976, have higher gradients: 8 percent in Noels Draw, 10 percent in Long Gulch, and 12.5 percent in Dark Gulch. Smaller, shorter gulches and gullies have even steeper gradients.

From Drake downstream to the canyon mouth, Big Thompson Canyon varies from a wide valley localized by faulting to a steep-sided narrow canyon cut into metamorphic rocks. Along this 8-mi stretch, the river drops more than 800 ft, and the gradient ranges from

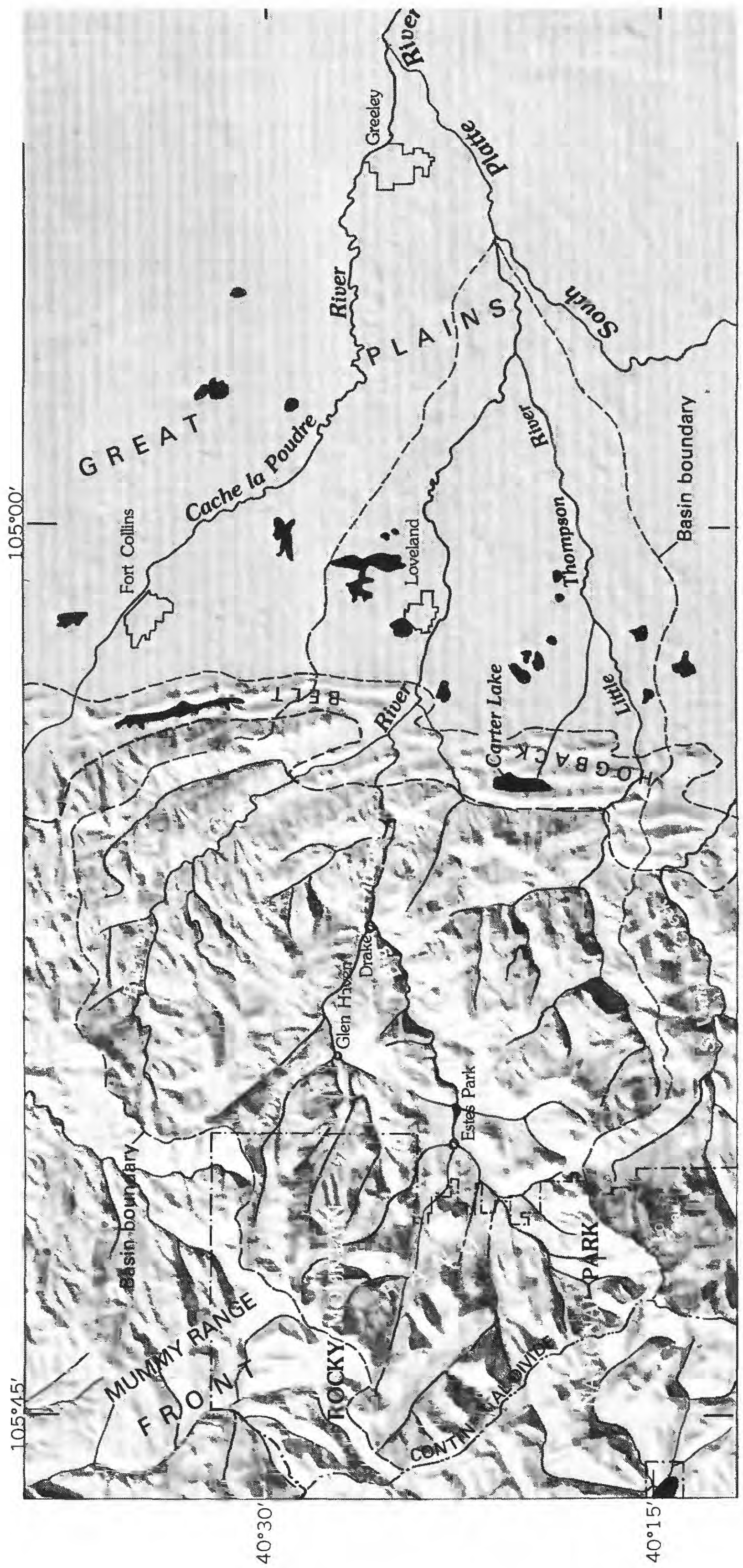


FIGURE 62.—Map showing geomorphic setting of the Big Thompson River drainage basin, north-central Colorado.

less than 1 percent to more than 4 percent. The width of the canyon floor ranges from less than 100 ft to as much as 600 ft. Wide places in the canyon have been much used as building sites. Ease of access is combined with favorable soil conditions for excavating foundations and for installing wells and waste disposal systems. Drake, Midway, and Cedar Cove became focal points for summer and year-around homes and for tourist-oriented businesses, such as motels, restaurants, trailer courts, and shops. About half a mile below Midway, the river had been dammed for a downstream hydroelectric powerplant serving the town of Loveland. Below Cedar Cove some water had been diverted for cropland irrigation.

East of the mountain front, the Big Thompson River flows generally eastward about 35 mi across the Colorado Piedmont section of the Great Plains to its confluence with the South Platte River (pl. 1). Between the mountain front and Loveland, the river crosses a belt of alternate strike valleys and hogback ridges, formed by differential erosion of interlayered soft and hard, tilted strata. This belt, however, has little effect on the behavior of the river; the river crosses it with no significant change of gradient. From the Loveland area to the South Platte, the river flows between discontinuous alluvial terraces on a flood plain that locally is more than a mile wide. The river gradient is about 0.7 percent from the canyon mouth to Loveland and about 0.2 percent (or about 10.6 ft/mi) from Loveland to the South Platte River.

GEOLOGIC FACTORS RELATED TO THE FLOOD

BEDROCK

Bedrock at first thought might seem to have little influence on the behavior of the 1976 flood or its geomorphic effects. Closer inspection indicates clear cause-and-effect relationships—some subtle and some more obvious. Canyon widths are related to the erosive resistance of the bedrock and local base levels; the gradient is related both to the resistance of the bedrock and to the width of the canyon; the velocity and competence of the river in flood, in turn, are closely related to the gradient.

Between its source and its confluence with the South Platte River, the Big Thompson River flows across rocks of widely varied composition and age. The mountainward part of the basin is eroded entirely from crystalline rocks of Precambrian age; the greater part of the canyon, along both the main stem and the North Fork, is cut into a metamorphic complex of gneiss, schist, and migmatite (Tweto, 1976). This complex is intruded by many small stocks of Boulder Creek Granodiorite and is bordered irregularly on the west by a batholith of Silver Plume Granite. In addition, the metamorphic complex is intruded by uncounted pegmatite dikes and lesser plutonic bodies. Pegmatite is especially abundant in the area between Long Gulch, Glen Haven, and Drake.

At the mouth of Big Thompson Canyon the river passes from the Precambrian terrane onto a belt of tilted sedimentary rocks of successively younger Paleozoic and Mesozoic age. This terrane is complicated somewhat by faulting and folding, which cause stratigraphic repetitions across the strike and even bring Precambrian rocks to the surface locally east of the mountain front. From a point just west of Loveland to the South Platte River, the Big Thompson River flows across a thick sequence of gently dipping Upper Cretaceous rocks which, however, are beveled almost flat and are largely concealed by surficial deposits of Quaternary age (Colton, 1978).

The bedrock geology of the Big Thompson area from the hogbacks west of Loveland into the mountains is complicated by abundant faults and shear zones of varied ages, sizes, and orientations. The predominant trend of fractures is northwestward, and many dikes follow that trend also. From Drake east toward the mountain front and down the North Fork from Dunraven Glade, the Big Thompson River and the North Fork cross and recross a broad west-northwest-trending fault zone called the Thompson Canyon fault (Braddock, Calvert, and others, 1970). This zone has been mapped for a distance of about 24 mi (Tweto, 1976). In many places the fault zone and the canyon floor coincide, so the fault zone must have influenced the course of the river. At Cedar Cove the zone probably exceeds 600 ft in width (Braddock, Nutalaya, and others, 1970). Toward the canyon mouth the river swings north away from the zone and passes instead through The Narrows in resistant nearly vertical metasedimentary layers (Braddock, Calvert, and others, 1970).

At the west end of Big Thompson Canyon, a north-northeast-trending fault about 12 mi long borders Estes Park on the east. Dry Gulch, Devils Gulch, and Fish Creek about coincide with its trace. Many other gulches and tributary ravines also coincide with faults in the Big Thompson area and must have been localized by them, through the process of differential erosion.

Between Olympus Dam and river mile 50.5 (miles indicated on pl. *2A*, *2B*, *2C*), the river crosses a large body of granitic rock, mostly of the Silver Plume variety, and the gradient is about 60 ft/mi (pl. 3). At about river mile 48, the river crosses onto a terrane of very resistant pegmatite interlayered with metamorphic rocks. Here, the gradient steepens to about 160 ft/mi; the canyon is constricted and steep sided, and the bed of the river is very bouldery. These conditions persist downstream about to Drake. At and below Drake, and up the North Fork from Drake, the valley bottom coincides with the Thompson Canyon fault, the canyon widens conspicuously, and the gradient flattens. Where the river swings away from the fault, the canyon again constricts and steepens just as noticeably—for example, below Midway, above Cedar Cove, and at The Narrows.

In the wider reaches, the river down through time has built discontinuous flood plains, commonly as much as 500 ft across and locally much wider. The July 31 flood spread out in these bottomlands and deposited much of its load. At Drake the river deposited a huge bar of cobbles and boulders across the old preflood channel; in slacker water it deposited sand and pebble gravel along with a great mismash of tree trunks, branches, lumber, fuel tanks, household items, and parts of demolished buildings. Conversely, scour predominated in the steeper, narrower reaches; for example, 1.9 mi of highway was destroyed at The Narrows when the highway embankment was obliterated (fig. 63). These details are further discussed in subsequent sections.

Subtle effects of bedrock on the degradation and aggradation patterns of the flood extend along the main drainages and up the tributaries. Granitic terrane in Big Thompson Canyon generally has yielded larger and more abundant boulders to erosive processes than metamorphic terrane has, partly because the granite is more massive, and the metamorphic rock tends to be strongly foliated and closely jointed. Consequently, reaches of the river flowing across granite tend to be rougher and more bouldery than reaches flowing across metamorphic rocks.

SURFICIAL DEPOSITS

Surficial deposits greatly influenced the distribution and character of the effects of the flood. To a large extent they determined the sediment yield of the involved streams and, hence, the erosion and sedimentation effects on the whole drainage system.

Surficial deposits mantle bedrock discontinuously throughout the study area. In most places, except in valley bottoms, the surficial mantle is patchy and thin; in many places, bedrock forms cliffs or bold outcrops.

In its headwaters the Big Thompson River crosses deposits laid down by a succession of late Pleistocene glaciers. These glaciers terminated just west of the town of Estes Park where they built massive moraines, but outwash gravel extended on down the canyon and out onto the plains. Down through the years, much of the outwash has been reworked by the Big Thompson River, but patches still remain in the canyon.

In many places in the canyon, hillsides are mantled with soil or with stony sandy colluvium and slope wash to depths of several feet. The colluvium occasionally passes upslope into coarse talus and downslope into alluvium. Loamy soils high in some tributaries, such as Piper Meadows, may have been augmented by eolian deposition. During the July 31, 1976 storm, much saturated colluvium collapsed and moved downslope as small landslides. Also, much colluvium was transported down hillsides and into the drainage courses by sheetflooding, rill erosion, and gullying in countless small channels.

On gently sloping granitic terrane, especially on Silver Plume Granite, prolonged weathering has produced a patchy friable grus and (or) sandy colluvium, commonly 3 ft or more deep, interspersed with rounded outcrops. This kind of regolith is very vulnerable to scour, and it was severely eroded locally on July 31, 1976. Regoliths on metamorphic terranes seemed to have been less vulnerable to scour, but the reasons why are unclear; factors such as rainfall intensity and discharge might have been as important as erodibility.

The floors of most sizeable tributary canyons, gulches, and ravines are bottomed with nearly continuous fills of alluvium and slope wash. Many of these were severely scoured during the storm. Most of them have soil profiles that indicate ages of at least several hundreds of years. The Big Thompson itself flows across a virtually continuous fill of mostly coarse grained bouldery alluvium, which in wide places such as Drake covers several acres. The course of the river, moreover, is bordered by discontinuous gravel terraces, some of which were drastically altered by the flood. Some buildings on terraces or colluvial slopes above the flood were carried away when lateral scour caused the banks to slump.

During the flood, many alluviated tributaries were scoured to bedrock, especially toward their mouths, through old fills as much as 10 ft thick (fig. 70). Although in many places the Big Thompson severely scoured its bed, it rarely uncovered bedrock in the bottom of its channel; but in many places it cut laterally into alluvial terraces, colluvial slopes, and road embankments; and it released many small landslides. As it scoured the channel floor and reworked and redeposited its bedload, its channel shifted from side to side, causing much property damage in the process.

Nearly all large tributaries of the Big Thompson and the North Fork, and many small tributaries, have debris fans at their mouths. (See "Glossary," fig. B.) These fans are the products of multiple episodes of deposition, and most of them are graded to the flood plain or to slightly higher stands of the river. Nearly all of them in the area of heavy downpour were modified by the storm. They were variously entrench-

FIGURE 63.—The Narrows of Big Thompson Canyon, August 2, 1976, after the flood had receded. U.S. Highway 34, obliterated in this section of canyon, had followed the left bank in this view looking upstream. Valley floor here is about 80–100 ft wide.

ed or aggraded by runoff down their own drainages, or they were truncated by the Big Thompson; some fans deflected the course of the Big Thompson. Fans were affected by combinations of four processes: (1) entrenchment, (2) aggradation, (3) truncation by the Big Thompson or the North Fork, and (4) deflection of the Big Thompson or the North Fork. All four processes caused extensive damage.

As in other canyons along the Front Range, debris fans are widely used in the Big Thompson area for building sites. They offer open ground with easy access, but they are vulnerable to flash flooding, and many structures above any conceivable main-stem flood were damaged or destroyed by torrents from minor side gulches.

VEGETATION

Vegetation was important in the Big Thompson storm and flood in two different ways: (1) as ground cover it modified the way the downpour and flooding affected the land surface, and (2) as a large component of the transported debris—trees, logs, limbs, branches, and uprooted shrubs—it modified and even intensified the damage effects. For example, open well-sodded grassy slopes withstood the impact of the storm in the heaviest downpour areas without sustaining serious erosion, but where the grass cover had been broken, as along a dirt road or trail, severe gullying was common. In pine forests, where the ground cover beneath the trees was thin, sheetflooding carried away large amounts of soil; whereas in overbank areas along the major streams, trees and shrubs slowed the current and acted as natural sediment traps. Uprooted vegetation carried along by the flood rammed the sides of buildings, clogged and pushed aside culverts and bridges, and immensely complicated the tasks of salvage and cleanup operations.

The storm and flood straddled the boundary of two major vegetational regions: the plains grassland region and the montane forest (Marr, 1964, p. 36–39). These regions have resulted from climatic differences that in turn are the result of varied physiography and altitude. Thus, the plains grassland coincides with the Colorado Piedmont section of the Great Plains physiographic province, and the montane forest coincides with the lower mountain section (the foothills by some definitions) of the Southern Rocky Mountains (Crosby, 1978). Each of the vegetational regions contain many different plant communities (Marr, 1964, table 1; 1967).

PLAINS GRASSLAND

The plains grassland east of the mountains has been greatly modified in the past hundred years or so by cultivation and grazing. Some of the area inundated by the flood was planted in cash crops, such as corn and sugar beets, but along the banks of the Big Thompson River uncultivated expanses of grassy meadow are interspersed with brush thickets and cottonwood groves; these areas bore the brunt of the flooding east of the mountains. Close to the mountains are isolated trees and local stands of ponderosa pine and Rocky Mountain juniper, some of which—on the banks of the river—were carried away by the flood. Sedimentation predominated over erosion along the flood plain, although there was considerable scour on the outside bends of some meanders. Part of the flotsam carried along and redeposited by the flood was timber uprooted by the river, but part of it was old deadfall material buoyed up and floated off by the current.

MONTANE FOREST

Upstream in the mountains is the montane forest, which is divisible into lower and upper zones (Marr, 1967, p. 25, 39). These zones have distinctive characteristics, but the boundary between them is indistinct. Most of the affected area was in the lower montane forest, which normally extends up to an altitude of about 8,000 ft; ponderosa pine predominates, but this forest varies widely in character, depending on slope aspect, soil moisture, and human use. Climax grassland occupies areas of thick loamy soil in places, such as Piper Meadows. On dry rocky south-facing hillsides Rocky Mountain juniper is interspersed with scattered ponderosa pine (Marr, 1964, p. 38; 1967, p. 27–28). Forest cover is much denser on north-facing than on south-facing slopes. Vegetation is sparse under the trees and does not completely cover the ground. Such bare ground is very vulnerable to sheet erosion.

Along the streamsides and moist valley bottoms are groves of narrow-leaf cottonwood, willow, and river birch; ponderosa pines dot the well-drained gravel terraces. Many of these plants, including trees probably over 100 years old, were ripped out by the 1976 flood. Those that remained standing trapped large quantities of debris. On more northerly exposures, Douglas-fir competes favorably with the pines, extending from river level to the top of the zone in dense and nearly pure stands.

The upper montane forest lies generally above 8,000 ft and, hence, includes only the higher mountain tops in the study area. Douglas-fir predominates. This zone was little damaged by the July 31, 1976 storm.

GEOMORPHIC EVIDENCE OF PAST FLOODING

Geomorphic evidence supports the certainty of intense past flooding and, by inference, the probability of future flooding on Front Range streams. Most canyons along the Front Range, including Big Thompson Canyon, are physiographically similar and have had parallel geologic histories; all share the orographic controls that led to the July 31, 1976, cloudburst. Nearly all Front Range canyons in the lower montane zone (below 8,000 ft) bear evidence of intense channel scour in geologically recent time. Some of this evidence is historic and has involved the destruction of segments of roads and railroad grades. Large debris fans also are common in nearly all canyons in the lower montane zone, and they are clearly the products of torrential runoff; some of them have been modified by historic flash flooding. Morphologically, they are close counterparts of fans that were involved in the 1976 flooding of the Big Thompson. Big Thompson Canyon itself contains many such fans that predate the 1976 flood. Finally, the channels of most Front Range streams contain bouldery flood gravels analogous to those transported and deposited by the Big Thompson flood of 1976.

GEOLOGIC AND GEOMORPHIC EFFECTS OF THE FLOOD

As flooding poured from the tributarties, the Big Thompson rose rapidly toward record discharge. The geologic and geomorphic effects of the 1976 flood are summarized in table 6. Figure 64 is a schematic representation of flood effects in various parts of the Big Thompson Canyon. The surging flood caused widespread changes in channel geometry and in distribution and texture of sediment as the river eroded its banks, scoured new channels, cut off meanders, reworked its bed material, and deposited a vast amount of sediment. The river accomplished more erosion and deposition than it normally does in years, decades, or even longer periods. Many tributaries in the downpour area scoured rapidly down to bedrock through thick surficial fills; total degradation, expressed as transported sediment, was many thousands of cubic yards. James Balog (1977) estimated that the major tributaries in the area of heavy precipitation yielded about 265,000 yd^3 of sediment; this figure omits scour along the main drainages of the Big Thompson and North Fork and scour caused by sheet erosion. Very little bedrock actually was eroded, but because of the removal of surficial material by channel scour and sheet erosion on hillslopes, much bedrock was newly exposed to further weathering and erosion.

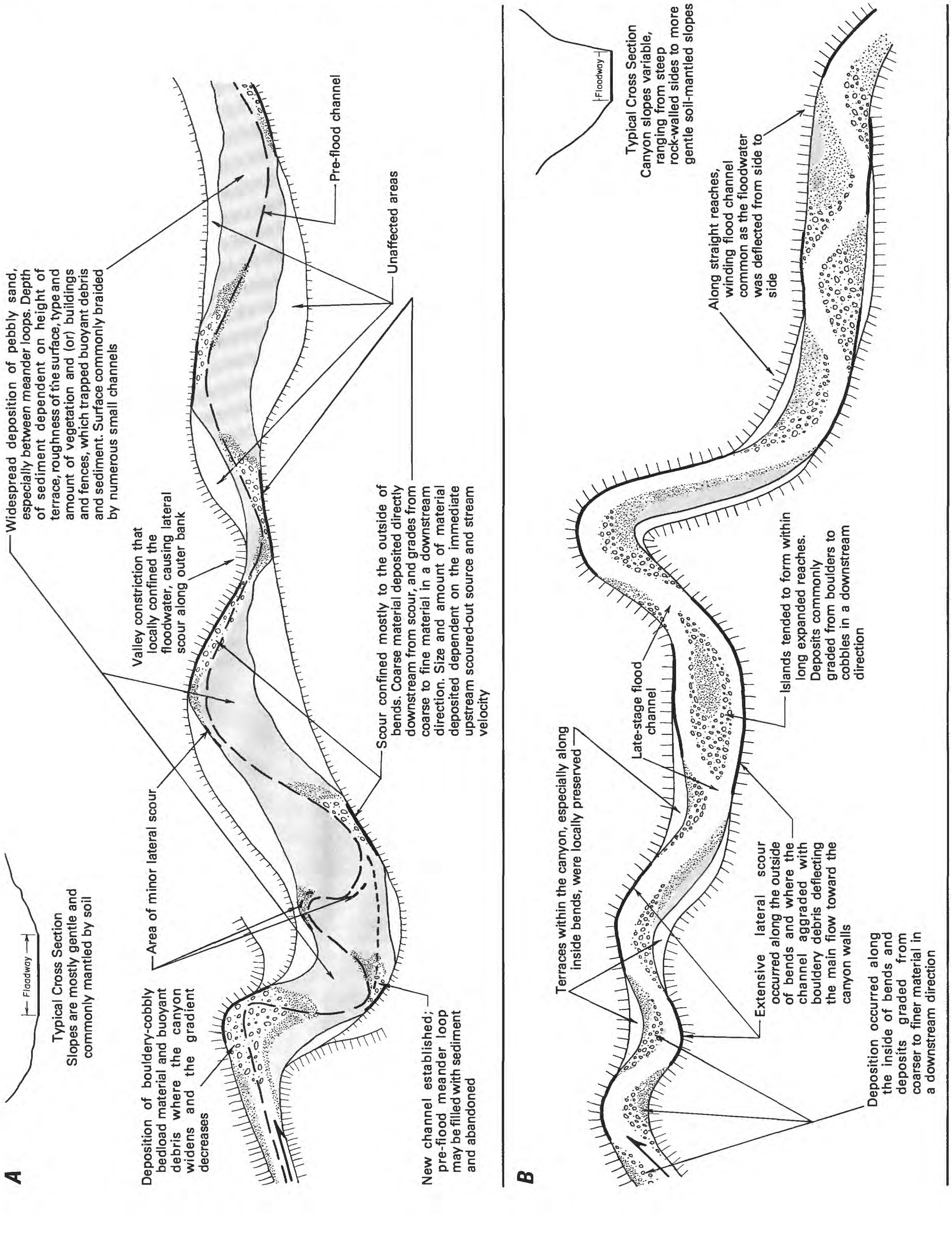
BIG THOMPSON RIVER AND TRIBUTARIES FROM ESTES PARK TO DRAKE

ESTES PARK AREA

VALLEY SLOPES

Geologic effects of the July 31, 1976 storm in the Estes Park area increased toward the east and decreased rapidly toward the west (pl. 2*A*). This distribution reflects the strong precipitation gradient, which ranged from about 1 in. at the town of Estes Park to about 10 in. near Olympus Heights (pl. 2*A*). Sheet erosion was most intense on forested slopes on the east side of Dry Gulch and on the south flank of Mount Olympus. Nearby gravel roads and nonvegetated artificial fills were also eroded by storm runoff. Sheet erosion was negligible in areas of continuous, undisturbed grass cover, even though the grass was laid flat in many places by the surface flow. In steep grassy areas, however, the runoff locally scoured small, widely spaced depressions in the dense turf. Along some intermittent streams the grass was reduced to stubble by the abrasion from the sediment-laden floodwaters. Sheetwash from eroded slopes formed thin veneers of fine to coarse sand that contained scattered pebbles and cobbles (fig. 65) commonly alined downslope. These deposits accumulated chiefly at the base of grassy hillslopes and on valley bottoms and were usually less than 4 in. thick. Sand sheets as much as 1–2 ft thick were deposited locally against obstructions such as fences and buildings. Cobbly to bouldery debris was deposited at the mouths of some of the small gullies that headed on steep forested slopes (fig. 66).

Unimproved dirt roads, particularly those on or intersecting grass-covered natural drainageways with gradients of more than 10 percent, were extensively gullied. Runoff along shallow-rutted dirt roads eroded narrow steep-sided gullies as much as about 600 ft long, 7 ft deep, and 20 ft wide. Most gullies gradually deepened upslope and terminated abruptly in steep headcuts. Drainage ditches along steep roads were eroded to bedrock in many places. Mass wasting effects were limited to the south flank of Mount Olympus, near Crocker Ranch, where two small landslides developed on slopes greater than 65 percent.


A
Typical Cross Section
Slopes are mostly gentle and commonly mantled by soil
Floodway
Deposition of bouldery-cobbly bedload material and buoyant debris where the canyon widens and the gradient decreases
New channel established; pre-flood meander loop may be filled with sediment and abandoned
Area of minor lateral scour
Valley constriction that locally confined the floodwater, causing lateral scour along outer bank
Scour confined mostly to the outside of bends. Coarse material deposited directly downstream from scour, and grades from coarse to fine material in a downstream direction. Size and amount of material deposited dependent on the immediate upstream scoured-out source and stream velocity
Widespread deposition of pebbly sand, especially between meander loops. Depth of sediment dependent on height of terrace, roughness of the surface, type and amount of vegetation and (or) buildings and fences, which trapped buoyant debris and sediment. Surface commonly braided by numerous small channels
Unaffected areas
Pre-flood channel
B
Terraces within the canyon, especially along inside bends, were locally preserved
Late-stage flood channel
Extensive lateral scour occurred along the outside of bends and where the channel aggraded with bouldery debris deflecting the main flow toward the canyon walls
Deposition occurred along the inside of bends and deposits graded from coarser to finer material in a downstream direction
Islands tended to form within long expanded reaches. Deposits commonly graded from boulders to cobbles in a downstream direction
Along straight reaches, winding flood channel common as the floodwater was deflected from side to side
Typical Cross Section
Canyon slopes variable, ranging from steep rock-walled sides to more gentle soil-mantled slopes
Floodway

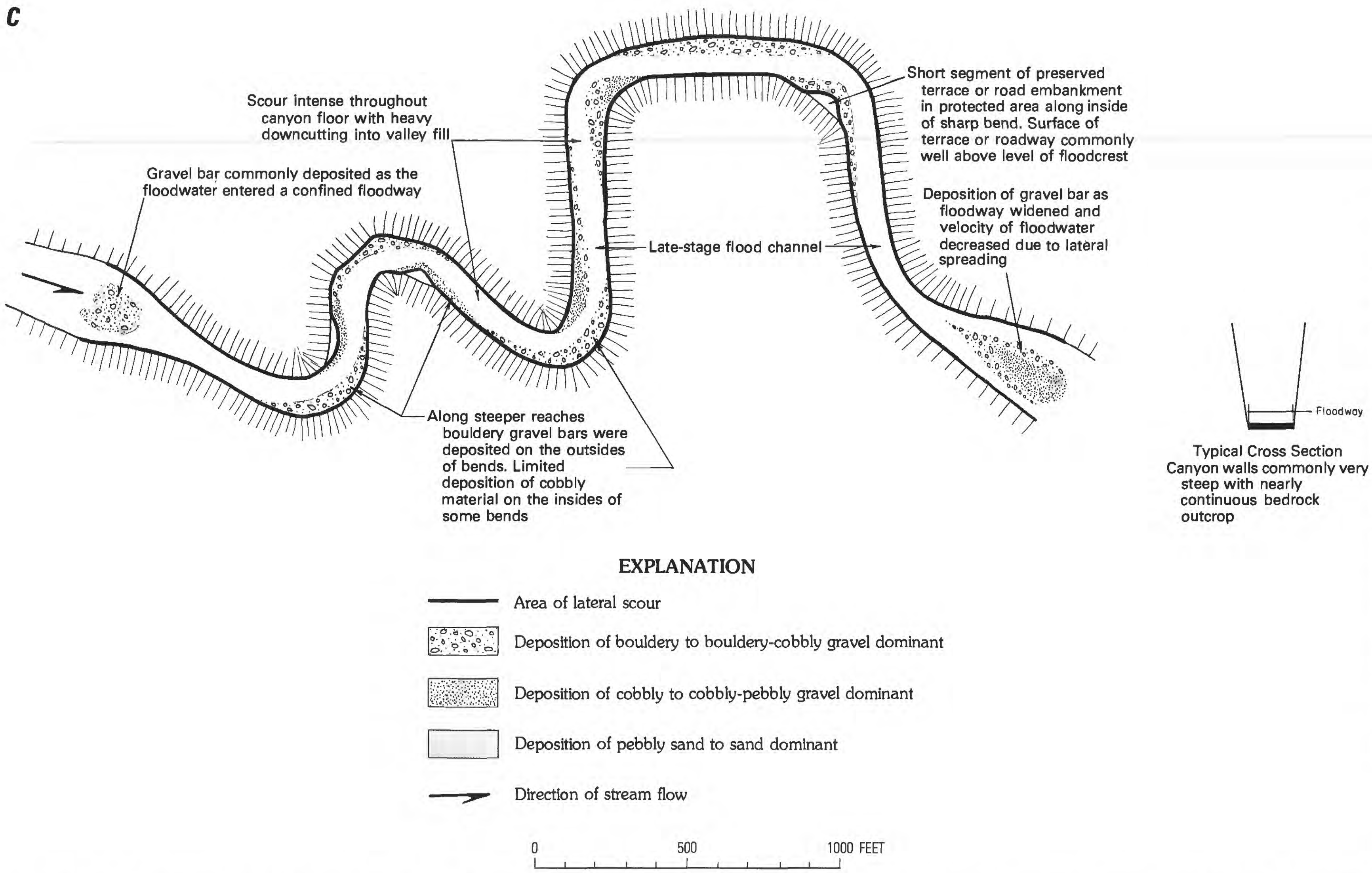


FIGURE 64.—Schematic diagram showing three modes of flood erosion and deposition within the canyons of the Big Thompson River and North Fork Big Thompson River. *A*, limited scour and widespread deposition along broad floodway commonly more than 250 ft wide and having gradients less than 2 percent; *B*, extensive scour and deposition along intermediate-width floodway commonly 150–250 ft wide and having gradients from 2 percent to greater than 4 percent; *C*, intensive scour and limited deposition within narrow and confined floodway less than 150 ft wide and having gradients from 2.3 percent to greater than 4 percent. Scale approximate.

TABLE 6.—*Summary of geologic and geomorphic effects of the July 31– August 1, 1976, storm and flood on the Big Thompson River and its*

[NA, not applicable; blank spaces for geologic and geomorphic effects indicate that effects were not noted or

Landscape elements		Geologic and geomorphic effects		Big Thompson River and tributaries from Olympus Dam to confluence with the North Fork (mile 57.5 to mile 44.9)																
				Big Thompson River					Major tributaries								Minor tributaries			
									Dry Gulch	Unnamed gulch at Glen Comfort	Dark Gulch	Noels Draw	Rabbit Gulch	Long Gulch	True Gulch	Unnamed gulch at Waltonia	Unnamed			
				Mile 57.5–54.4–	Mile 54.4–48.3–	Mile 48.3–47.7–	Mile 47.7–45.2–	Mile 45.2–44.9–	Mile 57.4–	Mile 54.4–	Mile 53.0–	Mile 52.7–	Mile 50.1–	Mile 49.6–	Mile 47.4–	Mile 46.9–	Mile 57.5–54.4–	Mile 54.4–48.3–	Mile 48.3–47.7–	Mile 47.7–44.9–
Slopes	Erosion	Sheet erosion		×	×	×			×	×	×	×		×			×	×	×	
		Gullying	Dirt roads and modified slopes.	×	×	NA	NA		×	×	×	×	NA	×	NA		×	NA	NA	NA
			Natural slopes	×	×	×			×	×	×	×		×			×	×		
		Landsliding	Debris Slides	×	×	×					×	×	×	×						
			Rockslides	×	×		×													
			Debris flows	×	×													×		
			Rockfalls and (or) debris avalanches.	×	×	×	×													
	Deposition	Lag deposits and (or) sheetwash		×	×	×			×	×	×	×		×			×	×	×	
		Landslide deposits		×	×							×		×						
Main channel, flood plain, and low terraces	Erosion	Lateral cutting	Stream and (or) slope deposits.		×	×	×	×	×	×		×	×	×						
			Manmade fills and embankments.		×	×	×	×	×	NA	NA	×	NA	NA	NA	NA	NA	NA	NA	NA
		Channel-bank slumping																		
		Channel scour		×	×	×	×	×	×	×	×	×	×	×	×		×	×	×	
	Deposition	Channel fill	Boulder gravel			×	×	×			×									
			Boulder to cobble gravel.	×	×		×	×		×			×	×	×		×	×	×	
			Cobble to pebble gravel.	×	×		×	×		×		×	×	×	×		×	×	×	
			Pebble gravel	×	×			×	×			×	×	×	×		×	×	×	
			Pebbly sand	×	×			×	×			×	×	×	×		×	×	×	
			Coarse sand						×											
			Medium to fine sand.																	
		Debris fans at mouths of gulches		NA	NA	NA	NA	NA	×	×	×			×			×	×		
		Debris flows at mouths of gulches		NA	NA	NA	NA	NA											×	
		Overbank sediments	Boulder gravel					×												
			Boulder to cobble gravel.				×	×		×										
			Cobble to pebble gravel.				×	×		×										
			Pebble gravel				×	×		×										
			Pebbly sand	×	×		×	×	×	×										
			Coarse sand	×	×		×		×	×										
			Medium to fine sand.		×															
			Fine sand to silt.		×															
			Silt																	
		Large deposits of bouyant debris			×		×	×												
Average gradient (percent)				1.1	1.6	6.7	3.1	3.2	3.3	9.1	11.8	8.1	6.8	9.6	13.3	10.0	15–35	15–40	NA	NA
Peak discharge (ft^3/s)				4,330			28,200		4,460	8,700	7,210	6,910	3,540	5,500						
Velocity (ft/s)				8			22		12	26	28	21	13	19						

tributaries from Olympus Dam to the confluence with the South Platte River, including average gradients and selected hydrologic data

were minor and of very limited extent; blank spaces for hydrologic data indicate that data was not collected]

North Fork Big Thompson River and tributaries from above Glen Haven to confluence with the Big Thompson River (mile 10.0 to mile 0.0)													Big Thompson River from confluence with the North Fork to canyon mouth (mile 44.9 to mile 37.0)						Big Thompson River from canyon mouth to confluence with the South Platte River (mile 37.0 to mile 0.0)			
North Fork Big Thompson River					Major tributaries					Minor tributaries												
					Fox Creek	Devils Gulch–West Creek	Unnamed gulch from Piper Meadows	Dunraven Glade	Black Creek and lower part of Miller Fork	Unnamed												
Mile 10.0–8.3	Mile 8.3–6.7	Mile 6.7–5.0	Mile 5.0–3.0	Mile 3.0–0.0	Mile 8.5–	Mile 8.4–	Mile 7.3–	Mile 6.5–	Mile 5.6–	Mile 10.0–6.5	Mile 6.5–1.5	Mile 1.5–0.0	Mile 44.9–44.1	Mile 44.1–41.3	Mile 41.3–41.0	Mile 41.0–40.4	Mile 40.4–38.9	Mile 38.9–37.0	Mile 37.0–34.3	Mile 34.3–25.0	Mile 25.0–15.7	Mile 15.7–0.0
						×	×				×											
×	NA	×	×		×	×	×	×	×	×	×											
×		×	×	×		×	×	×	×	×	×											
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	×	×	×	×		×	×	×	×	×	×		×	×	×	×	×	×	×			
																			×	×	×	×
	×	×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×	×	×		
			×										×	×	×	×	×	×	×			
	×		×			×	×		×				×	×	×	×	×	×	×			
	×	×	×			×	×		×				×		×	×	×	×	×	×		
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		×		×	×			×	×	×	×						×		×	×	×	×
									×		×								×	×	×	×
NA	NA	NA	NA	NA		×	×	×	×	×	×		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA					×				NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
														×	×	×		×				
			×											×	×	×		×	×			
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	×		×			×			×		×		×	×	×	×	×	×	×			
×	×	×	×	×		×	×	×	×	×	×		×	×	×	×	×	×	×	×		
×	×	×	×	×	×	×	×	×	×	×	×		×	×	×		×	×	×	×	×	
×		×	×	×	×	×	×	×			×		×		×		×	×	×	×	×	×
		×		×		×		×			×				×		×		×	×	×	×
				×													×			×	×	×
		×	×	×		×	×						×	×	×	×	×	×	×	×	×	×
3.7	2.6	1.9	.5	1.8	3.8	6.4 3.2	12.1	8.2	13.1 4.0	15–35	10–40	NA	1.4	2.7	2.5	2.5	0.8	2.3	1.3	0.4	0.2	0.2
890				8,710	1,300	2,810 2,320	9,670		1,990 2,060				30,100					31.200				2,470 Mile 0.9
8				12	9	12 7	29		11 12				16					26				

FIGURE 65.—Helicopter view showing effects of sheetflooding along foot of Mount Olympus at Crocker Ranch. Thin layers of sandy sheetwash (light tones). Bouldery gravel (darker tones) at mouth of gully in upper left of photograph. This area received about 10 in. of rain.

DRY GULCH

Dry Gulch, which had a peak discharge during the storm of 4,460 ft³/s and a velocity of 12 ft/s (Part A, table 4), was slightly affected by minor channel scour, lateral cutting, channel aggradation, and overbank deposition. Downcutting appears to have been most intense just upstream from Eagle Rock, where the average gradient of the gulch increases from 2.4 to 5.0 percent. Downstream from this point, sandbars accumulated at the insides of bends, and the floor of the gulch was partly filled with coarse pebbly sand. Lateral cutting along the outsides of bends removed a small amount of bank material and trimmed the toe of Olympus Dam (fig. 67). Culverts and roadfill in the gulch were washed away. At one point, the stream abandoned a short section of manmade channel and reoccupied its original course. At the confluence with the Big Thompson River, sediment from Dry Gulch built a large alluvial fan that partly filled the stilling basin at the base of Olympus Dam. Between the dam and the head of the canyon, floodwaters from Dry Gulch deposited point bars at the insides of bends and a small amount of sandy overbank alluvium on low terraces.

BIG THOMPSON CANYON, OLYMPUS DAM TO DRAKE

SHEET EROSION AND GULLYING

The Big Thompson Canyon and its tributary gulches above mile 50 received in excess of 10 in. in rainfall during the storm (pl. 2*A*). On steep forested slopes, intense runoff and saturation of the surficial mantle caused widespread erosion.

Sheet erosion locally removed the thin layer of organic litter and as much as a foot of pebbly sand from the underlying colluvium, leaving thin lag deposits of pebble- to boulder-size rock fragments on eroded slopes. Slopes with subtle surface irregularities and a sparse understory of grass were the most susceptible to sheet erosion. Erosion was much reduced by large tree roots, which helped stabilize the substrate and trapped pebbly sheetwash on their upslope sides. Sheetwash deposits also accumulated on the upslope sides of large boulders. Logs and other obstructions together with accumulating sediment deflected the surface flow and concentrated its erosive power in unobstructed areas. Small alluvial fans and thin alluvial aprons formed at the bases of eroded slopes (fig. 65).

Surficial deposits along minor drainageways were gullied to as deep as 5 ft. Channelized runoff commonly scoured the surficial mantle down to bedrock and carried away material as large as 16 in. in intermediate diameter. Natural drainageways containing unpaved roads were the most extensively gullied.

LANDSLIDING

Rapid mass movements, including debris slides, rockslides, debris flows, and rockfalls, were activated between miles 56.2 and 47.7 on northeast- to northwest- to southwest-facing slopes where the inclination was from about 60 to 85 percent. Debris slides and valley-side debris flows generally developed in thin colluvial mantles, less than about 6 ft thick, that are composed of angular rock fragments in a matrix of slightly silty sand (fig. 68). These colluvial mantles overlie bedrock slopes that tend to be parallel to the present topography. Slope failures developed at or near the colluvium-bedrock contact, and most of them were probably caused by rapid infiltration of precipitation, which increased the weight and decreased the shear strength of the surficial material by increasing the pore-water pressure within the mass. Some debris sliding, however, was caused partly by lateral stream cutting at the bases of steep slopes

FIGURE 66.—Tongue of bouldery debris deposited by sheetflooding along the base of Mount Olympus at Crocker Ranch. This is a ground view of the area shown in the upper left part of figure 65. The two large boulders on the right in the middle distance were not moved.

FIGURE 67.—Toe of Olympus Dam, scoured by floodwaters of Dry Gulch, viewed toward the south.

along the outsides of bends (fig. 108). Most debris slides ranged in volume from a few tens to several hundreds of cubic yards.

At several localities between miles 56.2 and 47.7, small boulders to blocks of rock as large as about 30 ft across were set into motion down natural and modified slopes. Most rockslides occurred either at building sites where colluvium had been excavated to provide additional building space (fig. 69) or at steep highway cuts.

Colluvium near mile 56.1 and surficial deposits in some of the small tributary gulches between miles 52.2 and 49.9 were mobilized and redeposited during the storm as debris flows. Debris flows that developed on colluvial slopes moved down minor drainageways. These flows were long and narrow, and they were flanked by prominent levees 1-3 ft high that formed when the flanks of the flows stabilized while the central parts continued to move. The levees consisted of angular clasts as large as 1.8×5.1×5.2 ft in a matrix of very slightly silty sand. The channels between the levees contained thin deposits of pebbly to bouldery material. Trees in the paths of debris flows were scarred by impacts on their upslope slides to a height of about 5 ft.

Debris flows deposited at the mouths of small tributary gulches were lobate, steep sided, and without distinguishable levees. The flanks and centers of these flows appear to have come to rest at the same time, so levees did not form. The deposits ranged in thickness from about 3 to 9 ft and consisted of pebbly to bouldery sand. The sides and toes of some debris flows were strewn with broken tree trunks, as much as 16 in. in diameter that were stripped of limbs and bark, along with boulders as large as 2.1×3.2×3.6 ft. Most debris flows were partly covered by a thin layer of coarse-grained water-laid sediment. Bouldery debris thought to have been deposited by highly sediment charged

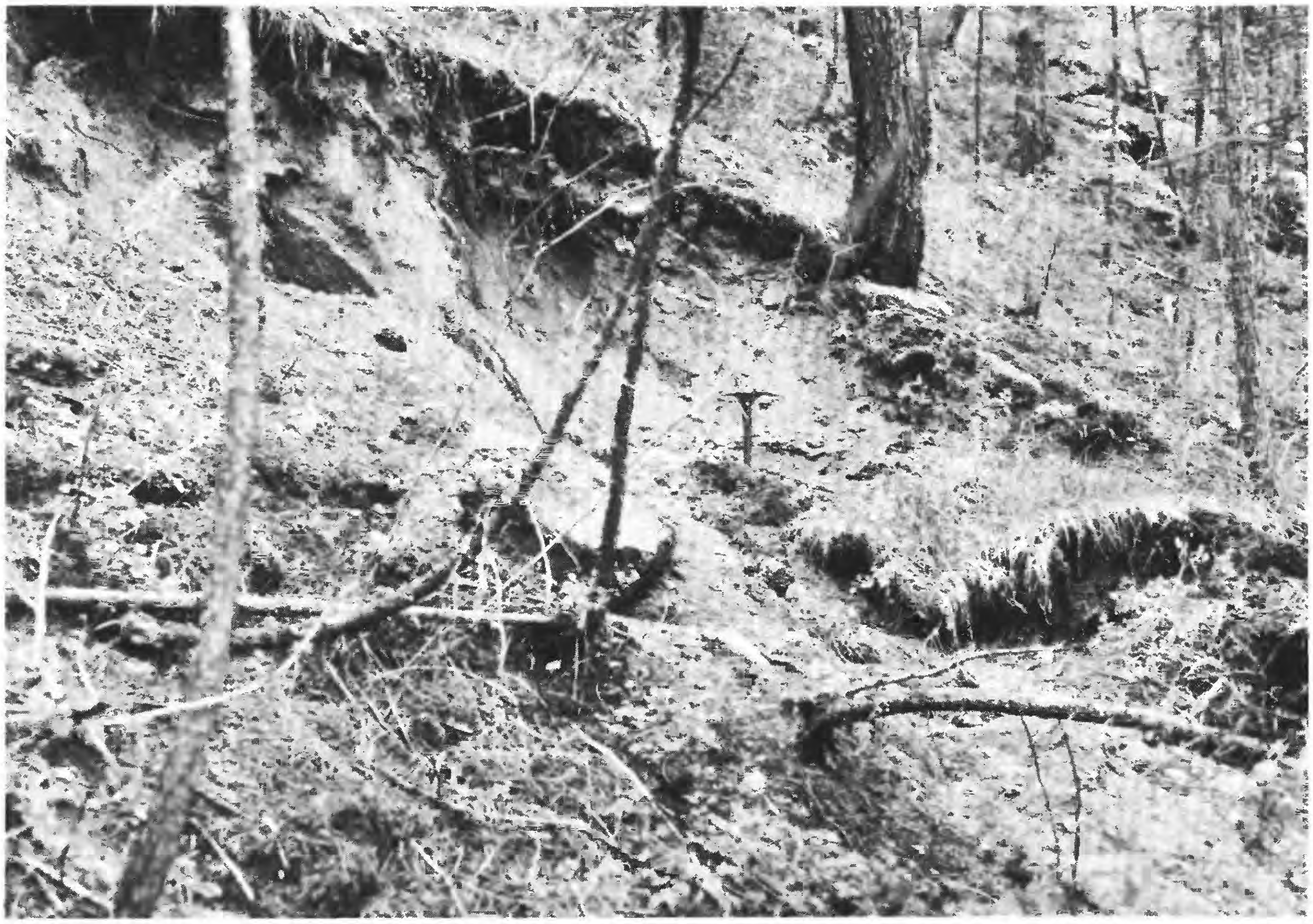

FIGURE 68.—Small debris slide in stony colluvium on 67-percent slope near mile 53.2 This area received about 11.5 in. of rain.

runoff accumulated at the mouths of some of the small tributary gulches (fig. 103). These deposits lack the characteristic features of debris flows, although they appear to be of somewhat similar origin.

Rock fragments dislodged from numerous cliff faces fell and bounded down steep slopes during the storm. The largest rockfall was near the west end of Glen Comfort, where falling granite slabs measuring as large as 2.3×6.0×6.4 ft splintered mature ponderosa pines and Douglas-firs growing at the base of the slope. At other localities, airborne rock fragments as large as 1.1×2.3×3.5 ft broke off trees as much as 9 in. in diameter and produced impact scars as high as 5 ft on the uphill slides of larger trees.

MAJOR TRIBUTARY GULCHES

Major tributary gulches between Loveland Heights and mile 49.6 (pl. 2*A*; table 6) were extensively scoured during the storm. Near the center of maximum precipitation, two gulches with average gradients of 9–12 percent—the unnamed gulch at the east end of Loveland Heights (mile 54.4) and Dark Gulch—were stripped of surficial material for distances of as much as a mile. Side gulches along these major tributaries were also deeply eroded. Granite bedrock along the main gulches was exposed at depths of about 2–8 ft below the level of the preflood channel. A few bouldery deposits, however, were laid down at the insides of sharp bends; boulders larger than 5 ft in diameter were not moved. The amount of lateral scour generally increased downstream. Postflood channel width ranged from about 15 to 35 ft along Dark Gulch and was as much as about 90 ft near the mouth of the unnamed gulch. Both gulches had peak discharges in excess of 7,000 ft^3/s and velocities of 26–28 ft/s (Part A, table 4).

Surficial deposits exposed by scour in streamcuts in the tributary gulches consist mostly of sandy slopewash over pebbly to bouldery flood gravels (fig.

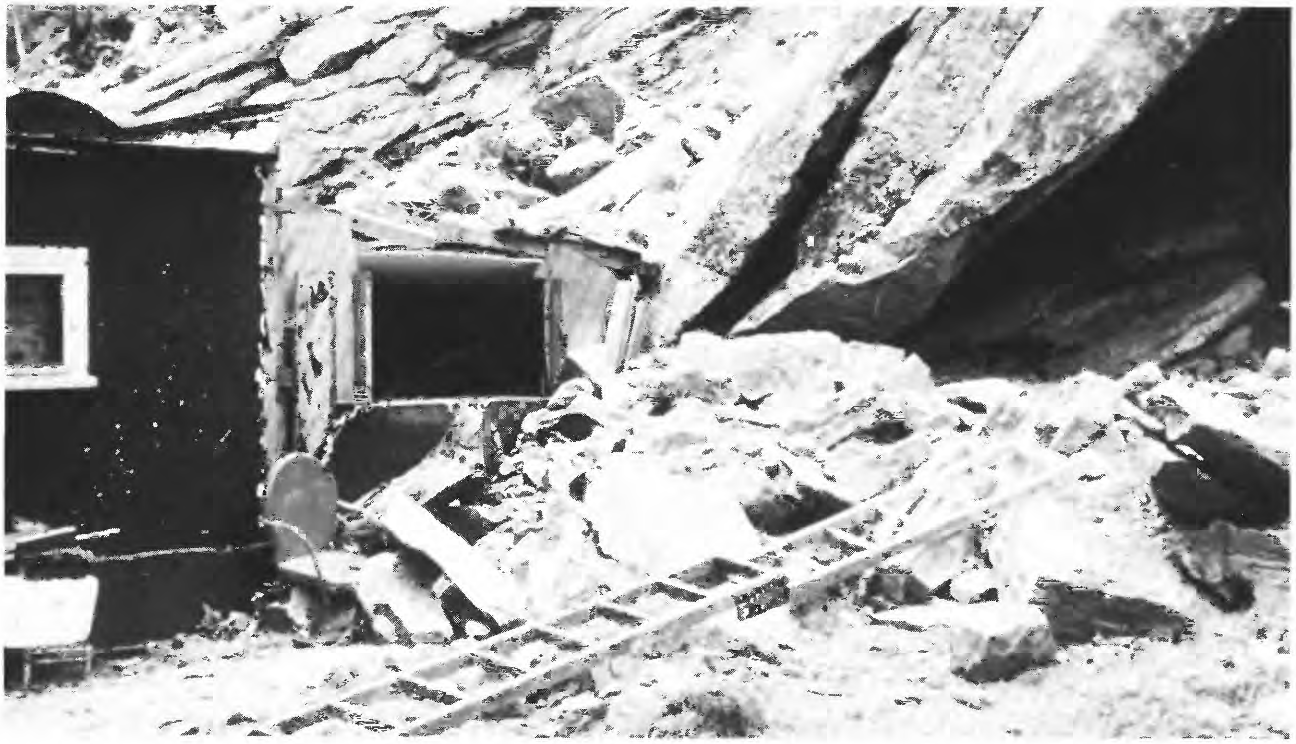

FIGURE 69.—Motel unit damaged by a rockslide on an oversteepened bedrock slope near mile 56.0. Movement was along a sloping joint plane in granite. This area received about 10 in. of rain.

FIGURE 70.—Unnamed gulch, viewed about 100 yd upstream from its confluence with the Big Thompson River, at mile 54.4. Floodwaters with a calculated velocity of 26 ft/s and a peak discharge of 8,700 ft^3/s (Part A, table 4) scoured the gulch to bedrock, exposing sandy slope wash and an older bouldery flood deposit. Before the 1976 flood, this part of the gulch was a flat-bottomed grassy meadow without perennial surface drainage.

70). In most exposures, the slope wash is humic throughout and appears to be a cumulative A horizon that is at least a few hundred years old. The underlying alluvium may date from the last major flood. the preservation of the buried alluvium suggests that it was deposited by a flood of lesser magnitude than the 1976 flood.

Unimproved dirt roads on grassy slopes of about 7 percent along the lower reach of the unnamed gulch at Loveland Heights and in the large meadow in its headwaters were gullied to depths of as much as 5-10 ft (fig. 71). Roads parallel or oblique to the contour of the ground were less deeply gullied than those perpendicular to the contour. Flood debris along the unnamed gulch and Dark Gulch was deposited at heights of about 7-9 ft above the present streambed.

Major tributary gulches with average gradients of less than 10 percent, peak discharges of less than 7,000 ft^3/s, and velocities of less than 25 ft/s (Part A, table 4)—including Noels Draw, Rabbit Gulch, and Long Gulch—were less severely eroded than gulches of comparable size with similar or steeper gradients, higher peak discharges, and higher velocities. The lower half a mile of Noels Draw (fig. 101*B*) and its side gulches slightly farther upstream were scoured to bedrock. The depth of scour was about 1-7 ft on the side gulches and about 5-6 ft on the main gulch. Upstream from this segment of Noels Draw, the gulch was eroded and partly backfilled with pebbly to bouldery gravel in which the floodwaters later cut braided channels. Transported boulders were as large as 3.0×3.5×4.5 ft. The height of flood debris above the present floor of Noels Draw ranged from about 8.5 ft in the lower 500 ft to about 6 ft above the confluence with Solitude Creek.

Cobbly tunnel tailings in Noels Draw, about 0.9 mi above the mouth, were gullied to depths of about 6-15 ft by the discharge from a small tributary gulch. The sparse vegetation on the tailings provided little protection against erosion, and coarse rock debris from the tailings pile accumulated in alluvial fans at the mouths of the eroded gullies. Debris slides were set off along the flanks of the tailings pile by lateral stream cutting.

Elsewhere in Noels Draw and its side gulches, debris slides developed in thin layers of saturated colluvium resting on steep north- to west-facing bedrock slopes.

FIGURE 71.—Gully cut by intense runoff channeled along the shallow ruts of a dirt road in a grassy area, upper part of unnamed gulch at mile 54.4 Rainfall here was about 10 in.

The largest slides were along the upper part of Solitude Creek.

Long Gulch was scoured to depths greater than 6 ft and was partly backfilled with coarse gravel more than 3 ft thick. The lower ends of most side gulches were cut to bedrock. Old debris fans at the mouths of small side gulches were truncated by the floodwaters of the main gulch, exposing boulders as large as a few yards across. Bouldery gravel bars were deposited along insides of bends. Stranded driftwood lay 8 ft above present drainage a mile upstream from the mouth of the gulch and 11 ft above drainage at the mouth.

MINOR TRIBUTARY GULCHES

Minor tributary gulches between miles 55.6 and 50.9 were severely scoured; many of them to bedrock, through 2–3 ft and locally as much as 6 ft of surficial material. The postflood width of channel scour ranged from about 10 to 30 ft and generally increased with the size of the gulch. Boulders as large as 1.7×3.0×4.5 ft as well as finer grained sediment were removed by the floodwaters. Some gulches were stripped to bedrock for distances of as much as a quarter of a mile, although most contained discontinuous flood deposits. Coarse gravel deposits with boulders as much as 3 ft across accumulated to a thickness of as much as 13 ft against massive log jams and to a thickness of about 3–5 ft behind large boulders, mature standing pine trees, and fallen trees. Deposits with elongate rock fragments commonly displayed imbricate structure. Small sandbars were deposited at the insides of bends and in other protected areas. In narrow bouldery gulches, smaller boulders jammed behind larger ones created shallow basins filled with pebbly to bouldery sand. Undercutting and sliding of slope material contributed considerable sediment to the flood-swollen gulches. Some boulders as large as 8 ft in intermediate diameter were undercut and transported a few yards downstream. In the steeper reaches of some gulches, sand- to small boulder-size material was washed away, leaving the floors of the gulches mantled with chaotic lag deposits of massive boulders. The height of flood debris above the present floors of many minor gulches varied from about 5 to 8 ft and increased downstream.

BIG THOMPSON RIVER

OLYMPUS DAM TO LOVELAND HEIGHTS

In the upper 2.2 mi of the canyon, the Big Thompson River lacked the volume of water and competence to cause extensive erosion and damage. Along this reach lateral cutting was restricted to outsides of channel bends where small volumes of roadfill were removed and a house founded on artificial fill was severely undercut. Near the head of the canyon, the Big Thompson River moved small boulders as large as 1.0×1.2×1.3 ft (table 7). Farther downstream, small sandbars were deposited at insides of bends. Below mile 55.7, the decks of most private bridges were washed away, and their concrete center piers were rotated by local scour that cut to depths of at least 1–2 ft. Low stream terraces in the vicinity of Loveland Heights were overtopped by the floodwaters and were covered by a thin layer of sand.

TABLE 7.—*Size and lithology of largest boulders transported by the 1976 flood in the Big Thompson Canyon, mile 56.4 to mile 54.7*

[River mile locations are shown on plate 1]

River mile	Location	Size (feet)	Lithology
56.4	Near head	1.0× 1.2× 1.3	Granite.
	of canyon.	0.5× 1.1× 1.8	Do.
		0.5× 0.6× 0.9	Do.
54.0	0.7 mile	1.5× 2.3× 2.8	Granite.
	upstream	1.2× 1.9× 2.5	Do.
	from Glen	1.2× 1.7× 3.0	Do.
	Comfort.	1.1× 1.7× 3.3	Do.
		1.1× 1.3× 3.0	Do.
53.3	At upstream	2.8× 3.0×10.7	Granite.
	end of Glen	2.6× 3.2× 6.0	Do.
	Comfort.	2.5× 3.8× 6.0	Do.
		2.3× 3.0× 7.1	Do.
		2.0× 4.8× 5.1	Do.
52.3	Near downstream	1.6× 2.3× 4.3	Granite.
	end of Glen	1.3× 2.3× 3.0	Do.
	Comfort.	1.3× 1.9× 2.8	Do.
48.1	1.1 mile upstream	6.0× 6.5×10.0	Pegmatite.
	from	6.0× 6.0× 9.0	Do.
	Waltonia.	4.4× 5.7×12.0	Granite.
		3.5× 8.6×12.3	Do.
		3.0× 9.0×19.5	Pegmatite.
46.4	1.0 mile	1.8× 2.0× 2.2	Pegmatite.
	downstream	1.4× 1.5× 2.6	Do.
	from	1.3× 1.9× 2.1	Do.
	Waltonia.	1.2× 1.7× 2.0	Do.
		1.0× 1.6× 2.2	Do.
45.7	0.5 mile	7.3× 8.0× 9.0	Granite.
	upstream	4.8× 5.3× 9.7	Do.
	from Drake.	4.0× 8.3× 9.7	Do.
		3.5× 6.1× 8.5	Do.
		2.6× 8.0× 9.0	Do.

Upstream from Loveland Heights, the Big Thompson River received a small amount of sediment from the valley sides and from tributary gulches. A major source of sediment was a debris slide at mile 56.1, which released a few hundred cubic yards of colluvium into the main stream during the storm. Alluvium was deposited mostly above the mouths of most gulches; only minor amounts entered the Big Thompson River. The gulch at mile 55.6, however, contributed a significant amount of sediment to the mainstream. A bouldery fan accumulated at the mouth of the gulch, and gravel bars extended down the Big Thompson River for a distance of about 300 ft.

LOVELAND HEIGHTS TO DRAKE

Debris-charged floodwaters from major tributary gulches between miles 54.4 and 49.6 transformed the Big Thompson River into a raging torrent that caused extensive channel modification and widespread destruction all the way from Loveland Heights to the mouth of the canyon. The Loveland Heights area was near the center of the downpour (pl. 2*A*), and much of the storm runoff entered the mainstream along this reach. Between the east end of Loveland Heights and Noels Draw, relatively minor lateral cutting washed away a small amount of roadfill. Downstream from Noels Draw, however, lateral scour along outsides of bends completely removed short segments of the highway and, at mile 52.4, destroyed a house and reactivated a large debris slide (fig. 108). Near Glen Comfort, stream-polished boulders as large as 2.8×3.0×10.7 ft (table 7) were undercut and carried downstream. Boulders transported during the 1976 flood were identified on the basis of one or both of the following criteria: (1) fresh impact scars on the downstream side (fig. 72), and (2) deposition on or against flood debris or surfaces previously free of sediment. Channel scour to a depth of at least several feet caused minor settlement of the concrete center pier of the highway bridge at mile 52.2.

Major tributary gulches funneled large amounts of coarse sediment into the mainstream. Coarse debris deposited at the mouths of the unnamed gulch at mile 54.4 and Dark Gulch created bouldery alluvial fans that partly constricted the main channel. Much of the pebbly to cobbly sediment from these gulches,

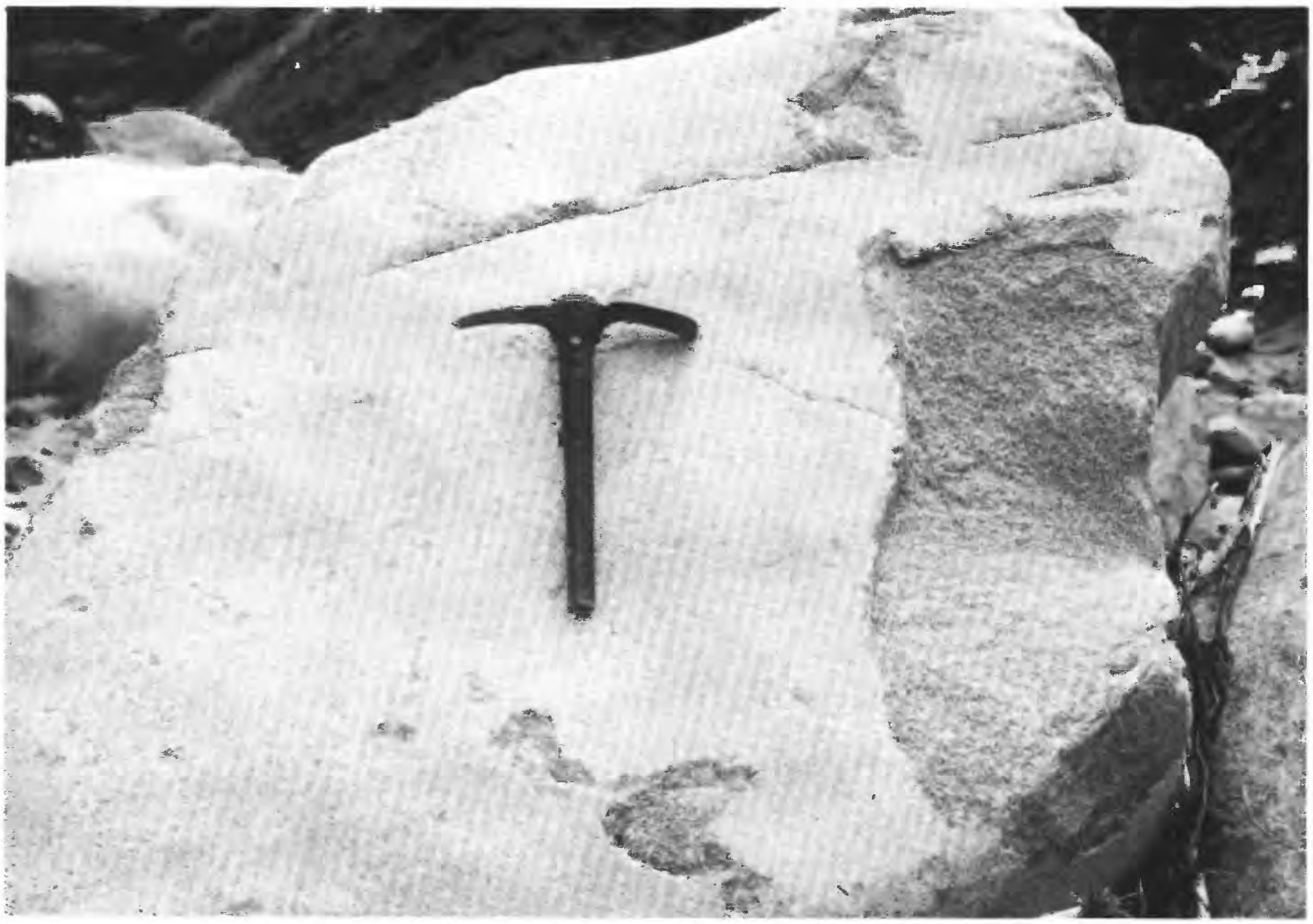

FIGURE 72.—Granite boulder near mile 42.7, showing fresh impact scars. Pick is 17 in. long. Such scars on the downstream sides of boulders indicate movement during the flood.

FIGURE 73.—Overbank sand and buoyant debris on the south side of the Big Thompson River at mile 54.4. Frame house in center of photograph was lifted off its foundation and pushed against trees. Much of the damage here was caused by a surge of water from the tributary on the opposite (north) side of the river.

FIGURE 74.—Debris pile on the upstream side of highway bridge at mile 52.2.

however, accumulated a short distance downstream in gravel bars that were deposited on low islands and at inner bends. The tops of most gravel bars were washed free of sand and were cut by shallow cross channels. Coarse pebbly sand partly filled the main channel as far downstream as half a mile below the major gulches. Thin layers of sand to silty sand were deposited on low forested terraces along inner bends where the vegetation impeded the overbank flow. Floodwaters from the unnamed gulch deflected the mainstream flow against the opposite bank where a house was floated off its foundation and deposited a short distance downstream (fig. 73). Piles of floating debris commonly accumulated in wooded areas along the river and on the upstream sides of highway bridges (fig. 74).

From the mouth of Long Gulch to mile 48.3 bouldery gravel bars were deposited on the insides of bends; small amounts of roadfill and slope material were washed away, primarily on the outsides of bends. At mile 48.3, the stream gradient increases from an average of 1.3 percent to 6.7 percent. This section of the canyon, about 3,700 ft long, was deeply scoured along its entire length. Boulders as much as 9 ft in intermediate diameter were transported downstream (table 7), locally exposing the underlying bedrock and leaving the channel lined with massive blocks of granite and pegmatite together with a minor amount of bouldery gravel. Lateral erosion removed short segments of highway; undercut colluvial slopes collapsed into many small debris slides.

Between mile 47.7 and the confluence with the North Fork at mile 44.9 the stream gradient is relatively uniform and averages 3.1 percent. Along this reach lateral erosion removed about 1 mi of highway. The longest segments of intact road were preserved at the insides of bends. Three old debris fans that extended an estimated 40-50 ft into the canyon, between miles 45.4 and 46.3, were washed away by the flood (fig. 75), as was a riverside motel complex at Waltonia (mile 46.9; fig. 76). Considerable channel scour took place along a 1,000-ft segment of the Big Thompson near mile 46.3, where the gradient abruptly increases from about 2.9 to 6.7 percent.

Widespread coarse flood gravel was deposited in the main channel and on low terraces below mile 47.6. Large gravel bars accumulated along the insides of bends and along relatively straight and slightly expanded reaches. The surfaces of most of these gravel bars were mantled with boulders as large as 7.3×8.0×9.0 ft (table 7). Shallow channels cut diagonally across the bars. These bars were as much as 9 ft thick, and they displayed crude horizontal stratification. Sandbars accumulated outside the main channel in overbank areas of lower flow velocity, such as the downstream sides of closely spaced houses. These bars were as much as 3 ft thick and consisted of micaceous, thinly bedded, horizontally stratified very fine to very coarse sand.

The flood caused widespread property damage at Drake (fig. 77). At the south end of town the river abandoned its preflood course and cut a new channel along a gravel road on the east side of the canyon. Then a bouldery gravel bar was deposited at the upper end of the new channel, partly filling it (fig. 78). This obstruction deflected the floodwaters against the west wall of the canyon where a second channel was cut along U.S. Highway 34. Coarse flood alluvium deposited by a series of shallow distributary channels along the eastern margin of the second channel completely filled the preflood channel.

BIG THOMPSON RIVER FROM DRAKE TO THE CANYON MOUTH

Many canyon occupants were caught by surprise on the night of July 31, 1976, because little or no rain had fallen within this stretch of the canyon. Many buildings, mobile homes, campers, and cars were destroyed—some with their occupants inside. At Drake the electric power was lost and heavy rain was known to be falling upstream, but many residents still were unaware of the impending danger. The flooding at Drake, first from the Big Thompson River at about 2100 MDT, then about half an hour later from the North Fork, took at least 13 lives and destroyed many buildings and other properties. Some buildings were merely shifted off their foundations, but others were swept away (fig. 79). Buildings that still stood were partly filled with sediment, and most of them were damaged to the extent that they had to be demolished. Extensive structural damage was caused by impact from floating and saltating debris and by hydraulic pressure. Most structural failures were near points of weakness, such as windows and doors (fig. 80).

Scour was severe along most of the river channel and along many parts of U.S. Highway 34. Boulders, one as large as 3,200 ft^3, were moved by the current. The concrete dam below Midway was destroyed. Sediment deposited in the flood plain contained all sizes of material from sand to bouldery gravel. The tributaries along this stretch of the canyon were outside the area of heavy rainfall and added nothing to the flood.

As the flood moved down the canyon, erosion and deposition were influenced by the gradient of the river, the sinuosity of the canyon, and the width of the flood plain. Reaches steeper than 2 percent were scoured, especially on the outsides of bends and where the channel was constricted. Deposition took place where the

FIGURE 75.—House undercut by Big Thompson River near mile 45.4. House was located on a debris fan at the mouth of the small gulch in background. Rainfall here was relatively light, and the gulch carried no water of any consequence.

gradient decreased to less than 2 percent, at wide places on the flood plain, and at the insides of bends. Deposition of large boulder bars diverted the river from its preflood channel. Deposition was intensified where the flow was impeded by bridges, buildings, and dense vegetation.

DRAKE TO MIDWAY

From Drake (mile 44.9) to Midway (mile 44.0), the canyon coincides with the Thompson Canyon fault zone; and the course of the river, therefore, is relatively straight, the valley is broad, and the gradient is only 1.6 percent. Channel modifications by the flood were moderate along this reach, except that the highway was destroyed along the outside of the bend just upstream from Midway. Boulders deposited in this reach of the main channel were as long as 3.9 ft (table 8, mile 44.3). Pebbly sand to cobble gravel was deposited in overbank areas.

At Midway, the flood reportedly rose from normal flow to flood stage in less than 5 min. Here, the gradient steepens from 1.6 percent to locally more than 3 percent, and scour intensified along the winding channel. At the outsides of bends, lateral scour triggered some small landslides and destroyed short segments of the highway. Inside of bends were aggraded with bouldery alluvium. A bouldery gravel bar about 9 ft thick was deposited on a low terrace on the inside of the bend just west of Midway (mile 44.1). Boulders on this bar were as much as 6.4 ft in longest dimension; some of the larger boulders probably were scoured from a road fill about 450 ft upstream.

MIDWAY TO CEDAR COVE

In the 4 mi between Midway (mile 44.0) and Cedar Cove (mile 40.0), scour removed about 40 percent of the highway and destroyed many manmade structures, including a diversion dam, a restaurant and motel, and a

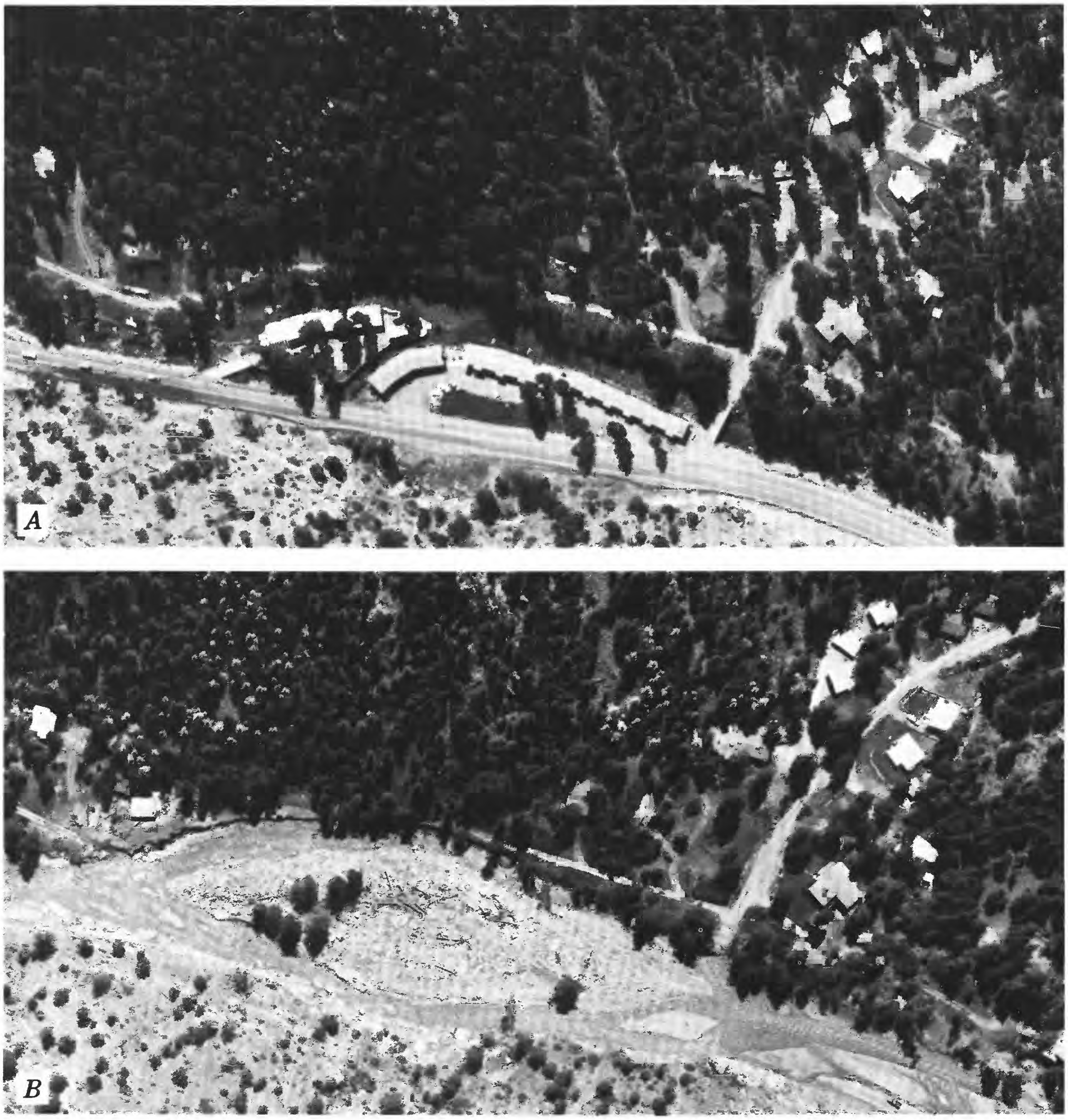

FIGURE 76.—The riverside community of Waltonia, mile 47.0, before and after the 1976 flood. Approximate scale: 1 in.=200 ft. *A*, Preflood view. Most of Waltonia is built on a large debris fan. Prior to 1976 flood, U.S. Highway 34, two large motels, and several other buildings were located here in Big Thompson flood plain. *B*, Postflood view, August 3, 1976. Virtually all of Waltonia on flood plain was obliterated.

powerplant. Along most of this stretch the river swings away from the Thompson Canyon fault zone, and the canyon floor is generally narrower and steeper than in stretches just upstream and downstream. Locally, the gradient is as steep as 4 percent.

The dam below Midway at mile 43.25, was about 25

◀ FIGURE 77.—Helicopter view showing flood damage in part of Drake. Downstream (north) is at top of picture. Before the flood the channel of the Big Thompson River was just to the left of the houses, but it shifted widely during the flood and was far to the left outside the picture at the time the photograph was taken. Rainfall here was about 4 in.

TABLE 8.—*Size and lithology of largest boulders transported by the 1976 flood in the Big Thompson Canyon, mile 44.3 to mile 39.5*

[River mile locations shown on plate 1]

River mile	Location	Size (feet)	Lithology
44.3	0.3 mile downstream from Drake.	1.9× 2.2× 3.9	Granite.
		1.8× 2.0× 3.9	Do.
		1.4× 2.3× 3.5	Do.
		1.3× 1.3× 3.9	Do.
44.1	Upstream end of Midway.	4.7× 5.4× 5.8	Pegmatite.
		4.1× 5.2× 5.9	Do.
		4.0× 4.2× 4.7	Granite.
		3.5× 5.5× 6.4	Pegmatite.
		2.7× 3.2× 6.2	Do.
43.3	Upstream side of hydroelectric diversion dam.	5.0× 5.3× 8.3	Granite.
		4.9× 5.0× 7.3	Do.
		3.9× 4.9× 6.0	Do.
		2.9× 3.9× 6.0	Do.
		2.9× 3.2× 8.2	Do.
		2.8× 4.7× 6.0	Do.
43.2	Downstream side of hydroelectric diversion dam.	11.8×12.0×22.9	Granite.
		6.5× 7.0× 9.5	Do.
		6.0× 7.2×12.5	Do.
		5.0× 5.3× 8.0	Do.
		4.5× 5.5× 7.0	Do.
		4.0× 5.0× 7.0	Do.
42.6	Covered Wagon Restaurant area.	5.4× 7.3×10.5	Granite.
		4.5× 4.9× 7.2	Do.
		4.3× 5.5× 8.3	Do.
		4.0× 4.0× 7.0	Do.
		3.9× 6.7×10.0	Do.
41.2	Loveland power plant.	3.2× 3.3× 4.9	Granite.
		2.3× 2.7× 4.4	Gneiss.
		2.1× 2.8× 3.2	Granite.
		1.8× 2.3× 3.1	Do.
		0.9× 1.7× 3.6	Gneiss.
39.5	Cedar Cove area.	2.2× 2.6× 3.7	Granite.
		1.7× 2.8× 3.8	Do.
		1.6× 2.3× 3.3	Pegmatite.
		1.1× 2.2× 3.2	Gneiss.
		0.7× 2.2× 2.8	Do.

TABLE 9.—*Concrete blocks carried downstream from destroyed diversion dam at river mile 43.25*

Block size (in ft^3)	Approximate weight (tons)	Distance from dam (ft)
720	54	0
600	45	65
1,650	124	90
270	20	115
280	20	160
30	2	325
4	.3	2,400

ft high and 100 ft wide. It was built in the late 1920's to divert water to the hydroelectric powerplant about 2 mi farther downstream. The flood first overtopped then rapidly breached the dam, carrying large sections of concrete and boulders downstream in a wave of water at least 23 ft above present stream level (fig. 81). Just upstream from the dam, as much as 10.0 ft of main stream gravel and at least 8.5 ft of overlying slack-water sediments were scoured out. Boulders deposited upstream from the dam were as large as 8.3 ft in longest dimension (table 8, mile 43.3). The south abutment of the dam remained in place, even though about 5.5 ft of alluvium was removed from its base. Below the dam a large newly deposited bouldery gravel bar extended about 650 ft downstream. The bar stood about 11 ft above present stream level and contained blocks of concrete as large as 1,650 ft^3 (table 9) and many large boulders. The largest boulder apparently moved by the flood was 11.8×12.0×22.9 ft (table 8, mile 43.2) and weighed an estimated 275 tons.

Within the 0.6-mi reach between the breached dam and the site of the Covered Wagon Restaurant, the floodwaters deeply scoured the 100–200-ft-wide flood plain. Here, the gradient was about 4 percent. Scour removed most of the highway on the north side of the canyon and parts of the aqueduct on the south side.

THE COVERED WAGON RESTAURANT AREA

The Covered Wagon Restaurant and parts of an adjoining motel had stood on a low terrace on the north side of the river (mile 42.6). One canyon resident who watched the flood from high ground reported that rising water first simply surrounded the buildings and trapped the occupants inside. Moments later, a surge of water carried off the restaurant and nearby buildings. When the flood subsided, a large bouldery gravel bar occupied the site.

This stretch of canyon (mile 42.8 to mile 42.3) is about 200 ft wide and is relatively straight, but a winding channel was cut by the flood as the current was deflected from side to side, and bouldery gravel was deposited along the insides of bends. A gravel bar about 5 ft thick formed at the site of the restaurant, and its surface was strewn with boulders as much as 10.5 ft long (table 8, mile 42.6). Opposite the bar on the south bank, lateral scour on the outside of the bend exposed bouldery alluvium deposited by a previous flood.

From the Covered Wagon Restaurant area downstream to the Loveland powerplant, a distance of 0.9 mi, about 65 percent of the highway was destroyed. Along this stretch the canyon is walled by bedrock, except for the scoured-out highway embankment, and deposition was limited to insides of bends and places where the current was slowed or impeded. A bouldery gravel bar was deposited just downstream from a highway bridge that remained standing. The bridge (mile 41.8), although overtopped was spared serious

FIGURE 78 (above and facing page).—Preflood *(A)* and postflood *(B)* view taken near south end of Drake showing part of a huge boulder deposit that caused severe damage to part of the community. Houses in background were outside its path and were little damaged. Peak discharge here was about 28,000 ft^3/s (Part A, table 3).

damage because the flood scoured out the east abutment and formed a new channel. Another bar was formed at the inside of the bend just upstream from a 25-ft-wide bedrock constriction in the canyon wall at mile 41.4. Below the constriction, the canyon widens as it again coincides with the Thompson Canyon fault zone. Here, the flood spread out in the wide valley bottom where the Loveland powerplant had stood.

LOVELAND POWERPLANT AND VICINITY

The brick hydroelectric plant (mile 41.3) and a grassy picnic area shaded by large trees (fig. 82) had stood about 600 ft downstream from the bedrock constriction mentioned in the previous paragraph. As the flood poured out of the constriction, it spread across the valley bottom to depths greater than 10 ft above present stream level. Here, the valley is as wide as 400 ft and has a gradient of about 2 percent. Only the foundation and generators of the powerplant remained after the flood, and almost all the trees were carried away as the flood shifted from its existing channel, reoccupied an old channel at the southern margin of the flood plain, and deposited a debris bar 800 ft long and 200 ft wide between the two channels.

Deposition within this bar varied widely. Along the upstream 450 ft, near the site of the powerplant, about 20 in. of pebbly sand to bouldery gravel was deposited. It, in turn, was blanketed by flood debris, scattered boulders, and a thin layer of micaceous sand. On the remaining 350 ft of the bar, large standing trees created a log jam 9 ft high that trapped coarse alluvium as much as 2 ft thick containing boulders as large as 4.9 ft

in maximum dimension (table 8, mile 41.2). Many logs were more than 2 ft in diameter.

Downstream from the bar to mile 41.0, a distance of about 1,200 ft, channel scour reworked the riverbed and removed most of the finer materials and resulted in a bouldery streamway. A bouldery gravel bar was deposited above a constriction of the canyon at mile 41.0. Between mile 41.0 and Cedar Cove at mile 40.4, the river again swings away from the Thompson Canyon fault zone, the valley-bottom is narrow and sinuous, and the river is confined by a rock-walled canyon 50–150 ft wide. As the floodwater entered this dogleg part of the canyon, it rose to as much as 22 ft above present stream level. Where the canyon again flared out, diminished velocity reduced the tractive force of the flow, and a bouldery gravel bar was deposited. Erosion triggered a small rockfall and scoured the canyon-bottom alluvium. Boulders deposited at the sharp bend at mile 40.5 were as large as 5.8 ft in longest dimension.

CEDAR COVE AREA

Cedar Cove (miles 38.9–40.4) was one of the most densely developed areas in Big Thompson Canyon. Most of the homes here were built on low terraces along the river on a wide stretch that coincided with a part of the Thompson Canyon fault zone. Down through time, erosion along the fault zone and alluviation by the Big Thompson River and Cedar Creek had built a flood plain about 500 ft wide and more than a mile long, with a gradient of only 1 percent. As the flood spread over the valley floor its velocity was greatly reduced. Much of its load of cobbly to bouldery material was deposited as a large braided gravel bar at the upstream end of Cedar Cove. Slightly farther downstream, a large quantity of pebbly sand was deposited as the flood, deeper than 10 ft above present stream level, overtopped the low banks and spread throughout the community.

The mainstream channel and the outsides of bends were heavily scoured, damaging or destroying stream-

FIGURE 79.—Wrecked house and other debris, including large mobile home, lodged on a damaged private bridge at mile 44.7, 0.5 mi downstream from Drake, looking upstream.

FIGURE 80.—Flood damage along the Big Thompson River near center of Drake, looking upstream. Frame house in foreground was washed off its foundation and damaged beyond repair. Exterior wall on the north side of this house was pushed outward around the window. Side of log cabin in background also was offset in a downstream direction.

FIGURE 81.—Remains of diversion dam below Midway at mile 43.25. Before breaching the dam, the water rose at least 5 ft above the crest and left a log wedged in the window of the shack on the right abutment.

front buildings. Buildings on the flood plain were inundated with sediment, and some were carried away. Buildings, fences, debris piles, and trees on the flood plain all retarded the current and intensified deposition (fig. 83). Especially on insides of bends, as near mile 39.5, sand accumulated to depths of more than 3 ft. This sand was horizontally bedded, micaceous, and fine to medium grained. It graded into gravelly sand toward the mainstream channel. Flood alluvium along the main channel was mostly sandy to cobbly gravel, but locally derived boulders were as long as 3.8 ft (table 8, mile 39.5). Below Cedar Cove, the floodwaters entered The Narrows.

THE NARROWS

At The Narrows, mile 38.9 to mile 37, the canyon is only 80–100 ft wide at river level and is walled by steep cliffs of metamorphic rock as much as 1,000 ft high. The mean gradient of the river along this reach is 2.4 percent. In The Narrows, U.S. Highway 34, an irrigation diversion system, and an overhead siphon were all destroyed by the flood.

Along this stretch, the effects of flooding were distinctly different from those at Cedar Cove. Floodwater leaving the Cedar Cove area was loaded with silt, sand, and pebbly gravel, but within The Narrows it quickly picked up coarser debris. Rising 14 ft above present stream level, the flood damaged the concrete dam and diversion system at mile 38.65. It ripped out a 110-ton siphon at the canyon mouth when a floating building knocked out one of the supports (fig. 84). The road embankment, which had occupied about one-half of the canyon floor, was completely removed except for a few tens of feet along insides of bends.

Deposition in The Narrows was confined to gravel bars at the insides of some bends and to small patches of gravelly sand on bedrock walls along the outsides of a few bends. Boulders on the gravel bars were derived chiefly from the roadfill and were as large as 5 ft in maximum dimension. In protected slackwater along the canyon wall, finely laminated and horizontally bedded fine- to medium-grained micaceous sand accumulated to heights of about 12 ft above the canyon floor.

Although the flood severely scoured the canyon in The Narrows, enough material remained in the channel to enable reconstruction of the pioneer highway without hauling in additional fill. The road embank-

FIGURE 82 (above and facing page).—Site of the Loveland powerplant at mile 41.3. *A*, Before and *B*, after the flood. All but the poured-slab foundation and the bolted-down generators was destroyed. Bouldery flood gravel was about 20 in. thick.

ment was simply rebladed from the valley-fill material to its preflood configuration and elevation.

The flood emerged from The Narrows at the mouth of the canyon (fig. 85) with a calculated peak discharge of 31,200 ft^3/s (Part A, table 3).

NORTH FORK BIG THOMPSON RIVER

Some of the heaviest rainfall of the July 31, 1976 storm fell on the North Fork just west of Glen Haven (pl. 2*A*). Flooding and its accompanying damage on the North Fork began near Glen Haven, where Devils Gulch poured substantial amounts of floodwater and debris into the North Fork. Below Glen Haven, the flood traveled down a sinuous, often narrow canyon to Drake—about 8½ mi away and 1,170 ft lower. Near Drake, the discharge of the North Fork was almost 7 times greater than the previous maximum. (See Part A, table 3.)

The canyon of the North Fork has long been a tourist attraction. Here and there were summer cabins, year-around homes, and daytime-picnic grounds; fortunately, the light population and a restriction on overnight camping held down the losses of life and property as compared with the main stem of the Big Thompson River.

ABOVE GLEN HAVEN

The small intermittent tributary in the upper part of Devils Gulch and the tributaries of West Creek, which enters Devils Gulch from the west, were responsible for most of the flooding in the Glen Haven area (pl. 2*A*). Devils Gulch and West Creek had calculated peak discharges of 2,810 ft^3/s and 2,320 ft^3/s, respectively; whereas the North Fork near the west end of the town had a calculated peak discharge of 890 ft^3/s (Part A, table 3).

DEVILS GULCH

Along the upper reaches of Devils Gulch, above mile 1.2, major sheet erosion and gullying occurred on the hillslopes and upland areas. Sheetwash from adjoining slopes was particularly widespread in the small upland meadows just north of the H bar G Ranch. Along this reach, the lower segments of most of the larger side gulches that join Devils Gulch were scoured to bedrock. A short segment of Devils Gulch about 1.5 mi above Glen Haven was also scoured to bedrock.

Culverts were destroyed along the steep (11 percent) upper reach of Devils Gulch, and large gullies were scoured in their place. As the road was overtopped, scouring on one or both sides of the road undercut and destroyed the pavement. The destruction of the Devils Gulch Road severed access to Glen Haven and the North Fork from Estes Park.

WEST CREEK

A small tributary that enters West Creek from the south, about 1,100 ft west of Devils Gulch, received intense rainfall (pl. 2*A*). Floodwaters as high as 8.5 ft above present stream level removed as much as 6 ft of surficial material, scoured the channel to bedrock, and deposited a large gravelly fan at the mouth of the tributary. Lateral scour on the east-facing colluvial slope of the tributary triggered two small debris slides. Most of the drainage basin of West Creek upstream from this tributary, and most of Cow Creek were outside the area of heaviest precipitation, although West Creek rose 5 ft above present stream level just 500 ft upstream from the tributary.

Along Devils Gulch from mile 1.2 to Glen Haven (pl. 2*A*), the major effect of flooding changed from scour to deposition as the stream gradient decreases from about 11 percent to 2 percent and the valley bottom widens. In this reach, side slopes were slightly modified by sheetflooding and gullying. Small scoured tributaries flushed pebbly alluvium into the mainstream or deposited fans at the bases of slopes. Erosion was intense along unimproved roads.

Gravelly sand accumulated to a thickness of about 3 ft where West Creek enters Devils Gulch. In overbank

FIGURE 83.—Helicopter view of the Cedar Cove area near mile 39.6. Floodwater deeper than 20 ft above present stream level deposited a blanket of pebbly sand 3 or more ft thick. Boulders in the main channel were locally derived. Boulders on the high terrace remnant above the channel on far bank were deposited by an ancient flood.

areas, sand was trapped by trees, shrubs, and grasses. Buildings, access bridges, and high ground also trapped as much as 3½ ft of pebbly cobbly sand on their upstream sides.

Many buildings were damaged or destroyed by floodwater and floating debris. Well-constructed masonry structures fared better than wooden ones, even though many of them lost doors and windows and were partly filled with sediment. Some more lightly constructed frame buildings were destroyed when their upstream sides caved in and their downstream walls were pushed out (fig. 86). On the southeast side of Glen Haven, runoff gullied the hillside, scoured the tributary gulch, and deposited a large sandy fan that spread into Devils Gulch and engulfed buildings and automobiles.

WEST OF GLEN HAVEN

Although as much as 12 in. of rainfall was recorded about 1 mi west of Glen Haven between the North Fork and Fox Creek, the storm caused only limited slope erosion and minor damage to gravel roads within the vicinity of Glen Haven. Both Fox Creek and the North Fork overflowed their channels. Above their confluence, Fox Creek was as much as 5 ft above present stream level at mile 0.2; the North Fork was 2.5 ft above present stream level at mile 1.4 and was 3.7 ft above present stream level about one-tenth of a mile west of Glen Haven.

GLEN HAVEN TO MILE 6.7, INCLUDING PIPER MEADOWS DRAINAGE

From Glen Haven downstream to mile 6.7, the North Fork flows through a narrow, winding, steep-sided canyon walled by metamorphic rock. In some places the canyon is only 60 ft wide at river level. Consequently, the flood rose as high as 12.5 ft above present stream level, and it severely eroded its channel and major portions of the road. Redeposited mainstream alluvium was mostly pebble to cobble gravel.

FIGURE 84.—Flood damage at the mouth of Big Thompson Canyon, U.S Highway 34. At upper left of center is a short segment of the toppled overhead siphon, caught against a concrete abutment. The rest of the 110-ton siphon was carried farther downstream. ▶

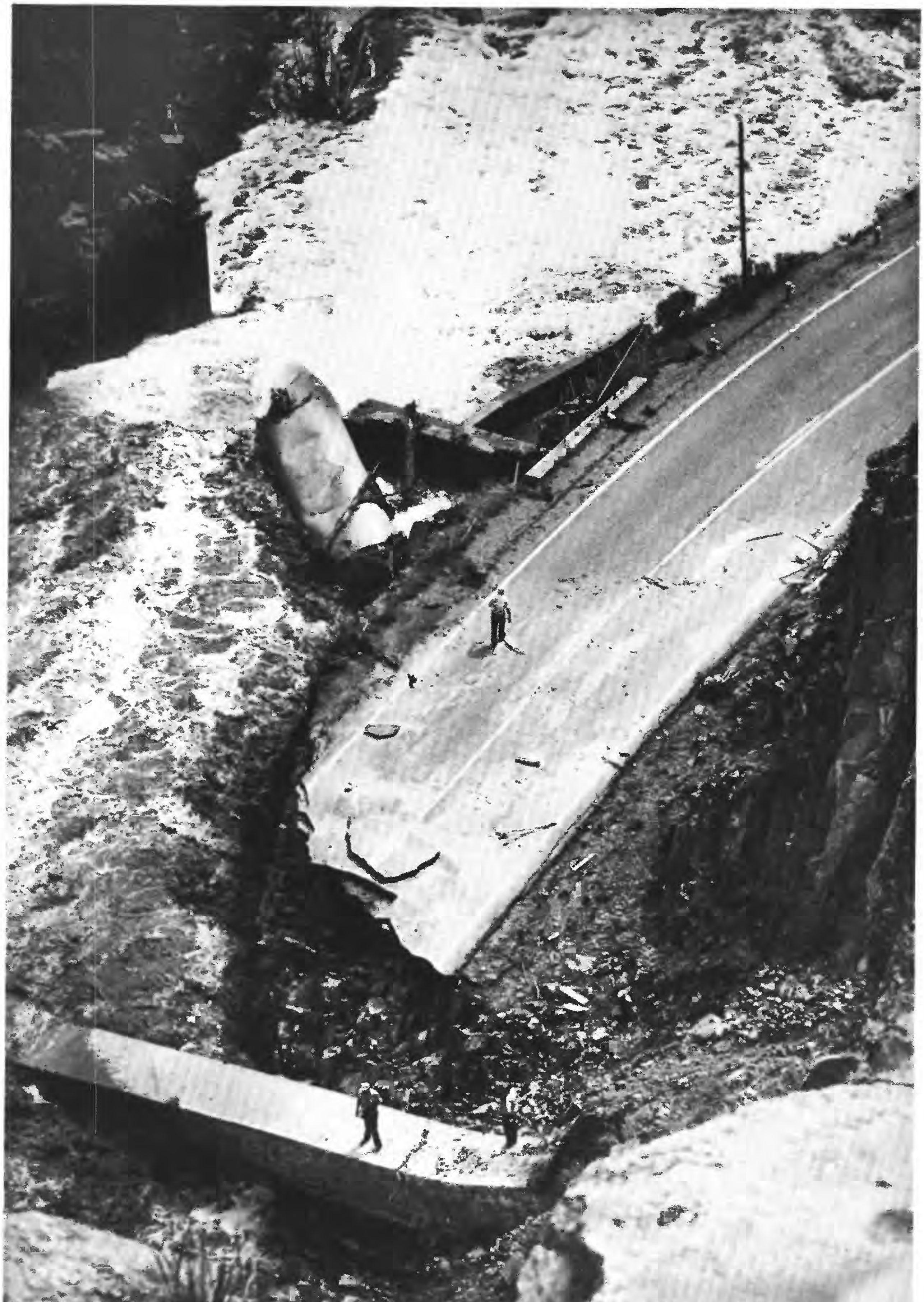

FIGURE 85.—View into The Narrows of Big Thompson Canyon taken from the canyon mouth the afternoon of August 2, 1976, during heavy rainfall. U.S. Highway 34 truncated by scour. Adverse weather and low clouds seriously hampered rescue efforts within the canyon. Crest had fallen but river was still in flood. See also figures 63 and 84.

At mile 7.3, the drainage from Piper Meadows enters the North Fork from the south at Glen Haven picnic ground. Although the basin is only 1.4 mi^2, this intermittent drainage produced by far the highest runoff of any tributary in the storm area (Part A, table 3). It had a calculated peak flow of 9,670 ft^3/s—or about 30 percent of the maximum discharge recorded at the mouth of the Big Thompson Canyon during the flood.

Despite the intense short-duration rainfall and rapid runoff in the Piper Meadows, degradation of the upland surface was relatively minor. Protected by dense native grass, the meadow area sustained little damage. Sheetflooding from the adjoining forested slopes washed sediment into the meadow and deposited about half an inch of sand. In the drainageways, where the gradient was about 7.5 percent, fast-flowing water as much as 3.5 ft deep and 25–30 ft wide flattened the vegetation. Where the sod was locally thin or absent, however, channels were scoured as much as 3.5 ft deep and 10 ft wide. The dirt road in Piper Meadows was gullied only to depths of a foot or two. Because the road follows the ridge crest, most of the drainage was away from rather than towards the road, and damage, therefore, was minimal.

Below Piper Meadows the gradient of the tributary increases to about 12 percent, and the drainage is confined to a narrow gulch bottom. Along this reach floodwaters 8 ft deep cut a channel as much as 6 ft deep and 27 ft wide through alluvial and colluvial material, exposing bedrock. Lateral cutting below steep colluvial slopes triggered a few small debris slides. Rivulets down the steep side slopes scoured out as much as 2 ft of surficial material.

About 0.6 mi above the North Fork, conditions in the Piper Meadows area changed markedly as the drainage crossed from a granitic to a metamorphic terrane. The metamorphic terrane is steeper, and runoff was confined to a steep-sided channel cut in bedrock. Gaining energy, the flow abraded and plucked the steeply foliated rock. Just above the confluence with the North Fork, the water was as deep as 9.5 ft, and it scoured out much of the unconsolidated material from the 45-ft-wide bedrock-walled channel. Lateral cutting in colluvium triggered small debris slides. Although channel alluvium was intensively scoured, erosion did not expose bedrock in the bottom of the channel.

At the confluence with the North Fork, the Piper Meadows floodwater, although charged with debris, contained little boulder-size material. On entering the North Fork it deposited a cobbly gravel bar that partly buried the picnic area downstream (fig. 104), and it scoured out the road on the opposite side of the canyon.

MILE 6.7 TO MILE 5.0

Leaving the confinement of the narrow canyon, the North Fork meanders 1.6 mi through a broad valley, with a gradient of about 2 percent. Here, the flood damaged or destroyed roads, bridges, and buildings. The increased valley width and decreased gradient limited lateral erosion and caused extensive deposition. Pebble to cobble gravel was deposited in the channel, especially along insides of bends. Low terraces, especially between meander loops, were blanketed with pebbly sand, often in a braided pattern. Overbank deposits varied considerably in thickness, but commonly they were thickest on rough ground. Buoyant debris and gravelly sandbars as thick as 3 ft were deposited where flooding was retarded by trees, fences, buildings, and road embankments. Gravel bars were derived chiefly from sources immediately upstream. At mile 5.3, the stream cut off a meander loop and filled the abandoned channel with sand and gravel.

DUNRAVEN GLADE

Tributaries entering the North Fork from the north and west between miles 6.7 and 5.0 were outside the

FIGURE 86.—House in the lower end of Devils Gulch, near Glen Haven, demolished by hydraulic forces and impact from floating debris. The upstream side of the house was pushed in and the downstream side was pushed out. Note thick overbank sand and flood debris caught on trees and fences.

area of most intense rainfall but were flooded nevertheless. In 2.5-mi-long Dunraven Glade, sheetflooding and gullying were confined mostly to the sparsely vegetated southwest-facing slope. These processes were intensified in and along the hillside road, where intense scour cut gullies as much as 5 ft deep and 20 ft wide into humic sandy surficial material. In the upper part of the tributary, sheetflooding deposited isolated patches of fine to coarse pebbly sand an inch or two thick in grassy areas. Downstream, a sandy veneer 0.5–2 in. thick was deposited in the valley bottom. The lower part of Dunraven Glade was only moderately gullied, but roads in the same area were extensively gullied and were washed out where culverts failed. A fan of pebbly sand was deposited at the confluence with the North Fork.

MILLER FORK

Miller Fork, the next north-side tributary below Dunraven Glade, lacked visible effects of heavy rainfall throughout most of its length. Within about 1.5 mi of its confluence with the North Fork, slopes and roads were slightly gullied and small fans were deposited at the mouths of intermittent minor tributaries. On the other hand, Black Creek—the chief tributary of Miller Fork—was scoured along much of its length, thus illustrating the spottiness of the downpour. Black Creek flows into Miller Fork about half a mile above the North Fork and has a gradient as steep as 17 percent. Its calculated peak discharge was 1,990 ft^3/s (Part A, table 3). In the upper reaches of Black Creek, runoff from the steep rocky slopes scoured out the valley fill and most of the road. A debris fan with many boulders a foot or so across was deposited at the mouth of Black Creek on top of an older larger fan that contained lichen-covered boulders as much as 4.4 ft in length.

Downstream from the mouth of Black Creek, Miller Fork locally scoured its channel and deposited overbank pebbly sand. Also, two large debris flows formed on the saturated southwest-facing slope at the colluvium-bedrock interface. At its confluence with the North Fork, Miller Fork had a calculated peak discharge of 2,060 ft^3/s. Miller Fork crested after the North Fork, and it deposited a large sandy debris fan across the channel of the North Fork.

OTHER TRIBUTARIES

The small tributary gulch at mile 5.8 that drains the northwest flank of Crosier Mountain contributed sandy debris to the North Fork. Erosion in this steep tributary was restricted mostly to the lower half a mile where sheetflooding and deep gullying eroded the thick surficial mantle.

Storm effects along tributaries on the north side of North Fork diminished downstream from Miller Fork. Local sheetflooding and gullying eroded southwest-facing slopes, producing small amounts of pebbly sand. Runoff in the first tributary below Miller Fork deposited a veneer of sandy alluvium on a preexisting fan and cut a channel about 4 ft deep and 15 ft wide that undermined and toppled a small building on the fan. Many buildings on debris fans elsewhere in the Big Thompson storm area were similarly damaged or destroyed.

DEBRIS AVALANCHES

Just downstream from the first tributary below Miller Fork, near mile 5.2, two small avalanches broke loose about 120 ft above the North Fork, cascaded down the steep south-facing slope, and dumped bouldery debris into the stream. This debris deflected the river, causing it to scour its north bank and aggrade its south bank. The larger boulders remained in the channel, but the finer debris was carried off by the North Fork.

At mile 5.1, a much larger debris avalanche originated below craggy outcrops about 520 ft above the North Fork. Sliding down a 55-percent slope, it left a conspicuous narrow scar on the hillside (fig. 87). Part way down the slope the avalanche bifurcated around a small bedrock knoll. Debris dumped onto the road and into the North Fork ranged in size from sand to boulders larger than an automobile, but most of the finer material was carried away by the flood.

Below mile 4, the flood plain of the North Fork broadens, and even though the gradient decreases to 3 percent, scour of the mainstream channel was heavy. Many large trees along the river survived, but large culverts were moved, and bridges and sections of the highway were destroyed. In some places the highway alinement became the new channel of the river. Lateral scour also triggered a few small debris slides in colluvium above the flood plain.

At bends in the canyon, gravel bars aggraded and displaced the channel. Locally derived cobbles and boulders and buoyant debris commonly accumulated on the upstream ends of the bars; pebbly sand accumulated on the downstream ends. Overbank areas were covered with pebbly sand that increased in thickness where trees had trapped much buoyant debris.

MILE 5.0 TO DRAKE

From mile 5.0 downstream to Drake damage was confined mostly to the main stream. Tributaries entering the stream from the south above mile 1.6 were scoured by runoff, but those from the north below mile

FIGURE 87.—Scar left by debris avalanche that entered the North Fork at mile 5.1. The avalanche originated just below craggy outcrops at right about 520 ft above the North Fork. It cascaded down the 55-percent slope (foreshortened in this view) dumping large boulders and smaller debris onto the canyon floor. Rainfall here was about 7 in.

3.0 showed no evidence of erosion. Two small intermittent tributaries between miles 3.0 and 4.0 that drain grassy upland areas underlain by thick surficial mantles were appreciably eroded and aggraded. The lower part of the tributary at mile 3.7 was scoured, and a debris fan was deposited at its mouth. Smaller fans of pebbly to cobbly sand accumulated at the confluences of some of the side gulches along this tributary. The tributary at mile 2.8 was also scoured; sandy material partly filled the lower end of the channel and built up in the area behind the highway embankment. The runoff that overtopped the embankment deeply incised the short section of streambed between the highway and the North Fork.

The severest damage to the North Fork was between miles 5.0 and 4.0 (fig. 88). There, the canyon floor narrows locally to a width of about 50 ft, and the gradient increases to about 4 percent. Severe scour destroyed most of the road and removed all but a few large trees. Mainstream channel alluvium was extensively reworked and redeposited primarily at the bends in the canyon. Small pebbly gravel bars accumulated on the insides of bends; whereas large bouldery gravel bars with clasts as much as 2×2.6×4.8 ft accumulated on some of the outsides of bends. A large bouldery gravel bar was deposited as an island at the lower end of the reach where the channel straightens and widens.

From mile 3 to Drake, the North Fork coincides with the Thompson Canyon fault zone. The gradient is less than 2 percent along this broad reach, and the floodwater spread out to a width of about 300–500 ft, blanketing the area with pebbly sand. Gravelly sandbars accumulated to thicknesses of 3 ft or more behind trees, buildings, and other obstructions. Locally derived cobble gravel accumulated downstream from confined reaches. Scour was limited to minor lateral cutting along outer bends.

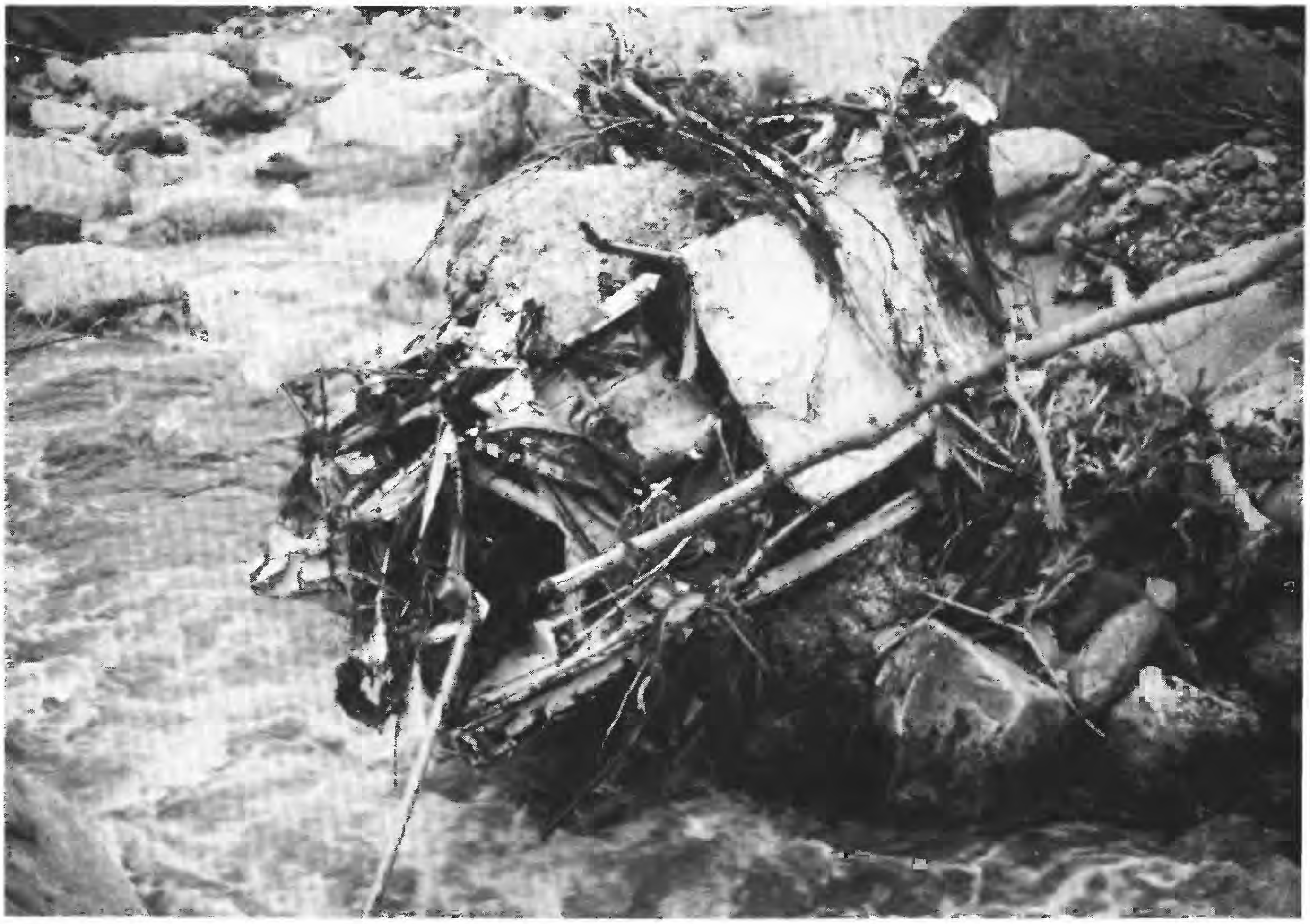

FIGURE 88.—Remains of a medium-size automobile flattened and wrapped around a large boulder in the North Fork near mile 4.5. The U.S. Army Corps of Engineers removed 197 such wreckages, some less and some more severely damaged, along the Big Thompson and the North Fork.

At the State fish hatchery, 0.6 mi upstream from Drake, dams, waterways, roads, and bridges were damaged or destroyed. Diversion systems, raceways, and ponds were filled with 3-4 ft of silty sand and pebbly gravel. As much as 3 ft of pebbly sand was deposited on lawns (Ron Boyd, Colorado Division of Wildlife, oral commun., Dec. 9, 1976).

Between the fish hatchery and Drake, at about mile 0.4, the valley of the North Fork is constricted by an old debris fan at the mouth of Bobcat Gulch (fig. 105). In this short segment floodwater destroyed two access bridges and scoured the fill from around their abutments. Scour along the outside of the bend of the constricted channel destroyed parts of the highway. Below the fan the valley widens again toward Drake where the gradient decreases to 1.2 percent. Along this reach, as much as 4 ft of sand and gravel was deposited (fig. 89).

BIG THOMPSON RIVER FROM CANYON MOUTH TO CONFLUENCE WITH SOUTH PLATTE RIVER

CHANNEL MODIFICATION

During the July 31-August 1, 1976 flood the channel of the Big Thompson River shifted laterally in many places in conjunction with bank cutting and bar building. In some places, especially between the canyon mouth and Loveland, supplementary channels near the outer edges of the flood plain were temporarily occupied. There were, however, no permanent relocations of the river, such as a new course across a meander neck, between the canyon mouth and the South Platte River.

Bank cutting on outsides of curves, commonly associated with widening or downstream extension of point bars on insides of curves, took place at intervals determined in large part by the spacing of changes in

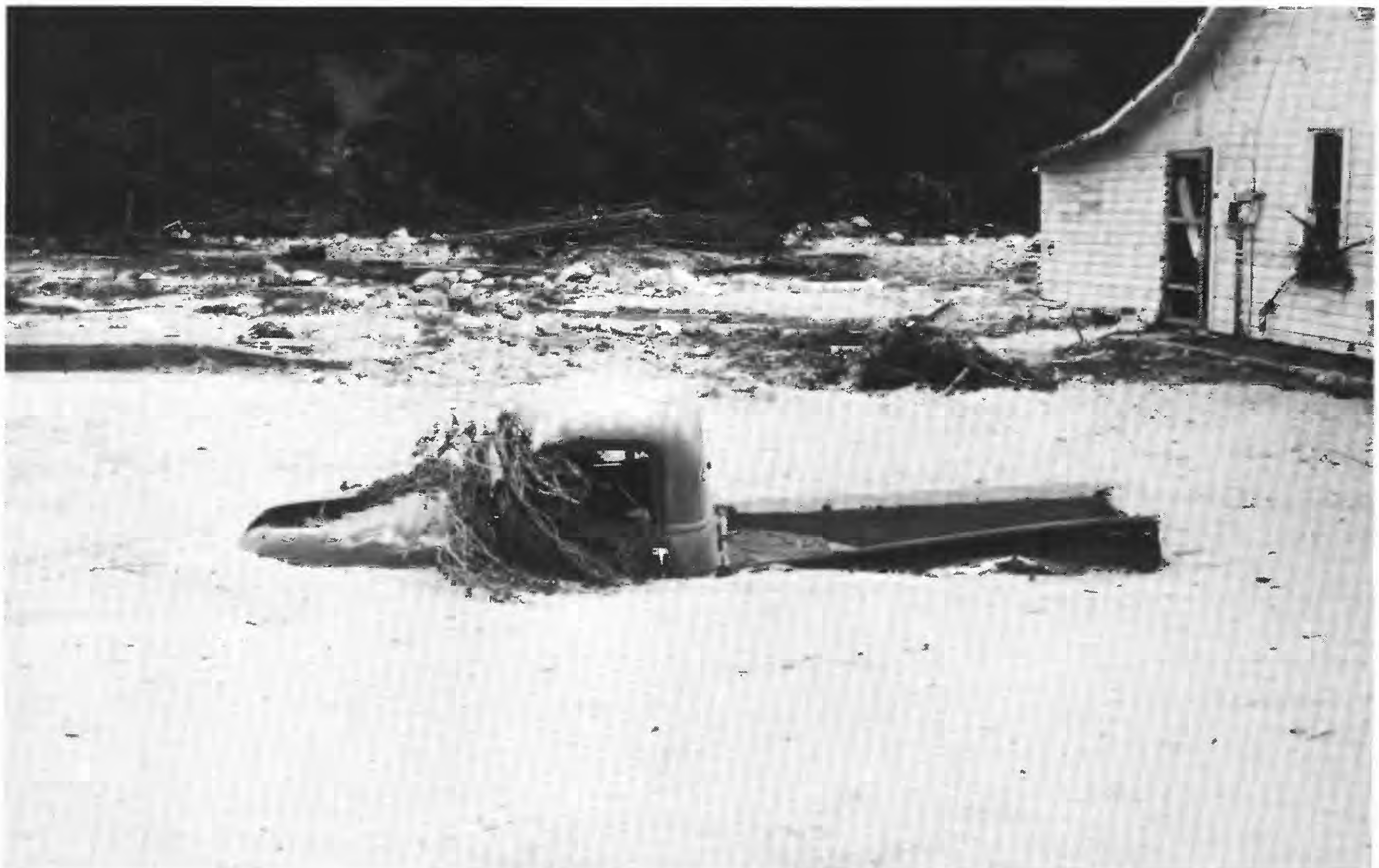

FIGURE 89.—Pickup truck partly buried by coarse sand deposited by the North Fork (in background) near its confluence with the Big Thompson. Note debris on cab of truck, in window of house on right, and on gravel bar in the background. Flow in this view was from left to right.

channel direction. Minor bank cutting became nearly continuous as the channel pattern changed downstream from long nearly straight reaches and a few bends east of the canyon to many meander loops in the wider part of the valley approaching the South Platte River. Most commonly, where the extent of cutting or slumping could be determined or estimated, a bank width of 3–6 ft or less was affected. Deeper invasion of banks was seen in several places, however.

Comparison of preflood (1971) and postflood aerial photography indicates that lateral scour cut at least 50–75 ft into the south bank between the powerplant near the canyon-mouth dam and an area beyond the first bridge below the dam. Houses on the south bank 10–12 ft above the river were undercut, and the bridge was destroyed. South-bank cutting was paralleled by deposition of a north-side point bar of sandy to bouldery gravel 100 ft wide and about 500 ft long. Other segments of the banks between the dam and the first hogback were cut back by amounts smaller than that in the area of the first bridge. At the first hogback, the river is between steep banks of hard bedrock or of artificial fill on which a narrow road had been constructed. Flood damage in this reach was restricted to destruction of parts of the road and underlying fill and removal of a steel bridge across the river (fig. 90).

Southwest of Loveland in high banks 500–600 ft west of Taft Avenue, an estimated 20 ft of lateral erosion was evident (fig. 91). On the upstream side of a meander loop 500 ft west of this area, the river cut into an 8–10-ft bank of old pebble and cobble alluvium, redistributing some of this material on the point bar on the tip and downstream side of the meander. Here and elsewhere on point bars, the clearest evidence of movement of coarse sediment by the flood was partial burial of grass, cattails, or smaller weeds beneath cobble or pebble gravel and sand (fig. 92).

Alluvium at channel edge was eroded back at least 20 ft in a 6–8-ft bank in the Riverview Campground about 2.5 mi downstream from the canyon mouth. In a pasture about 1 mi east of U.S. Highway 287, a high

FIGURE 90.—View of damage to road and abutment of steel bridge torn out by Big Thompson River where it crosses first ridge east of Big Thompson Canyon.

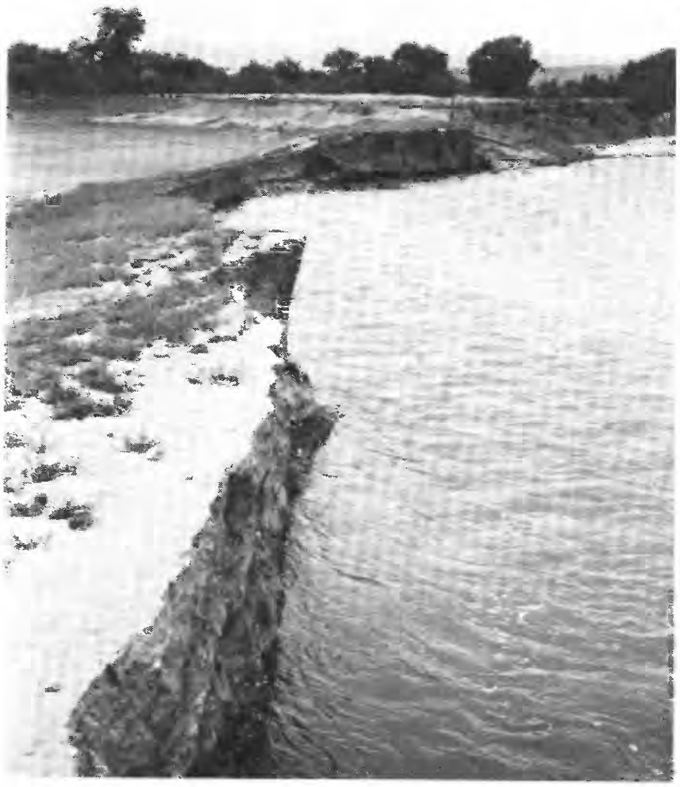

FIGURE 91.—Lateral cut, estimated at 20 ft, into south bank of the Big Thompson River west of Taft Avenue, southwest of Loveland. Abandoned gravel pit on the left was flooded.

bank was eroded back far enough to destroy vehicle tracks 7–8 ft wide near the bank edge. Comparable erosion appeared to have taken place in other areas as well, but we had no basis for making a specific estimate of the amount of bank removed.

Bank conditions varied widely after the flood. Grass or weeds growing on some steep cut banks indicated that bank materials were not everywhere eroded by the recent flooding, even on the outer sides of channel curves. More often, however, especially in the western part of the valley, the preflood bank face and its vegetation were stripped away; along wooded banks, tree roots were extensively exposed. In low pastureland, where the turf was thick, many detached blocks of turf and soil slumped to the water's edge, or sagged where the turf remained attached but where the underlying soil and fine-grained alluvium had been washed away. The undermining of turf 7–8 ft or more in width north of Johnstown may be characteristic of unusual flooding. The more common narrower turf blocks suggest a flood magnitude no greater than that which, according to residents closer to the South Platte River, occurred "several times" in recent years.

In general, bedrock along the channel banks was little affected by the flood. Some of the resistant ridge-forming sandstones in the hogback belt had only a faint stain line at high-water level. On the south side of the river less than 2 mi west of U.S. Highway I–25,

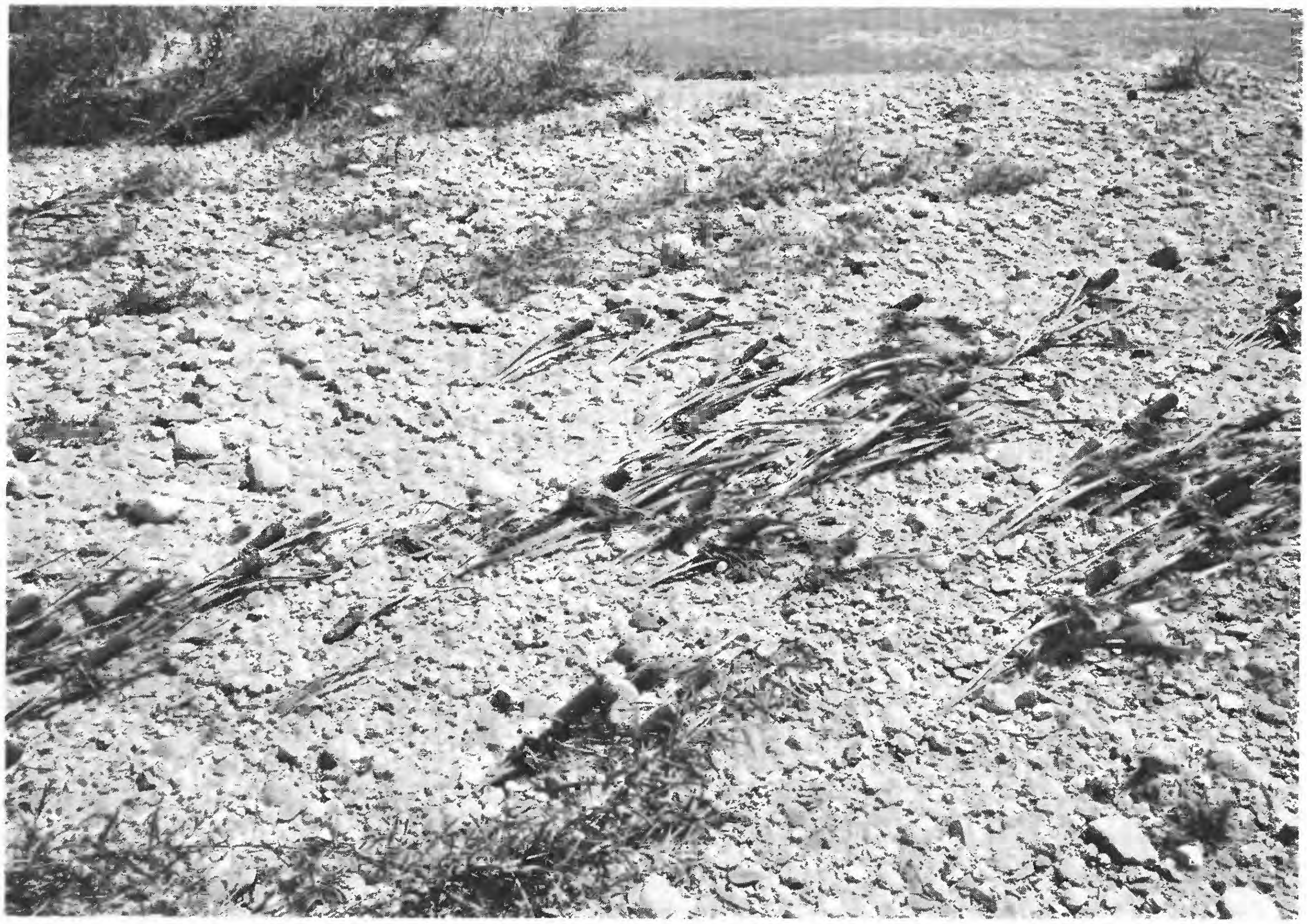

FIGURE 92.—Movement of small cobbles and pebbles on a point bar indicated by partial burial of cattails 2-3 ft tall; about 600 ft east of U.S. Highway 287 south of Loveland.

however, floodwaters cut into soft shale banks below a sharply defined, nearly horizontal line that appeared to be about 5 ft above normal river level. A few partly detached blocks of weathered shale and vegetation still clung to the bank below the flood-cut line.

Locally, banks were modified by water returning from overbank areas to the river channel by way of a low place in the edge of the bank. In such places the bank edge was eroded, and a crude fan of sediment was deposited on the bank face.

OVERBANK DEPOSITION

Deposition over the channel banks of the Big Thompson diminished rapidly downstream. Four major zones of overbank sedimentation between the canyon mouth and the confluence with the South Platte were recognized (pl. 2*A*, 2*B*). Each zone graded into the next, but each had an average identity in terms of sediment grain size, maximum thickness, distribution, and sedimentary structure. Some of the sediment described in the following paragraphs was removed in cleanup operations after the flood.

ZONE 1, CANYON MOUTH TO BIG THOMPSON SCHOOL

The first sedimentation zone downstream from The Narrows (mile 37 to mile 34.3) crosses two valleys and two hogback ridges in about 2.5 mi. Within this zone, overbank sediment was dominantly fine to very fine, very micaceous sand. Maximum thicknesses were probably as much as 6 ft in the western valley segment of the zone and approximately 4 ft near the east end of the zone. Thickness varied nonuniformly both downstream and between the channel edge and the outer edge of deposition. With few exceptions, the deposits were flatbedded and without obvious vertical gradation in grain size.

Between the mouth of the canyon and the first hogback ridge, overbank flow and deposition took place mainly on the north side of the river. Some current-swept areas near the riverbank retained only an inch or less of sand caught in turf. Sand deposits were thickest generally on the downstream or lee side of trees and debris piles and around houses. Where currents moved freely between obstructions, the sand was thinner. The outer parts of lee deposits were cut away at two or more levels as the water surface dropped. As much as 4-5 ft of sand and some coarser material accumulated around houses and as lee deposits at the first bend in the river below the dam. The greatest volume of sand, however, appeared to be immediately upstream from the hogback ridge. A right-angle change in channel direction and constriction of flow where the river entered the narrow passage through the ridge, as well as diversion of part of the flow across the flood plain toward Sulzer Gulch, presumably reduced the rate of flow and forced deposition of a major part of the sand load. After the flood, low channels between terraced mounds of sand as much as 3-6 ft thick made a ragged landscape that probably bore little relation to the preflood surface (fig. 93).

Although micaceous fine sand was by far the most abundantly deposited material, both coarser and finer sediments were left in parts of the overbank area. Cobbles, pebbles, and coarse sand from the channel moved over the low banks of the first river bend below the dam, and silt settled from water that was trapped in houses there and farther downstream. In a roughly triangular area at the mouth of Sulzer Gulch, near the hogback on the north side of the Big Thompson River, slightly silty very fine sand settled out of water that presumably was ponded by the large volume of sand deposited immediately upstream from the ridge. In this area, desiccation cracks formed irregular blocks 5-8 ft in maximum dimension (fig. 94). Closer to the main channel of the river, silt made up less than 10 percent (estimated) of most of the sandy alluvium.

FIGURE 93.—Flood-deposited sand near confluence of Sulzer Gulch and Big Thompson River showing two terraces cut below highest level of deposition.

FIGURE 94.—Desiccation cracks in slightly silty very fine sand trapped at mouth of Sulzer Gulch, west of first ridge east of mountain front. Large blocks are 5–8 ft in maximum dimension.

The floodwaters also deposited in this area large amounts of debris from above the canyon-mouth dam—trees, bridge timbers, parts of houses, highway markers, and other buoyant items. Several houses along this reach of the river were partly or totally destroyed by the force of the water or impact of debris. Along the edge of the flood plain, some trees and large masses of turf were torn out and pines were stripped of bark on the upstream side to heights of 9 or 10 ft above ground level (fig. 95). Bark from pines within this zone or farther upstream was found as far east as the Johnstown area, more than 20 mi downstream.

The narrow passage of the river through the first hogback is a small canyon that contains almost no overbank area capable of accumulating flood deposits. Downstream from the first ridge, the river follows a slightly sinuous course through a narrow flood plain in a southward extension of Green Ridge Glade. Most of the overbank sediment in this area was fine to very fine micaceous sand, thinly deposited in open areas but nearly 4 ft thick in the lee of large debris piles in the cottonwood groves north of the Highway 34 bridge (fig. 96). Unobstructed flood currents terraced the thick deposits of sand at one or two levels and left grass exposed in open areas, especially near bank edges. Here, as in other groves farther downstream, massive amounts of broken trees and other buoyant debris were filtered from the flood by standing trees that were able to resist the impact of the flood load. In some places the resulting debris dams provided protection to houses built within several of the groves, but, elsewhere, houses directly exposed to impact were partly destroyed—some beyond reconstruction (fig. 97). Some buildings were rotated on their foundations.

High-velocity flat bedding was the only sedimentary structure observed in the sand, except very local slump structures in beds that were laid down against bordering slopes at the outer edges of the flood plain. Sand

FIGURE 95.—Upstream side of ponderosa pines stripped of bark by impact of flood debris, between dam at mouth of Big Thompson Canyon and first ridge east of canyon; note also, destruction of flood-plain turf.

FIGURE 96.—Current-terraced deposit of sand, 3–4 ft thick, on downstream side of debris pile in cottonwood grove about half a mile west of Big Thompson School.

FIGURE 97.—Condemned damaged house and debris pile in cottonwood grove about half a mile west of Big Thompson School.

beds plastered against a steep curved border slope west of the river near U.S. Highway 34 extended at least 15 ft above late-August river level; close to the channel edge, 2 or 3 ft above water level, only a thin layer of sand was laid down.

Sediment both coarser and finer than the dominant fine sand was laid down in small quantities in overbank areas in the valley south of Green Ridge Glade. Dark clayey silt collected in a ponded area between the north side of the U.S. Highway 34 embankment and the ridge slope in the gap through the second hogback. Cobbles, pebbles, and coarse sand were noted in many places along the glade at or near bank edge. Channel edges here are generally very low banks or are gradational into the flood plain without distinct banks. Movement of coarse material from channel floor or cut banks to flood plain apparently had been accomplished easily in many places. How much of the coarse sediment reached the flood plain in the 1976 flood and how much in earlier floods of smaller magnitude is not clear, but recent movement of such material on the flood plain was indicated by crudely imbricated deposits of pebbles and cobbles over grass and by a cobble resting on a small transported tree.

ZONE 2, EAST OF BIG THOMPSON SCHOOL TO LOVELAND

In this zone (mile 34.3 to mile 25.0), silt was a major component of overbank sedimentation and increased downstream in proportion to sand. Sand, ranging from coarse to very fine, was still dominant near riverbanks. In bordering fields and cottonwood groves, deposits graded outward from sand through silty sand, sandy silt, and in some places silt or clayey silt. All overbank sediments were highly micaceous. Maximum thicknesses, usually close to the river, were nearly everywhere less than 2 ft. Changes in thickness across any one area were usually nonuniform. As in zone 1, thicker than average deposits accumulated on the downstream sides of trees and brush (fig. 98). Terraced mounds of sand not obviously trapped by vegetation were left isolated in several fields. In general, sand

FIGURE 98.—Lee deposits of flood-borne sand on down-current side of bushy weed (3-4 ft original height) east of Glade Road (sec. 7, T. 5 N., R. 69 W.).

deposits were flatbedded, but in a few places minor slump bedding developed or final draining of water left a thin coating of rippled sand.

Modification of flood effects by human use of the flood plain increased downstream toward Loveland. In fields southwest of the city, maturing corn was broken off or overridden by broken trees and other debris that floated across the fields or piled up in ragged wedges well within the stands of corn (fig. 99). Water flowing through the fields downstream from the debris piles left only a thin deposit of silt. This type of crop damage occurred more often in the heavily farmed segment of the valley east of U.S. Highway I-25 than in the area upstream from Loveland, but the reduced amount of both debris and water downstream caused less destruction, in most cases, to the invaded fields.

Close to Loveland, large gravel pits, both active and abandoned, gradually displace agricultural use of the land. Where floodwater broke into these pits and was temporarily retained, clay and silt settled out. Pits not normally containing water were floored with mud-cracked sediment after the floodwater drained away.

In the urbanized area south of Loveland, artificially high banks armored with riprap prevented overbank flow in some places but were overtopped or were absent in others. Where the river passes through the Larimer County Fairground, very little bank erosion occurred because of extensive riprapping, but nearly all parts of the grounds were flooded and blanketed with fine sediment. A dealer in used auto parts, east of U.S. Highway 287, reported thin silt throughout his car lot. In an unprotected low part of the lot, 18 in. or more of sand partly buried an auto body; in a slightly higher area closer to the river, only patchy sand and silt settled around bent-over grass that still indicated flow patterns two and a half weeks after the flood.

FIGURE 99.—Flood damage in cornfield southwest of Loveland. Debris-laden water, moving from left to right, broke cornstalks in part of the field and drove wedges of broken trees and other debris into corn that remained standing. Approximate scale: 1 in.=250 ft.

ZONE 3, SOUTHEAST OF LOVELAND TO LARIMER-WELD COUNTY-LINE ROAD

Thickness of overbank silt and sand in this zone (mile 25 to mile 15.7) generally decreased downstream from a maximum of about 1 ft to less than 6 in. Through most of the zone, the proportion of silt to sand increased downstream. All examined deposits were highly micaceous, except as noted in the following paragraph.

About 1.5 mi east of U.S. Highway I–25, coarse sand increased abruptly in overbank deposits. For nearly a mile along the south side of the river, coarse to medium sand was concentrated near the edge of the overbank area and in shallow linear depressions paralleling the bank. Thin deposits of finer sand or sandy silt between the depressions graded to silt away from the river or to clayey silt in old meander scars where floodwater was ponded. The percentage of mica in overbank sediment was markedly lower than the amounts observed both upstream and downstream from this area. These local changes in overbank sediment indicated local sources in the stream channel or in fresh cut bank alluvium. In this area, also, on the north side of the river, a downstream splay of large pebbles and coarse sand across very low bottomland was traced 40–50 ft directly back to a bank cut containing old gravel near water level. Some of the variation in amount and texture of overbank sand in zone 2 also may be due to local derivation of sediment, but the evidence is less conclusive there than in zone 3.

ZONE 4, LARIMER-WELD COUNTY-LINE ROAD TO CONFLUENCE WITH SOUTH PLATTE RIVER

Overbank sediment in zone 4 (mile 15.7 to mile 0) was predominantly silt. Fine sand and patches of coarser sand were deposited locally near bank edges. Overbank deposits were generally micaceous. Along some very low banks, pebble and sand splays or coarse to medium sand tongues extended over bottomland. Thickness of overbank sediment was generally less than 6 in. and commonly less than 1 in. On inundated pasture land, areas apparently free of any flood sediment occurred within the larger area of flood-deposited silt. Distribution of the very thin silt deposits seemed to have been controlled by nearly imperceptible variations in the surface. Outer edges of silting showed sharply against some sloping surfaces but were indistinct on many flatter surfaces. In crop areas it was sometimes difficult to distinguish flood silt from silt redistributed by irrigation of the fields.

In parts of zone 4, overbank deposits were less readily differentiated from channel-edge sediments than in much of the upstream area. Abundant meander scars locally merge channel and adjoining bottomland in a bankless quagmire of boggy mud churned by cattle. Floodwaters added silt and sand to these areas of confusion.

As the thickness of overbank deposits decreased downstream, recognition of the outer limits of such deposition became more difficult. To assist in locating the probable limits, an effort was made to estimate the height to which the water level rose. These estimates in zone 4 were made in part on sediment distribution and in part on the basis of grass caught on trees or fence wires and apparent high-water marks on trees and fence posts. Some flood sediment was found on ground higher than such markings, or water in higher fields was reported by farmers. Some of the so-called high-water markers, therefore, were interpreted as possible pause levels of receding floodwater. Our best controlled estimates in zone 4 indicated rises of at least 8 ft (above late-August water levels) in the upstream locations and about half of that amount where the Big Thompson River flows in a dredged channel between confining banks about a mile from the South Platte River. Residents along the South Platte River about 1.5 mi below the Big Thompson River confluence reported a water rise of between 1 and 2 ft at most.

Although freshly broken or uprooted trees were noted on the flood plains in zone 4, a large part of the debris appeared to be tree trunks and branches from previous overflow or from causes unrelated to flooding. Much of this material was redistributed by the 1976 flood. U.S. Army Corps of Engineers personnel, working with cleanup crews, stated that large amounts of preflood debris were being removed with that of the recent flood.

DAMAGE CAUSED BY GEOLOGIC PROCESSES DURING FLOOD-PRODUCING STORMS

By JAMES M. SOULE[2]

GEOLOGIC HAZARDS[3]

Damaging processes that were active in geologic-hazard areas above mainstream flood levels during the 1976 Big Thompson flood may be grouped under (1) water transport of soil, rocks, and vegetation debris and (2) mass wasting of slope materials. Water transport processes were sheet erosion and deposition of surficial materials, downcutting of drainageways, mobilization of large debris (including vegetation and manmade structures) on hillslopes, and deposition of debris on debris fans or movement of debris across debris fans and into major stream courses. Mass wasting produced landslides, including slumps,

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[3]In this section, "geologic hazards" refers mainly, but not exclusively, to such hazards above the legally defined 100-year-flood plain of the Big Thompson River. According to Colorado statute 106-7-103 (8) C.R.S., waterflooding is not considered to be a geologic hazard. For a discussion of the State of Colorado's involvement in geologic-hazard area identification and legel definitions of geologic hazards, see Rogers and others (1974).

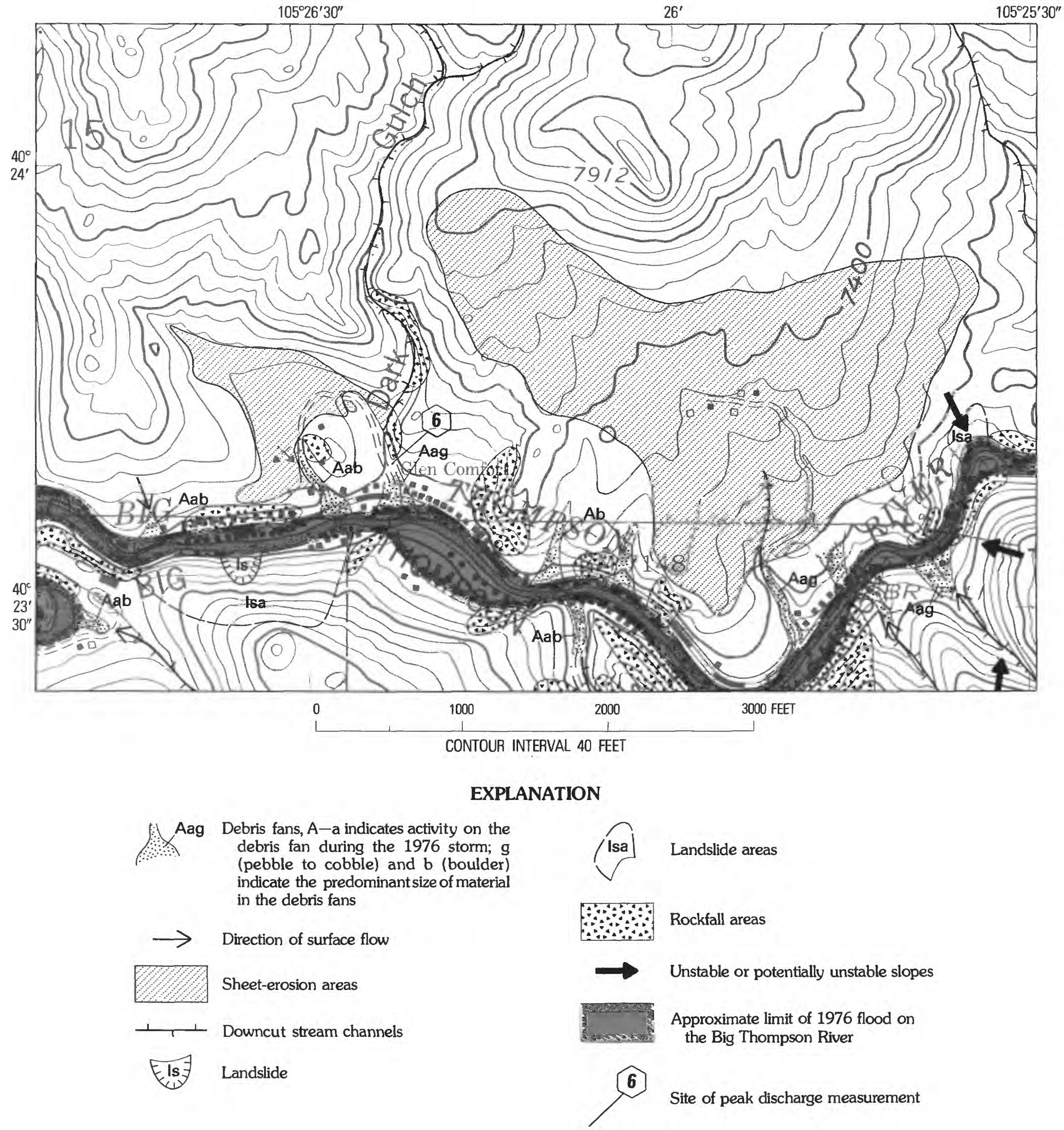


FIGURE 100.—Geologic hazards in the Glen Comfort area, between mile 53.4 and mile 51.9 on the Big Thompson River, are typical of much of the Big Thompson area (modified from Soule and others, 1976). Base from U.S. Geological Survey 1:24,000 Glen Haven, 1962.

rockfalls, rockslides, debris avalanches, and debris slides. The most common damages to structures were caused by impact by moving vegetation and earth-materials debris, failure or erosion of slopes or of roadways and other earthfill structures, and partial to complete burial of buildings by silt- to boulder-size colluvium or alluvium or by vegetation debris. The rates at which these processes operated apparently varied from nearly imperceptibly slow to exceedingly rapid. Distribution of geologic hazard areas along part of the Big Thompson River is illustrated in figure 100.

During the 1976 Big Thompson storm and flood, the disastrous effects of geologic processes on life and property above the 100-year flood level were mainly in areas of maximum rainfall, highest rates of rainfall, or greatest runoff. Geologic processes that could be activated by future storms have been identified in many other places throughout the Big Thompson area. Heavy damage to inhabited areas can happen, as it did in 1976, in heavy rainfall areas where runoff is channeled into steep tributaries and mainstream courses. Flash flooding in such places was so sudden and of such magnitude that little, if any, warning of the impending danger to residents was possible. In areas of light rainfall during the July 31, 1976 storm, much of the damage in geologic-hazard areas close to the flood level of the Big Thompson and the North Fork was caused by the swollen waters of the main streams, which picked up and transported much of their bed materials and undercut adjacent slopes.

In the examples discussed subsequently, much severe damage was caused by geologic processes acting above the legally defined 100-year flood plain. Not unexpectedly, many such areas have been preferred building sites in the past and presumably will continue to be under pressure for part-year or full-time recreational-residential development in the future. Many of the geologic hazards in these areas are the results of land use that was constrained by lack of practical alternative building sites. Early development of canyon bottoms and a few other gently sloping areas came about because of the attractiveness of streamside building lots and the difficulties associated with construction, water availability, and the accessibility of steeper valley sides. Because relatively large, esthetically pleasing building sites were available at some stream confluences and because these same areas provided easy access slightly above the mainstream flood plains, they have become the sites of most small communities in the canyon area.

In recent years limited development has taken place in a few higher areas away from streams. In developed high areas that have gentle to moderate (5–15 percent) slopes, erosion and redeposition of granitic grus and soil caused damage during the storm of 1976. In the relatively steep (>30 percent slope) parts of these high areas, places susceptible to mass slope movements, such as slumps and debris slides, are common. Slumping seems to be more common on predominantly north facing slopes, owing to the presence of relatively thick colluvial deposits. Predominantly south facing slopes, where the veneer of debris is thinner, are susceptible to debris sliding and debris avalanching. Rockfalls usually occur below cliffs. Although few of these mass movements are known to have caused major damage during the 1976 storm, the potential for future loss of life and property is great if susceptible areas are developed for residences.

DAMAGE IN GEOLOGIC HAZARD AREAS

Damage related to geologic hazards was most widespread where rainfall was very heavy, but severe damage in downstream areas of lighter rainfall resulted from erosion and deposition by the trunk streams, which carried abundant upstream runoff and debris. Damage in several types of geologic-hazard areas affected by the storm and flood, and the potential for similar damage in the future, are discussed in the following paragraphs.

DAMAGE ON DEBRIS FANS

Because of their number, total area, density of residential development, and potential for damage during heavy regional rainstorms or intense local thunderstorms, debris fans are the sites of serious geologic hazards in the Big Thompson drainage basin. A debris fan or a related but less clearly defined deposit of stream-borne rock debris exists at virtually every stream confluence in the Big Thompson area, including those of small ephemeral streams. Damage may result when the rising mainstream overruns the fan or cuts part of the fan away, or when flash flooding of the tributary itself mobilizes debris on the fan (fig. 101). The amount and type of tributary damage may be influenced by the size, slope aspect, and nature of the surface materials of the tributary drainage basin and by the gradient of the tributary drainage. Figures 102 and 103 illustrate typical heavy damage in the 1976 storm to structures on relatively small debris fans.

Slope aspect and composition of bedrock within a drainage sometimes influence the damage that may occur on a debris fan. In small steep drainages where south-facing slopes predominate, large boulders and nearly unweathered rock debris usually constitute the bulk of the slope material. Where north-facing slopes predominate, vegetation commonly makes up much of the debris. This mixed debris can greatly affect damage inasmuch as large rocks and pieces of trees or other vegetation can block the drainage channels and thus locally concentrate debris and flooding. To predict the resulting damage on the debris fan, therefore, is difficult or impossible. Owing to vegetation cover and greater soil moisture, predominantly north facing slopes tend to have deeper soil and less coarse weathering products than south-facing slopes. Surficial characteristics are similar where gentle slopes are composed primarily of granitic grus or fractured and weathered metamorphic rocks. Debris fans heading in these areas tend to consist of pebbly to cobbly, as opposed to bouldery, material (fig. 104). Structures built on such fans are perhaps unlikely to be damaged by impact from very coarse debris, but they are not less vulnerable to water damage than structures on coarse-debris fans.

Extensive flooding and spreading of bouldery debris on debris fans by tributary streams have occurred in the Big Thompson area in the past and could be a hazard in the future, although this did not happen in 1976. A conspicuous recent example of boulder flooding is at the confluence of Bobcat Gulch with the North Fork Big Thompson River (mile 0.5). As indicated in figure 105, the moderately large debris fan at this locality is strewn with little-weathered boulder debris that appears to be no more than a few hundred years old and may be considerably younger. The course of the North Fork seems to have been deflected toward its present location by one or more episodes of boulder-debris deposition. Although moderate erosion and flooding of the Bobcat Gulch debris fan during the 1976 flood was caused by the North Fork and not by the tributary drainage, the area clearly has potential for a catastrophic boulder flood, derived from the tributary. Consequently, Bobcat Gulch and similar areas are considered to be hazardous for houses and other structures.

DAMAGE ON VALLEY SLOPES AND IN TRIBUTARY DRAINAGES

Erosion and deposition of fine-grained surficial materials caused significant damage on valley slopes. Where heavy rain fell on steep, openly wooded slopes without protective ground cover of grass or other vegetation, sheet flooding eroded large amounts of loose surface material (p. 100). Sheet erosion also occurred on many gentle slopes where virtually no drainage net existed before the flood and where grass cover was sparse. In broad areas sheet erosion removed as much as 6 in. of material. In several residential subdivisions above flooding streams, extensive damage was caused by deposition of sediment on building lots (fig. 106), inside buildings, and on roads by erosion of unpaved roads and drainage control structures.

Gullying was especially troublesome in colluvial and residual materials derived from granitic rocks (fig. 107). In some places the breaking of grass cover by a wheel track had provided shallow channels that became gullies several feet deep (p. 100, 120).

In many parts of the Big Thompson drainage basin, sheet erosion and gullying are major potential problems for future residential developments on high ground above stream flood levels, especially where natural drainage is extensively modified by cuts and fills for roads and buildings or where sparse natural vegetation is greatly disturbed.

DAMAGE IN LANDSLIDE AREAS

Many places in the Big Thompson area are susceptible to slope failure, and many slope failures took place during the July 31, 1976 storm. Fortunately, only a few caused serious damage, largely because most of the affected areas lacked residential development. In some places, small landslides partly buried roads. Small slumps from banks of deepened tributaries caued minor damage and diversion of floodwater.

An existing landslide that was considerably enlarged by the 1976 flood caused the loss of a house and its access road (fig. 108). Several other canyon areas contain potential landslides that could be released in future storms and floods (Soule and others, 1976). Houses have been built in or downslope from some of these places.

The several debris avalanches near miles 5.2–5.4 of North Fork Big Thompson River (fig. 109) caused no major damage, but similar surface conditions elsewhere in the Big Thompson area suggest vulnerability in places that were not damaged by the 1976 storm.

Little apparent damage was caused by rockfalls in the Big Thompson area during the 1976 storm and flood, although moderate to extreme rockfall hazards exist on some of the steep canyon-side slopes. Minimal rockfall damage was due to two factors: (1) rockfalls in this area apparently are less commonly associated with storm precipitation and flooding than with winter and spring freeze-thaw cycles and (2) most rockfall hazard areas, because of their steep slopes and difficulty of access, have not been developed as building sites.

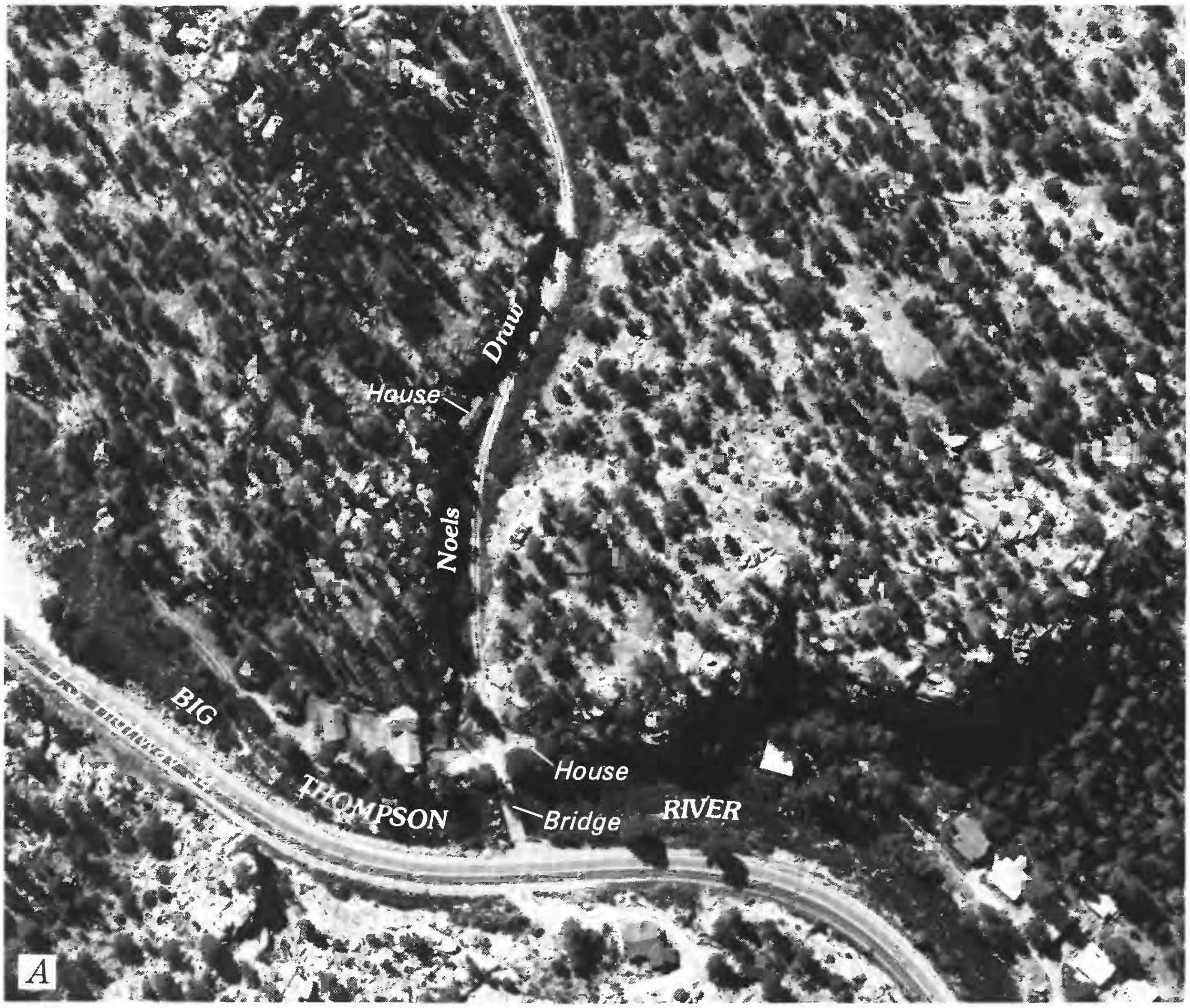
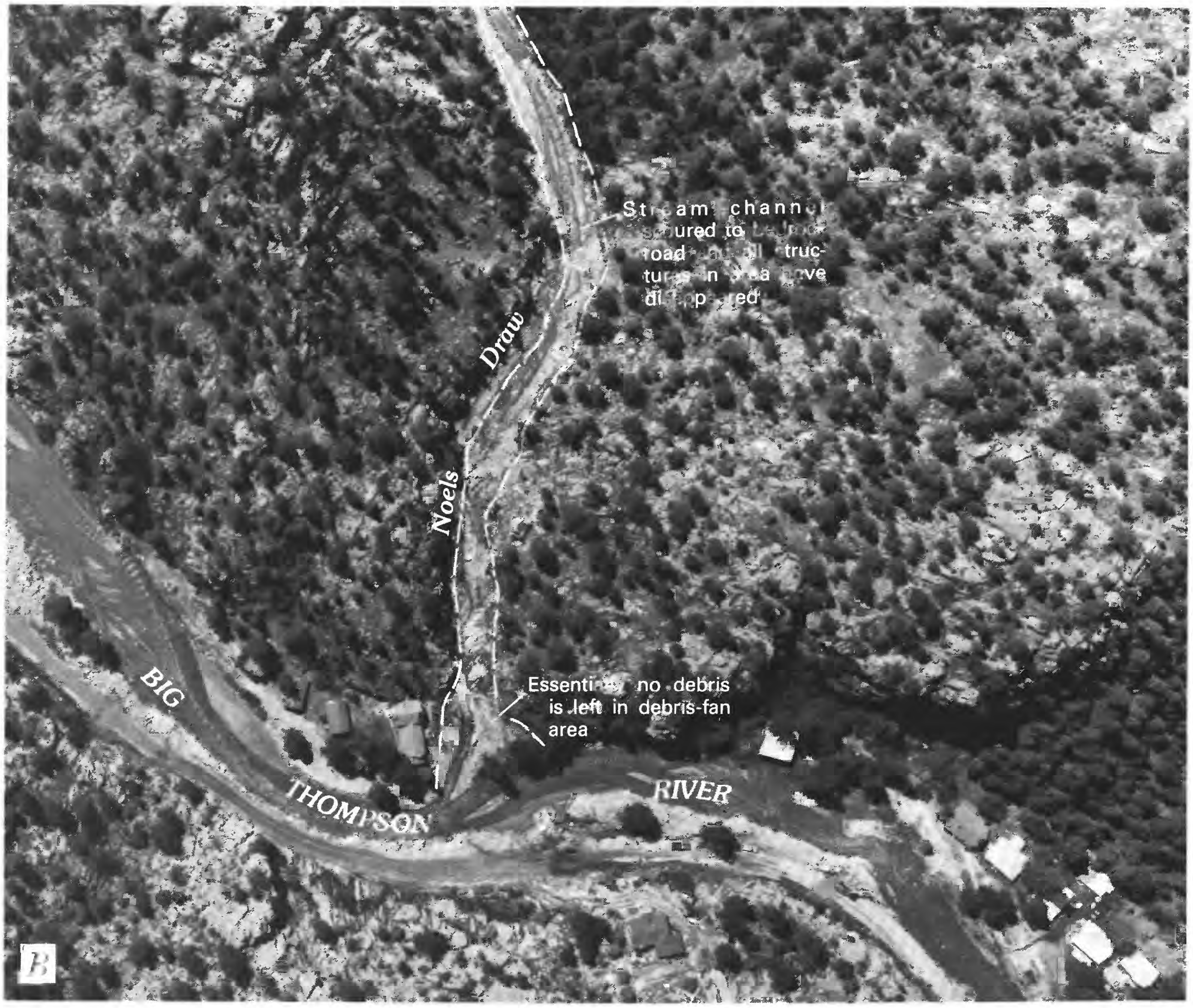


FIGURE 101 (above and facing page).—Aerial views of Noels Draw, mile 52.7 on the Big Thompson River, before and after the 1976 flood. *A*, Preflood view; *B*, postflood view, August 3, 1976. The bedload of Noels Draw had been transported and removed from the draw. This drainageway has a peak discharge of 6,910 ft^3/s during the 1976 flood. (See Part A, table 3.) All structures in or near the streambed (outlined) have been destroyed, and the debris fan has been partly eroded away. The bridge and house that were on the fan before the flood are gone. Approximate scale: 1 in. = 200 ft.

CONCLUSIONS

The Big Thompson storm and flood of 1976 were exceptional but not unique events. Comparable storms and floods have happened in the Front Range area in the past and probably will happen in the future. The flash flood environment developed when very moist, conditionally unstable air, carried into the Front Range by strong easterly circulation, was lifted orographically, triggering the explosive growth of very large thunderstorms. Weak westerly wind aloft retarded the normal drift of the thunderstorms as moist air continued to flow into the system from the southeast at lower levels of the atmosphere, thus localizing exceptional amounts of rainfall.

Unprecedented unit-area discharges from small tributary basins of the Big Thompson River resulted from the high intensity of the downpour and the steepness of the terrain. Feeding into the main stem, the runoff from these tributaries caused a flood in the



canyon 4 times larger than any previously measured at the canyon mouth. The great destructive energy of the flood and the ability of the flood to bring about geologic change were caused by the steep gradients and, hence, the high current velocities.

A pattern of hydrogeologic responses to high-energy discharge emerges from this study of a torrential mountain flood. Many of these responses seem self evident, but they are applicable to analogous settings elsewhere, and their reiteration might help foster an awareness of similar hazards in other areas that have not experienced a disastrous flood.

Following a heavy thunderstorm, a mountain torrent might increase its discharge and competence by several orders of magnitude, through a combination of meteorologic and physiographic circumstances. In the Big Thompson Canyon area, an extreme increase in discharge and velocity drastically raised the competence of the stream and, hence, its capacity to erode and transport material—in short, its ability to cause geomorphic change, damage property, and endanger life. Along the tributaries, geologic effects were confined largely to the zone of intense downpour, chiefly to places within the 6-in. isohyet and, foremost, within the 10-in. isohyet. But along the main stem, effects extended to the confluence with the South Platte River.

Under conditions of torrential discharge:

- The main channel tended to be scoured throughout its length.

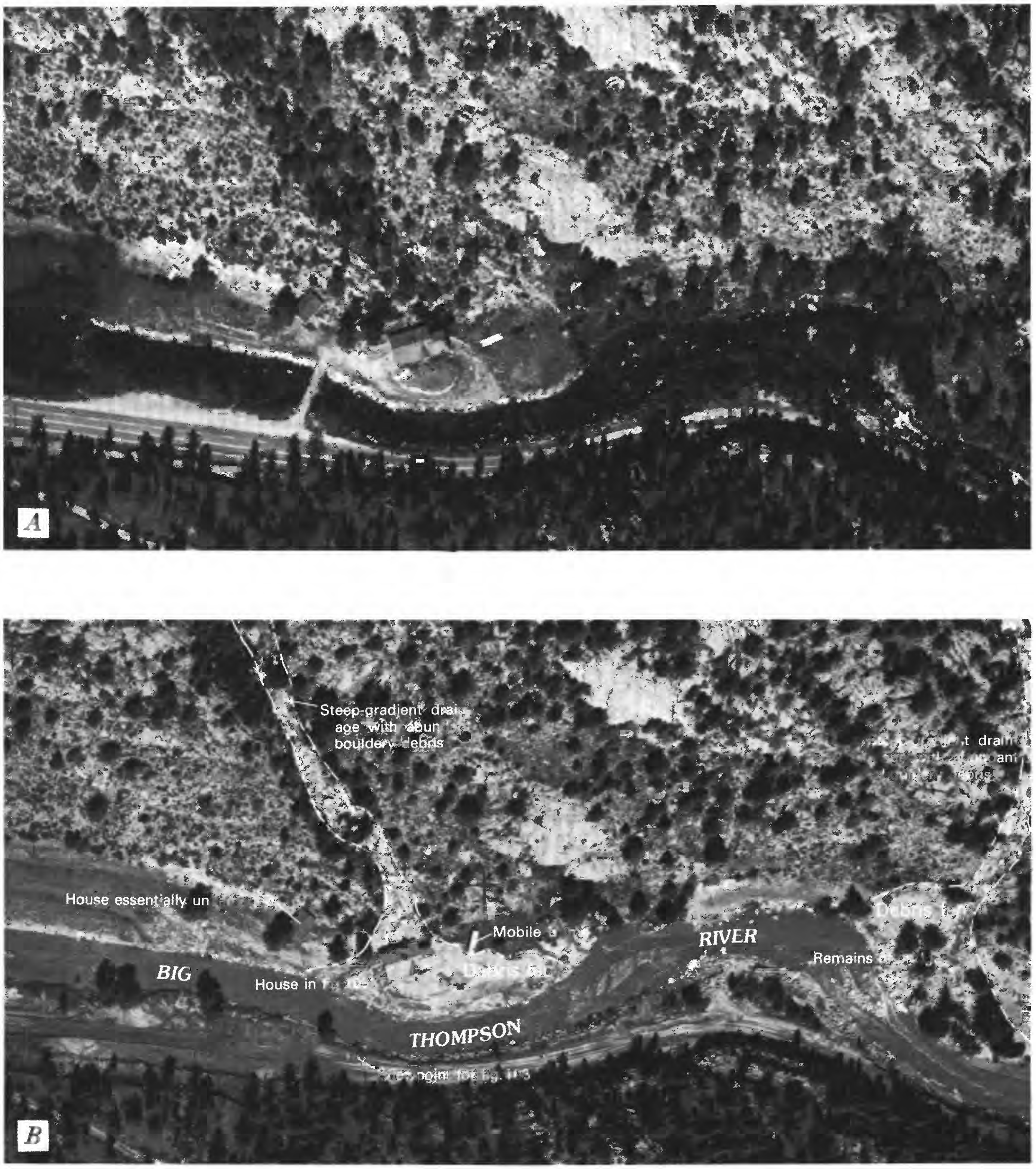


FIGURE 102.—Aerial views of debris fans, mile 51.1 to mile 50.9 on the Big Thompson River, before and after 1976 flood. *A*, Preflood view; *B*, postflood view, August 3, 1976. Note changes in the small debris fans and their associated tributary drainages (outlined); partial destruction of the house shown in figure 103 resulted. A large amount of boulder and vegetation debris is present on the predominantly south facing slopes in these tributary drainages. Approximate scale: 1 in.=200 ft.

FIGURE 103.—House on debris fan at mile 51.1, Big Thompson River, damaged by boulder debris. Part of the building has been crushed. The house was pushed about 4 ft off its foundation. The mobile home to the right and another home out of view to the left (fig. 102) were virtually undamaged.

FIGURE 104.—Deposit of sand- to cobble-size material on a debris fan near mile 7.3, North Fork Big Thompson River. Deposit is about 4 ft thick. The man is standing on a picnic table that was engulfed by the deposit.

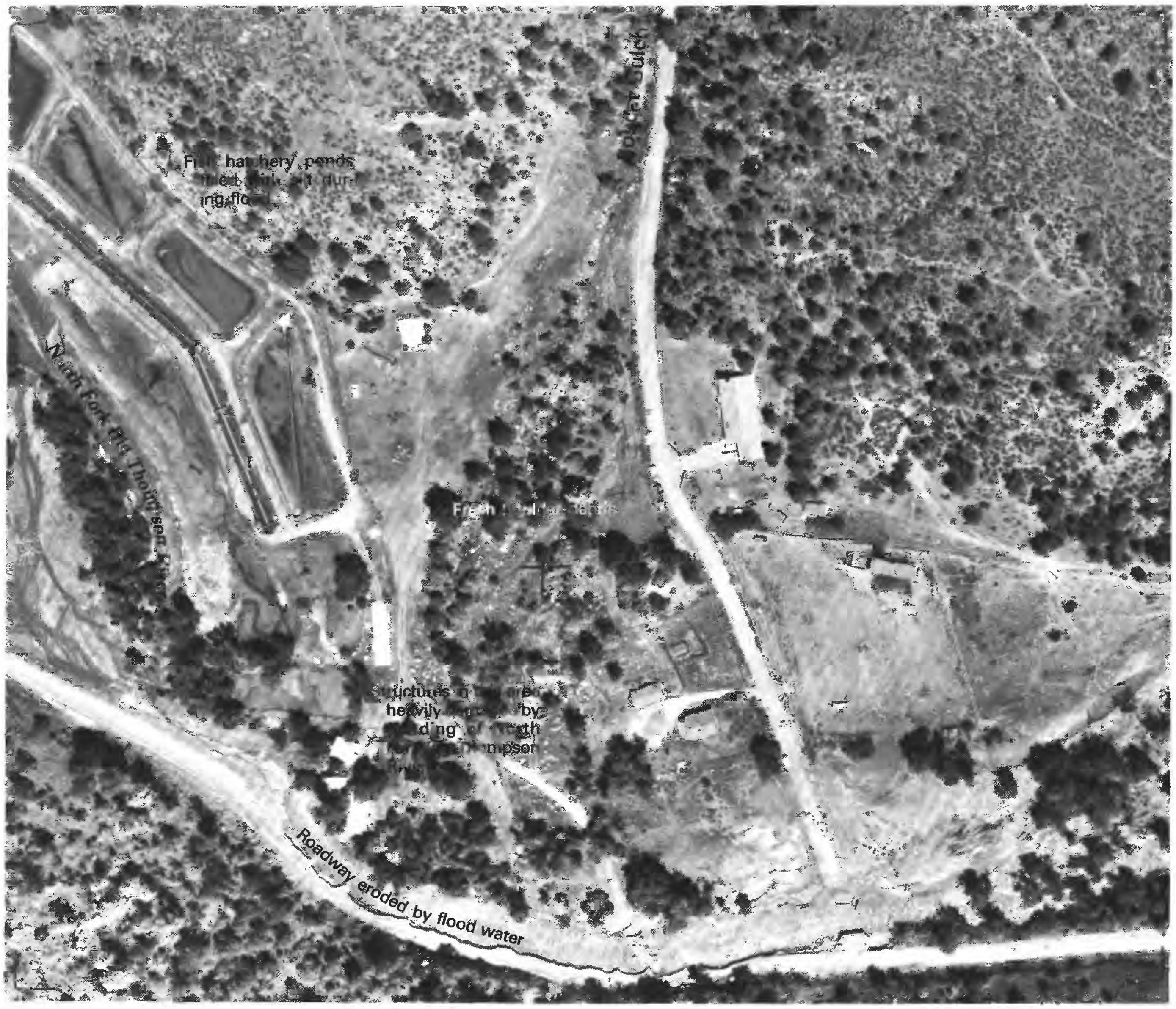


FIGURE 105.—Postflood aerial view of Bobcat Gulch debris fan, mile 0.5 on the North Fork Big Thompson River, August 3, 1976. The many fresh boulders on this debris fan indicate a relatively recent flood, although the water of the 1976 flood was deflected around this debris deposit. Approximate scale: 1 in. = 200 ft.

- The flood surface was not planar. Owing to centrifugal flow, it tended to be superelevated at the outsides of bends, often several feet higher than the water surface on the opposite bank; structures at the outsides of bends, therefore, were especially vulnerable to the effects of flooding.
- Places opposite flooding tributaries were vulnerable to flooding by the deflected main stream or by the tributary itself, pushing across the mainstream channel.
- Scour predominated at the outsides of bends.
- Scour increased at channel constrictions; deposition increased just upstream from constrictions.
- Scour increased greatly with an increase of gradient and diminished correspondingly with a decrease.
- Scour undercut colluvial slopes high above the peak elevation of flooding and thereby released landslides that endangered or destroyed structures safe from ordinary flooding.

FIGURE 106.—Building lot covered by sediment, in a subdivision where colluvium derived from grus was eroded and redeposited. There was little preflood indication of the potential problem. Meadowdale area, near the divide between the Big Thompson and St. Vrain drainages.

- Artificial fills in the floodway were very vulnerable to scour.
- Scour was minimal in overbank areas.
- The insides of bends were loci of deposition, often of bouldery point bars.
- Deposition was enhanced by reduced gradients, sharp bends, widened places along the channel, and overbank flow. Reduced gradients and widened channels usually coincided.
- Vegetation—trees, shrubs, log jams, and even grasses—and other obstructions were natural sediment traps in overbank areas. Dunelike bars commonly accumulated downstream from such obstructions.
- Impacts from heavy buoyant debris, such as logs and timbers, locally caused more damage to structures than was caused by the floodwater itself or saltating boulders.

In sheetflooded areas:

- Scour was inhibited by thick mats of vegetation, especially grasses.
- Scour was enhanced where the ground cover was thin or discontinuous, as in a pine forest, or where the cover was broken, as along an unimproved road.

At debris fans:

- Although many debris fans stood high above main-stem flooding, they contained inherent hazards because they are and were subject to episodic tributary flash floods; they in fact are formed from repeated increments of flood debris.

FIGURE 107.—Gully erosion in fine-grained, relatively thick colluvium or residuum derived from granitic rocks. Gully is about 4 ft deep in the foreground. Near mile 54.4 on the Big Thompson River.

- Any part of a fan is vulnerable to flash flooding or debris flowage inasmuch as the flood channel on the fan tends to be blocked and diverted repeatedly by its own debris at various times during the history of the fan.
- Only a random part of a given fan was flooded during the storm or is likely to be flooded during a future storm.

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FIGURE 108.—Landslide in Glen Comfort area, mile 52.4 on the Big Thompson River. This landslide was initiated, presumably, before the 1976 flood when a roadcut was made at the base of the slope. During the flood, the road and the house that it served were eroded away and destroyed. Additional erosion into the slope by the Big Thompson River caused further failure of the landslide. Note also the erosion under the house on the left.

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FIGURE 109.—Aerial view of debris avalanches from 1976 storm and flood, between mile 5.2 and mile 5.4 on the North Fork Big Thompson River. Debris avalanches were not common during the July 31, 1976 storm, but places susceptible to them are numerous in the Big Thompson area. The indicated features formed during the storm. Approximate scale: 1 in.=200 ft.

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