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Colorado's 1997 Flood Season in Review

The events, damages, and repercussions of the flooding that occurred in Colorado during the summer of 1997

Authorized by the
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1.0 INTRODUCTION

1.1 Project Summary

During late July and early August of 1997, 13 counties in Colorado (Baca, Clear Creek, Crowley, Elbert, Kiowa, Larimer, Lincoln, Logan, Morgan, Otero, Phillips, Prowers, and Weld) experienced intense rainfall and flooding to such a degree that President Clinton declared them eligible to receive federal disaster assistance for damages caused by the heavy rain, flash flooding, mudslides, landslides, and severe ground saturation. A map showing the locations of the affected counties is provided in ***Figure 1.1-1.*** Each county experienced varying degrees of flooding and damage and responded to a myriad of disaster-related situations. The types of flood damage ranged from washed out county roads, erosion of railroad embankments and ditches, destruction of property, inundation of lands, and the loss of five lives in Fort Collins [State of Colorado and FEMA (Federal Emergency Management Agency) 1997]. In addition to the 13 declared counties, several other counties and communities experienced flooding damage during the 1997 flood season, which extended from approximately June through September.

This document summarizes data collected, analyses performed, damage suffered, mitigation activities conducted, and general trends observed in the 13 counties and around the state during the 1997 flood season. More specifically, the subsequent chapters of this document define and describe the flood-impacted areas within the 13 disaster counties and throughout the state, provide flood histories for these regions, define the hydrologic and hydraulic information related to the storm events during this period, describe mitigation efforts and damage, and graphically illustrate the severity of damage experienced in many locations.

During the 1997 flood season, storm systems drenched other areas in northeastern Colorado, as well as several counties in southern Colorado. The Denver Metropolitan Area and Routt County also received flooding rains. Although these areas were not included in the presidential disaster declaration, relevant information from these areas is an important component in understanding the effects of such intense rainfall events on a statewide basis. To illustrate the flood events of 1997 as clearly as possible, information from non-declared areas also is included in this document.

1.2 Purpose of Study

In order to be better prepared for flooding events in the future, the objective of producing this document is to summarize all of the available statewide information regarding the flooding events in 1997 to facilitate mitigation

planning and disaster management. This planning and management can be applied not only to the 13 counties specifically addressed here, but to other regions throughout the state that may experience similar storm events in the future. Several of the significant storms specifically addressed in this document are shown in ***Table 1.2-1***. This document will provide residents, others affected by flooding, and agencies and entities involved in post-flood study and mitigation with basic information about the flooding and its impacts. The weather patterns observed, the hydrology described, and the damage recorded will serve as a baseline for managing future flooding events, and will pinpoint problem areas deserving of preventive mitigation. In these ways, the information in the document will contribute to preliminary decisions about flood hazard mitigation.

1.3 Study Authorization

It is the responsibility of the CWCB (Colorado Water Conservation Board) "...to devise and formulate methods, means and plans for bringing about the greater utilization of the waters of the state and the prevention of flood damages therefrom..." To this end, work on this project was authorized and funded by the CWCB through an agreement dated March 13, 1998, with RTi (Riverside Technology, inc.). In consultation with the Colorado Water Conservation Board and a variety of federal, state, and local agencies, RTi conducted the study and produced the subsequent document, a related Internet web page, and an interactive compact disk as a set of diverse education and planning tools to be used statewide.

1.4 General Study Area

The 13 counties that were subject to the most damage during the 1997 flood season are shown in ***Figure 1.1-1***. All are located east of the Continental Divide, both in northeastern and southeastern Colorado. Most of the 13 counties are located on the plains east of Denver, where annual precipitation ranges from 7 to 15 inches, compared to several storms that produced more than 10 inches of total precipitation in July and August 1997 (***Table 1.2-1***).

These counties are situated in four river basins within the state: the South Platte River, Arkansas River, Republican River, and Cimmaron River basins. Larimer, Logan, Weld, Morgan, Clear Creek, and portions of Elbert and Lincoln counties all have drainage tributaries to the South Platte River. Crowley, Kiowa, Otero, and Prowers counties have drainage tributaries to the Arkansas River, and portions of Elbert, Lincoln, and Baca counties are within the Arkansas River basin. Phillips and parts of Lincoln and Elbert counties have drainage tributaries to the Republican River. And a small part of Baca County has drainage tributaries to the Cimmaron River (State of Colorado and FEMA 1997).

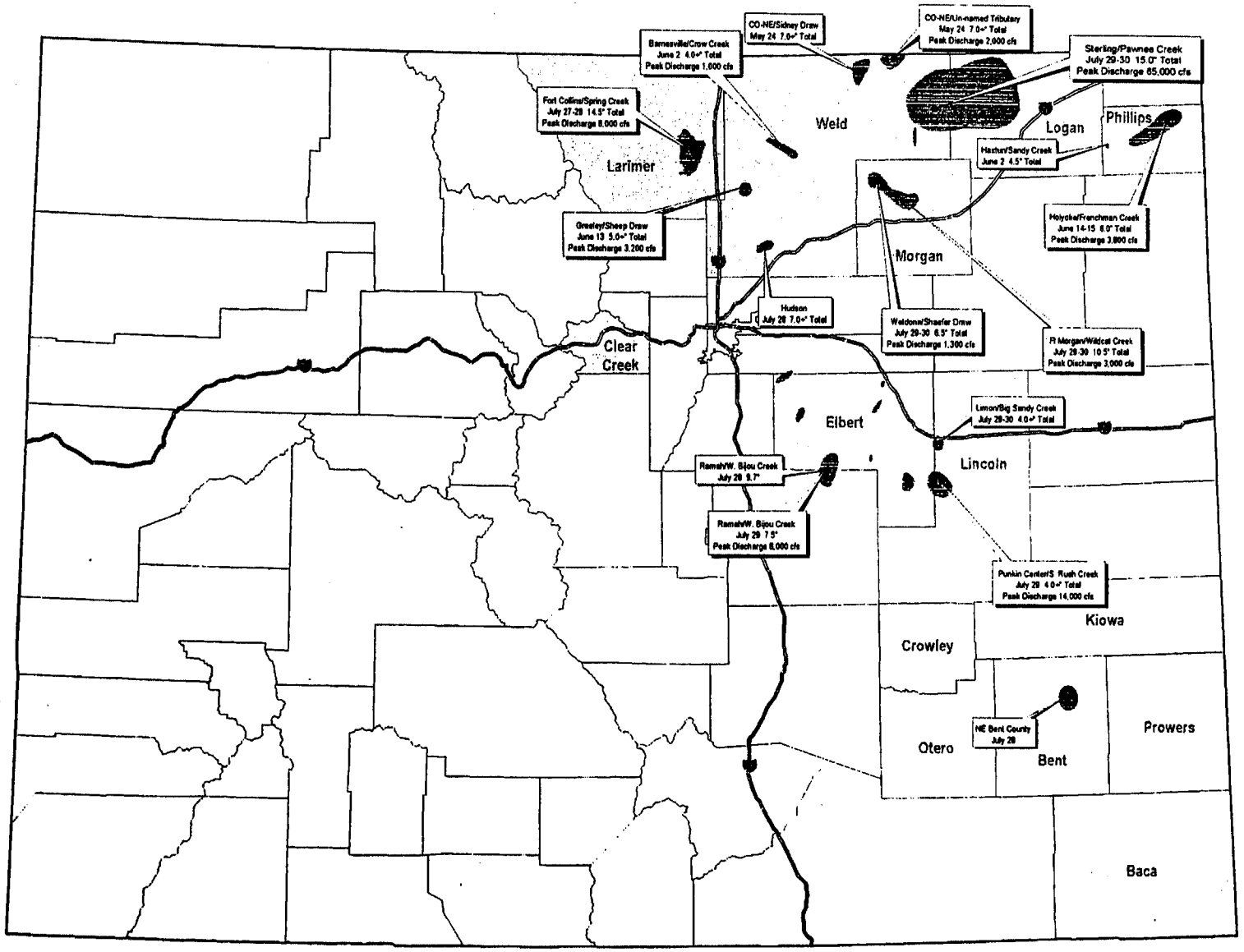


Figure 1.1-1

State of Colorado

Significant Storm Events of 1997

County Boundaries

Counties Included in Presidential Disaster Declaration

Storm Extent

Bullseye of Storm Event

Interstate Highway

Note:
Spatial extent of individual storm events shown on the map was defined by the 4.0" isohytal line for each storm.

N

20 0 20 40 60 80

Miles

Riverside Technology, inc.

Table 1.2-1
Significant Storms of the 1997 Flood Season
(greater than 4 inches total accumulation)

Location	County	Date	Maximum Point Precipitation	Climatic Region
Colo-Neb Border	Weld	May 24	7.0+ inches	Great Plains
South of Haxtun	Phillips	June 2	4.5 inches	Great Plains
Barnesville	Weld	June 2	4.0+ inches	Great Plains
Greeley	Weld	June 13	5.0+ inches	Great Plains
Holyoke	Phillips	June 14-15	6.0 inches	Great Plains
Fort Collins	Larimer	July 27-28	14.5 inches	Front Range
Hudson	Weld	July 28	7.0+ inches	Great Plains
Northeast Bent County	Bent	July 28	4.0+ inches (unofficial reports)	Great Plains
Ramah	Elbert	July 28-30	17.0+ inches (2-day total)	Great Plains
Punkin Center	Lincoln	July 29	4.0+ inches	Great Plains
Sterling	Weld/Logan	July 29-30	15.0 inches	Great Plains
Weldona	Morgan	July 29-30	10.5 inches	Great Plains
Limon-Hugo	Lincoln	July 29-30	4.0+ inches	Great Plains
Fort Collins	Larimer	August 4-5	4.0 inches	Front Range

1.5 General Observations

A number of known hydrological concepts were clearly in effect during the circumstances described in this report. These are discussed below in an effort to further examine the nature of the flood-inducing events and the man-made conditions that played roles along the Front Range and elsewhere in eastern Colorado during the summer of 1997.

1.5.1 Meteorology

During the summer months, the entire state is subject to convective thunderstorms that are capable of producing large amounts of rainfall over a very short time if sufficient humidity is present in the atmosphere. In eastern Colorado, these storms typically are supplied with moisture drifting in from the Gulf of Mexico and the central plains states. In midsummer and later, monsoonal wind patterns also bring moisture from either the Baja California area, the Gulf of Mexico, or both. This moisture moves into Colorado after coming northward across Mexico and the southwestern U.S., and it is the source of many late summer storms in the state (State of Colorado and FEMA 1997). In late July 1997, this tropical moisture was entering the state from the south. At the same time, a large high-pressure system had stalled over the central plains, and its clockwise rotation supplied moisture to Colorado from the east. A cold front associated with the high pressure

system over the plains set off thunderstorms as the moist air masses converged over the state. As a result of these thunderstorms, major flood damages occurred in the 13 counties declared as federal disaster areas. The most extensive damages took place in Larimer, Logan, and Morgan counties (Interagency Hazard Mitigation Team 1997).

The storm that occurred in Fort Collins (Larimer County) on July 28, 1997, had some characteristics in common with historically severe storms in the region, such as the Rapid City, South Dakota, and Big Thompson, Colorado, events in the 1970s. It also had highly unusual characteristics that differed dramatically from major historical events and other storms that would occur in eastern Colorado during the summer of 1997. Initially, tropical moisture flowed into Colorado from the southwest; moisture at the lower altitudes was directed toward higher elevations by nearly stationary cold fronts to the east. These conditions were similar to those for severe historical storms in the eastern Rocky Mountain region (Forecast Systems Laboratory 1998).

Given the direction of storm cell motion at the time, the resulting thunderstorms normally would have been expected to move off the mountains and onto the eastern plains. However, as resulting thunderstorms moved eastward, outflows were generated and moved back toward the foothills, supporting new storm formation at a relatively low altitude. At higher altitudes, tropical moisture continued to enter the area from the south. This rare combination of circumstances produced an unusually efficient process for developing rainfall. The Fort Collins storm presented very little lightning or hail, and the cloud top elevations were not as high as typical western thunderstorms. This pattern of convection is typical of tropical events in the southern and eastern U.S. and of tropical storms making landfall in maritime regions, but it is uncommon in Colorado. The precipitation that resulted probably would have caused significant flooding even in a relatively flat rural area (Forecast Systems Laboratory 1998).

In contrast, other storm events in the state lacked the extreme tropical nature of the Fort Collins storm. In the northern and central parts of Colorado, high-intensity rains also fell in June and late July. In some locations, the largest storms came on the heels of several smaller storms in preceding days. Late July and August events in the southern part of the state were typified by this sequential occurrence of rainfall, and flood damages resulted even though the rainfall amounts generally were not as severe as they were to the north.

The following are important factors in assessing flooding potential (from a meteorological perspective):

- The intensity of rainfall

- The duration of rainfall, particularly the length of time that storm cells form or remain over a given geographic area

- The areal extent of rainfall (This factor is considered to a lesser degree than the previous two factors.)

- Radar processing and interpretation (The Z-R relationship used by the NWS [National Weather Service] to convert NWS radar reflectivity to rainfall intensity is not constant in the spatial domain. Different Z-R relationships may be correct for the same evening, for different parts of the state, or for different storm types. An example of this occurred on the evening of July 28, 1997. Several storm cells developed across Colorado on that evening, one over Fort Collins [killing 5 people] and others in eastern Colorado. The single Z-R relationship used to estimate rainfall intensity underestimated the rainfall in Fort Collins, but overestimated rainfall to the east.)

1.5.2 Hydrology

The following are the most important factors in assessing flooding potential (from a hydrological perspective):

- Soil moisture levels in the watershed (How much rainfall has the watershed experienced prior to the current storm event?)

- Hydraulic aspects of the watershed (How many canals and gates are in the watershed, and what is their operational status? How much water is currently flowing in the canals and streams, and how much flow capacity remains within the banks? How much storage capacity remains available in retention basins?)

- The occurrence of man-made structures transecting watersheds and causing obstructions to natural drainage paths (The majority of damage across the state occurred at roads and road embankments where culverts were too small to handle flow and debris, at railroads and railroad embankments [again, culverts were too small], at irrigation canals that lacked adequate drainage by-passes or enough conveyance for collecting overland flows, and at bridges that underwent damage to piers, pilings, or approaches. Debris was a major flow-limiting factor or a source of structural impacts at many locations.)

- Urbanization (Sheet flooding in highly urbanized areas can produce heavy damage, and development of low-lying areas can exacerbate flood impacts.)

1.5.3 Emergency Preparedness and Response

Although the Fort Collins storm in particular presented highly atypical forecasting conditions, timely storm watches and warnings were issued. Additional radar tools are currently in research phases and show promise for improving rainfall estimation under atypical conditions. Public support for forecasting research and implementation has had positive results and hopefully will continue in the future.

Similarly, the extensive flood control measures taken by municipalities and other agencies have had a substantial effect on reducing flood severity, damages, and loss of life. Well-planned control and drainage measures prevented more extensive damages in most counties. Efforts by police and fire departments, sheriff's offices, road departments, and individual volunteers reduced adverse impacts for what could have been much worse circumstances. Continuing support for these efforts is essential for their success.

2.0 Meteorology for the 1997 Flood Season

The summer of 1997, particularly the months of July and August, will be remembered for the extreme precipitation experienced in Colorado and along the Front Range. The State of Colorado, among other states in the southwestern United States, experienced an unusually strong influx of warm, moist air from the south that contributed to a number of extreme precipitation episodes. A brief description of the large-scale meteorological conditions present in the state during the summer in general, and during the end of July and early August in particular, is provided here and is based primarily on two resources: The Fort Collins Flood: Atypical Rainfall and Runoff Complexities (Forecast Systems Laboratory 1998) and An Analysis of Rainfall for the July 28, 1997 Flood in Fort Collins, Colorado (Colorado State University, Department of Atmospheric Science 1998).

2.1 General Meteorology

The month of May displayed near average precipitation across much of the state except for western Colorado, which experienced above average precipitation. Early June exhibited typical early season atmospheric instability that manifested itself in several large, localized precipitation events in northeastern Colorado on June 2, June 6 through 7, and June 14 through 15, as well as a tornado in Boulder on June 6. South-central Colorado also experienced several large localized precipitation events. One such event occurred at the Colorado Springs/Fountain Creek area from June 13 through 14 where up to 5 inches of rain may have fallen in the span of 2 hours (Doesken 1998a). June was wetter than normal in much of the state, with most of the precipitation occurring during the first 2 weeks, while the last 2 weeks in June were dry across much of the state.

July was wetter than normal across much of the state. Beginning in mid July, the state experienced a gradual increase in atmospheric moisture caused by the unusually strong influx of warm, moist air from the south. This influx of tropical moisture continued throughout the summer and slowly trailed off by the end of September. Atmospheric moisture was enhanced sharply on July 27 and 28 when a cold front and high pressure area over the northern plains pushed moisture from the plains westward into eastern Colorado (Doesken 1998b).

The flood season ended with some unusually large precipitation events during the month of September. Extreme precipitation in northwestern Colorado from September 18 through 21 caused the Elk and Yampa Rivers to reach near flood stages. Four-day rainfall totals for this period in northwestern Colorado were on the order of 4 to 8 inches and were some of

the heaviest rainfall events in recorded history for the areas of Meeker and Steamboat (Doesken 1998b).

One of the final major events for the season occurred from September 20 through 21 in La Plata County. This event was one of the last associated with the tropical moisture pattern and was caused by a late season cold front combined with the tropical moisture still lingering in the state (Kelsch 1998).

2.2 Meteorology Associated with the Events of July and August, 1997

In mid July, a ridge of high pressure in the middle and upper levels of the atmosphere began to funnel deep tropical moisture northward into the southwestern United States. Disturbances on the eastern side of the Rockies generated weak cool fronts, which became quasi-stationary and helped move low-level moisture westward toward the mountains. Storm systems across the entire state were slow moving because of the weak steering currents. For the Front Range in particular, storms moved in a slow northward direction paralleling the terrain so that storms repeated over and over again as moisture was funneled into the mountains (Forecast Systems Laboratory 1998). This type of general, large-scale atmospheric condition can set the stage for flash flood events in Colorado and other states in the southwest and is similar to the conditions that were present during the Big Thompson, Colorado, and Rapid City, South Dakota, flash floods. The State of Arizona also experienced flash floods in 1997 associated with this large-scale monsoonal moisture pattern.

On July 27, a high pressure system perched over southern Canada began pushing a cold front south into Colorado. At the same time, moist tropical air continued its northward movement into Colorado from the south. A surface wind from the east developed during the day on the 27th as the cold front moved southward across Colorado. This wind began to move the moist air from eastern Colorado and Kansas westward into the mountains (Colorado State University, Department of Atmospheric Science 1997). Evening thundershowers developed during the night of July 27 along the Front Range and elsewhere in eastern Colorado, producing heavy precipitation.

On July 28, tropical moisture was present at all levels within the atmosphere across the state. The surface flow of moist air from the east continued as the cool front became quasi-stationary (Forecast Systems Laboratory 1998). This large-scale scenario changed very little during the day. Thunderstorms developed along the Front Range on the afternoon of the 28th. The thunderstorm cells formed a line and began moving slowly toward the east-northeast away from the foothills. As the thunderstorms moved east, they. produced an outflow that enhanced the low-level upslope back toward the foothills (Forecast Systems Laboratory 1998). The regeneration of storm cells

caused by the southeasterly outflow was one process working to generate the quasi-stationary storm complex.

The evening of July 28 produced copious amounts of precipitation throughout eastern Colorado; however, four extreme bullseyes of precipitation are clearly evident from observer reports and from available NWS radar data. Three of these bullseyes occurred in northeastern Colorado (Fort Collins in Larimer County, northwest of Hudson in Weld County, and in Elbert/Lincoln counties). The fourth bullseye of extreme precipitation occurred in northeastern Bent County in a rural portion of the state.

The atmospheric conditions present on July 29 were very similar to those seen on July 28. A quasi-stationary front of thunderstorms developed along the Front Range on the afternoon of the 29th. The front, however, was not as stationary as the one on the 28th and began to migrate toward the east. The storm complex continued to grow as it moved east, and it eventually dropped 14 to 15 inches of precipitation on portions of Logan and Morgan counties (Doesken 1998b).

The evening of July 29 also produced large amounts of precipitation throughout eastern Colorado; however, three extreme bullseyes of precipitation are clearly evident from the observer reports and from the available NWS radar data. These bullseyes all occurred in northeastern Colorado (Sterling in Logan County, Weldona in Morgan County, and near Hugo in Lincoln County).

A similar pattern of atmospheric conditions continued to develop throughout the next week or so, producing locally heavy rains in northeastern Colorado, the eastern plains, and southeastern Colorado.

In researching the meteorology associated with the 1997 flood season, it appears that the northeastern portion of the state (north of and including Lincoln County) received a greater frequency of extreme precipitation bullseyes than the southeastern portion of the state. This observation was presented to meteorologist Matt Kelsch, who responded with the following statement (Kelsch 1998b):

> The State of Colorado does exhibit a slightly greater tendency for focused storm events along and north of the Palmer Divide. Frontal systems often slow down or stop along east-west ridges, such as the Cheyenne Ridge along the Wyoming border, the Palmer Ridge in central Colorado, and the Raton Ridge along the New Mexico border. In addition, the geographic upslope along the northeastern Colorado Front Range and High Plains appears to be greater than the corresponding terrain slope in southeastern Colorado, which creates an up-slope condition slightly more conducive to focused precipitation.

In addition to the physical factors, demographics also may play a role in explaining the higher occurrence of extreme precipitation bullseyes in northeastern Colorado. Extreme precipitation bullseyes and their impact have a higher tendency to be observed in northeastern Colorado because of the higher population.

In general, the large-scale atmospheric conditions described here set the stage for the heavy precipitation that was observed across the state in late July and August of 1997. Atmospheric scientists continue to investigate the large-scale atmospheric conditions associated with the 1997 flood season. Detailed meteorological analyses will be available when these studies are complete. This report does not attempt to duplicate those efforts.

3.0 Flood Summary for the Denver-Metro Area

The information for this section was taken almost entirely from an on-line document written by Kevin Stewart with the UDFCD (Urban Drainage and Flood Control District) Floodplain Management Program and published in 1997. This document can be found on the Internet at http://www.udfcd.org/cover97.htm.

Although the Denver-Metro region was not declared a disaster area during the 1997 flood season, it did experience its worst flooding in 10 years between May 23 and September 4, 1997. While the rest of the state and the nation were focused on the devastating events in Fort Collins and other disaster counties, Denver had just come off of a 23-day dry spell that was followed by 18 days of significant precipitation and flood potential. This section chronicles the most notable events in the Denver-Metro area during the 1997 flood season.

May

The first of many flood-related events of the summer occurred on Friday, May 23, near 56th and Broadway, when a 66-inch water main ruptured, inundating businesses and residential areas along both sides of Interstate 25 in that area.

July

Denver received an official 5.60 inches of rainfall during this month—the second wettest July in Denver's 126-year record. In contrast, the average rainfall for Denver in July is just under 2 inches.

On July 19, a severe thunderstorm in northeast Denver and northwest Aurora produced 3.83 inches of rain in less than 1 hour. This accumulation exceeded the official Denver 1-hour record of 2.2 inches set in 1921. In addition to the record-setting rains, this area also received significant amounts of sizable hail—some stones were as large as 1.25 inches in diameter.

As a result of this extraordinary precipitation, Westerly Creek nearly overtopped Montview Boulevard in east Denver. Westerly Creek is a tributary to Sand Creek, which exceeded its gage record at Brighton Road in Commerce City by 590 cubic feet per second (cfs). This new gage record of 3,350 cfs was exceeded again twice by July 30. The July 19 storm also caused US Highway 36 to close after 4 inches of rain fell in Broomfield in the eastern part of the metropolitan area.

July 19 was the beginning of an 18-day onslaught of rain that culminated in flooding at Goldsmith Gulch in south Denver and a new storm that hit central Jefferson County. This storm produced 1.85 inches of rain in Golden. The National Weather Service issued a flash flood warning for Golden and Pleasant View; however, the storm was isolated and caused only minor flood damages.

On July 28, while Fort Collins was experiencing its devastating flash flood, Goldsmith Gulch had high flows for a second consecutive day, setting a new peak record of 2,040 cfs. On Goldsmith Gulch, downstream of Yale Avenue (*Figure 3.0-1*), flow was classified as a 10-year event. In fact, according to a hydrology model, the discharge in this area neared the 50-year mark.

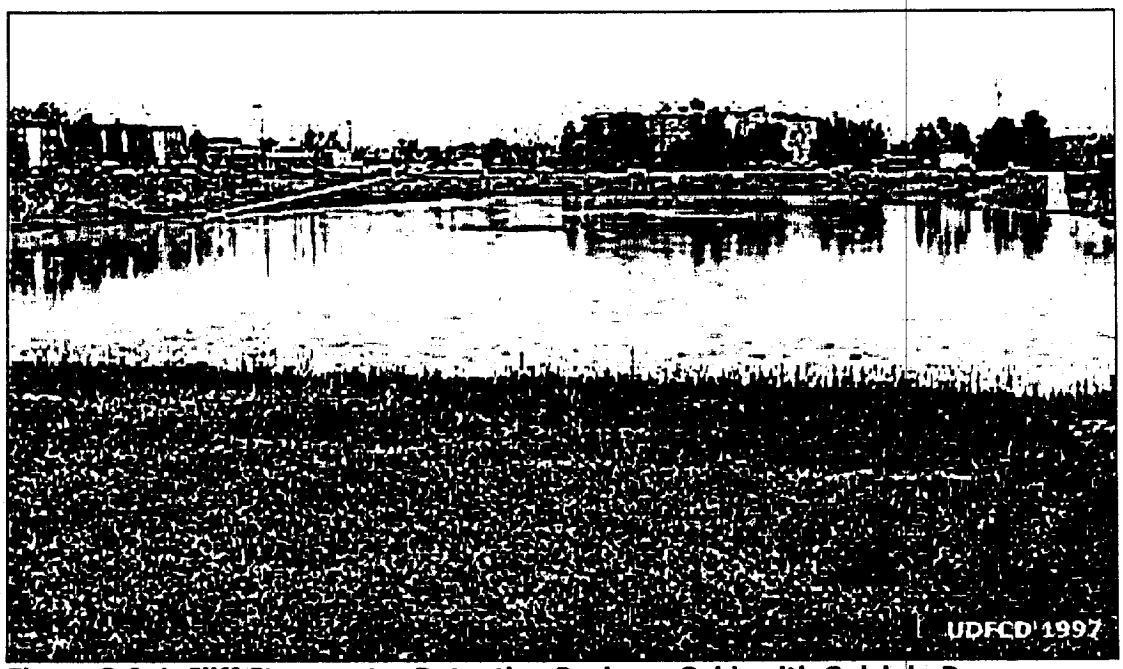


Figure 3.0-1 Iliff Stormwater Detention Basin on Goldsmith Gulch in Denver on July 27, 1997

Also on this date, heavy rains caused localized flooding in other parts of Denver and Aurora, affecting roads, parking lots, and basements. In fact, several roads were washed out in Aurora.

Evening rains fell again on July 28, causing record flows at the Sand Creek gage, 4.4 feet of water to overtop the pedestrian trail at Sand Creek Park near Interstate 225, and flooding of a magnitude to float a car in a parking lot at Quebec Street and Leetsdale Drive in Denver.

July 30 brought yet another flash flood warning; this time for Boulder Creek and small streams in northern Jefferson County. The rains on this day caused landslides in the mountains along South Boulder Creek, but did not instigate major stream flooding. However, in Aurora, the Utah Park

detention pond in the upper Westerly Creek basin overflowed into nearby streets. Public works employees were able to channel floodwaters back to Westerly Creek without significant impacts. Flood levels at this location were estimated at near the 100-year threshold. ***Figure 3.0-2*** shows the 10-minute rainfall amounts for this area. In addition, the Granby Ditch detention basin at East 6th Avenue, which is designed to accommodate 100-year runoff, ponded floodwaters 11 feet deep and came within 2 feet of overtopping the street.

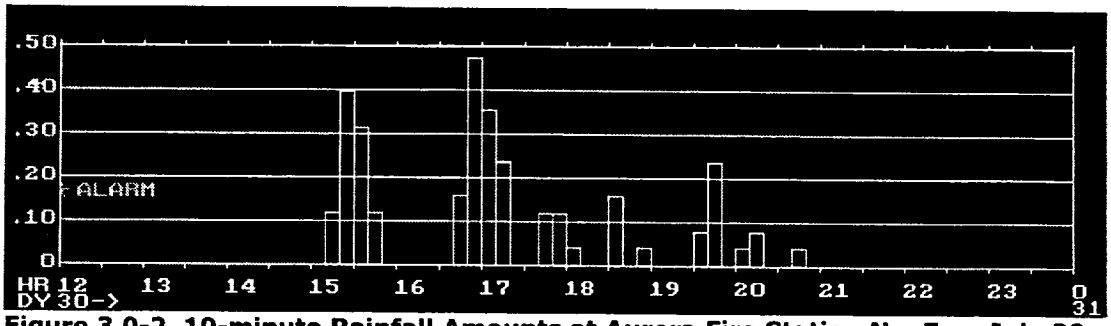


Figure 3.0-2 10-minute Rainfall Amounts at Aurora Fire Station No. 7 on July 30, 1997

Heavy rains fell again on July 31 causing new records for depth at the gages at Holly Dam on Little Dry Creek and at the Grant Street detention basin on Slaughterhouse Gulch.

August

In Adams County on August 4, Little Dry Creek flooded, damaging public facilities and homes in its lower reaches below Lowell Boulevard. To illustrate the force of the flow of water and debris on Little Dry Creek, ***Figure 3.0-3*** shows pedestrian bridges that were shifted along their foundations by as much as 3 feet. ***Figure 3.0-4*** captures how closely nearby railroad features came to being affected by flood waters.

August 4 also brought other severe weather events, including up to 2 feet of hail, driving rains, and high winds that caused an estimated $150-million in damage in Lakewood and Denver. A Cherry Creek gage in downtown Denver measured 1 inch of rain in a 10-minute period. With the additional runoff from melted hail, that total exceeded 2 inches. Lower Cherry Creek flowed wall-to-wall at a depth of approximately 5 feet and a peak discharge of 2,640 cfs.

September

On September 4, Lower Cherry Creek through Denver flowed wall-to-wall again because of heavy precipitation. In fact, five rain gages sounded alarms upon receiving 1 inch of rain in less than 1 hour along Cherry Creek.

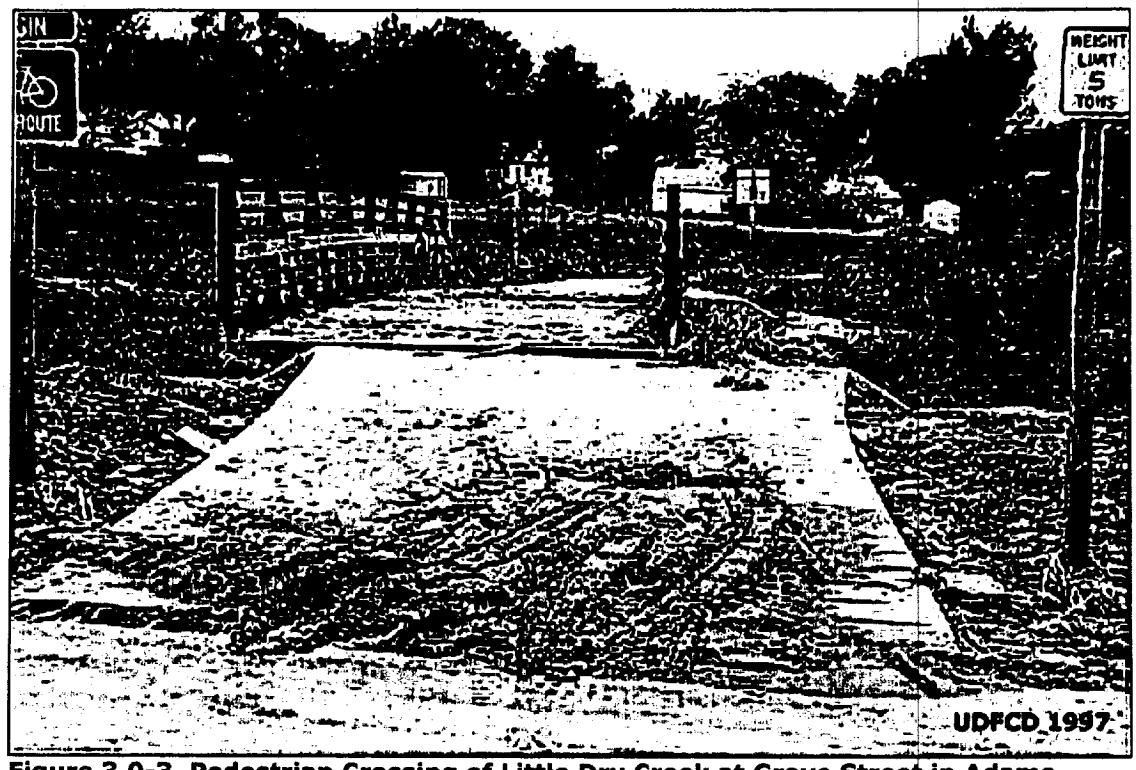


Figure 3.0-3 Pedestrian Crossing of Little Dry Creek at Grove Street in Adams County

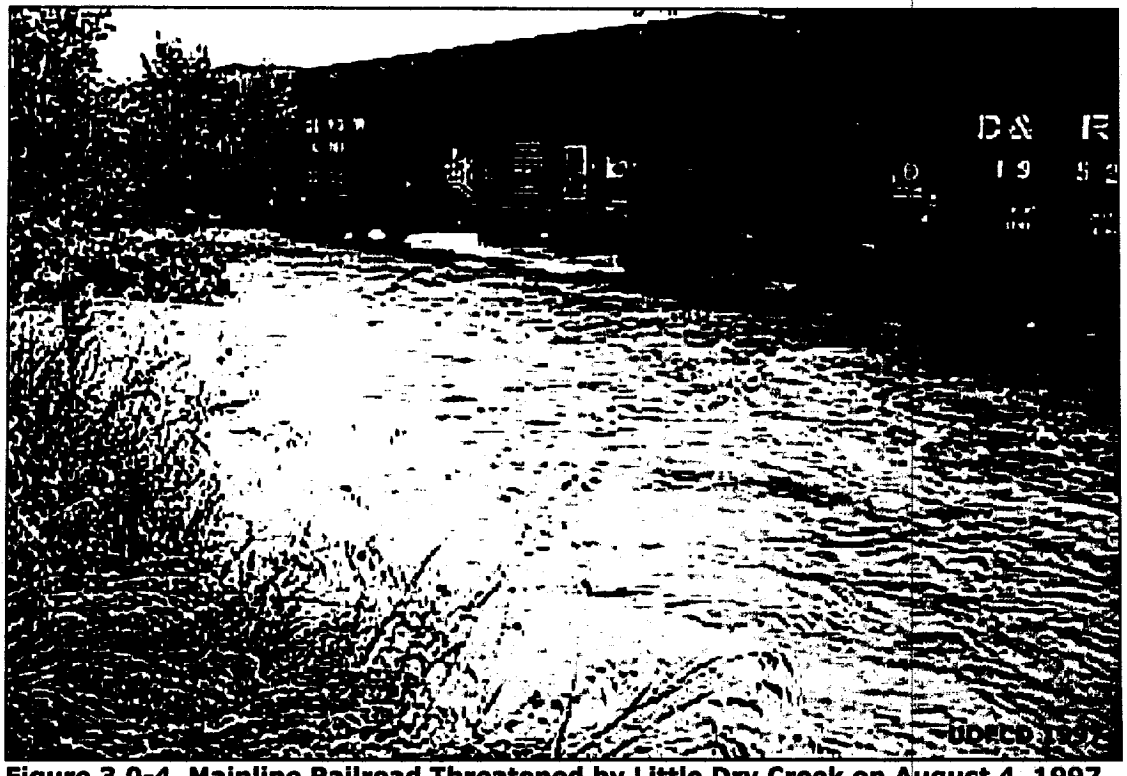


Figure 3.0-4 Mainline Railroad Threatened by Little Dry Creek on August 4, 1997

4.0 Flood Documentation

The following sections in this chapter document the various aspects of flooding that occurred in 1997 for each of the 13 counties that received a Presidential Declaration of Disaster. One additional county (Routt County) also is discussed in this chapter.

An attempt has been made to document consistently the aspects of flooding for each county. An outline was developed at the onset of the project to ensure consistency in the discussion for each county. However, the quantity and type of information available differs vastly from county to county. Therefore, the levels of discussion and detail presented in this document also vary considerably among counties.

4.1 Baca County

4.1.1 Study Area

Thunderstorms that occurred in late July through mid August of 1997 produced localized flooding throughout Baca County, located in the extreme southeastern corner of Colorado (see ***Figure 1.1-1***). Only unincorporated areas, with the exception of minor flooding in the Town of Walsh, were affected by the flooding, which was concentrated in the southeast and southwest corners of the county. The inundated areas in those portions of the county are located a few miles north of the Colorado-New Mexico and Colorado-Oklahoma state lines.

Additional flooding also occurred north of Springfield, which has a population of 1,500 people. Springfield is located approximately 30 miles to the east of the Colorado-Kansas state line and 30 miles north of the Colorado-Oklahoma state line.

In Baca County, county roads and bridges were seriously damaged as a result of the runoff generated in the Carrizo Creek, Cimarron River, Bear Creek, and Two Butte Creek drainages. Both Springfield and Walsh, the two largest towns in the county, are located within the Bear Creek watershed. These towns were relatively unaffected by the 1997 summer storm events.

Land use in Baca County is predominantly agricultural and includes cultivating milo, wheat, and corn and grazing livestock. Other parts of the county are designated Comanche National Grassland. ***Figure 4.1-1*** is a vicinity map of the county.

The topography of Baca County is relatively flat with low hills dividing watersheds. The mean annual precipitation for Baca County is approximately 13 inches.

4.1.2 Watershed Description

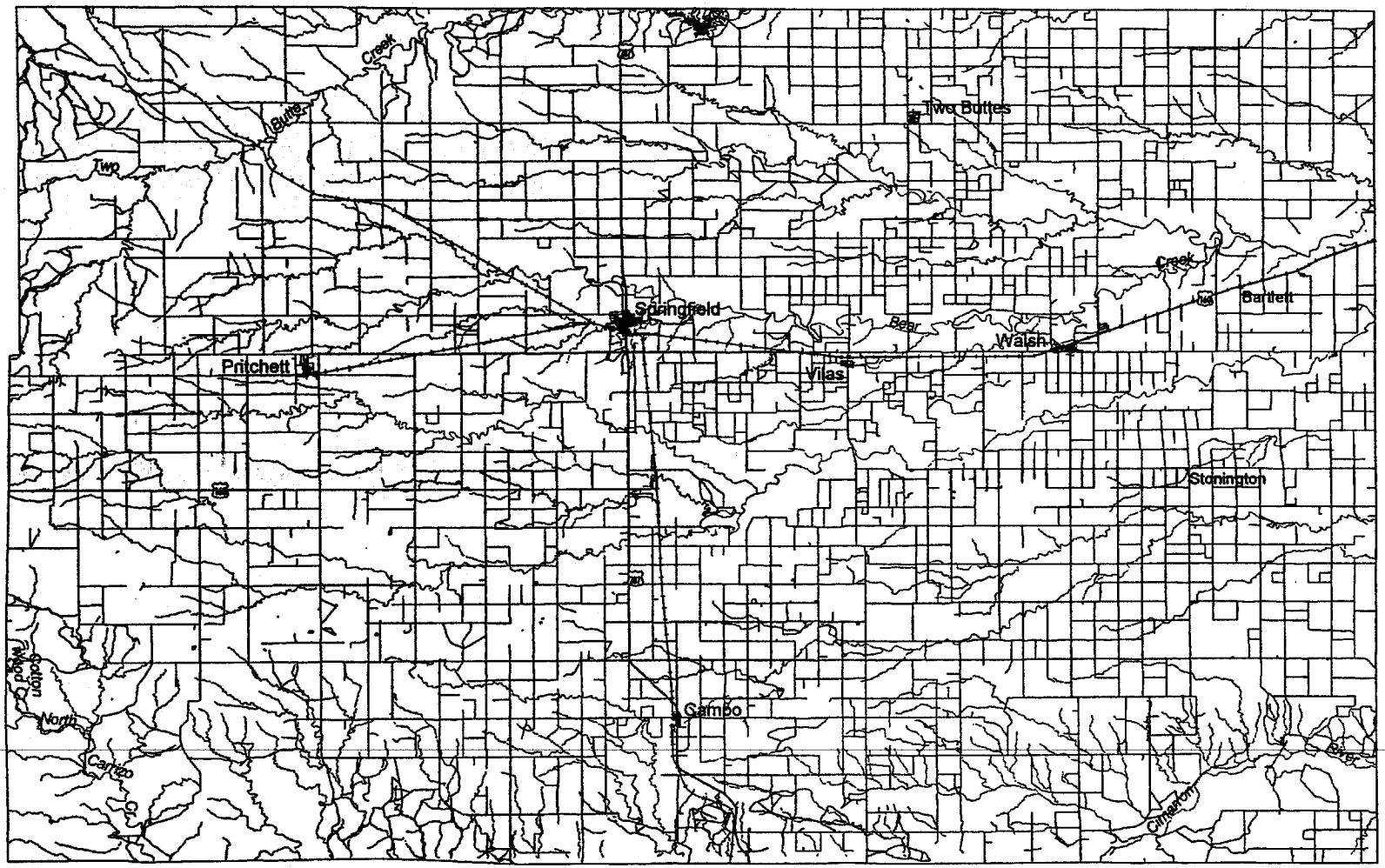
The watersheds of interest in Baca County include the Cimarron River, Carrizo Creek, Bear Creek and Two Butte Creek. Carrizo Creek flows eastward, meets the Cimarron River just south of the Colorado-Oklahoma state line, and eventually drains into the Arkansas River in Oklahoma. Two Butte Creek, located in the northern part of the county, flows northeast through Two Butte Reservoir and eventually into the Arkansas River approximately 4 miles west of the Colorado-Kansas state line near Holly.

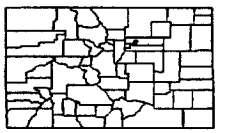
The headwaters of Carrizo Creek are located within Las Animas County, approximately 15 miles southwest of Kim. The total drainage area of Carrizo Creek at the Colorado-Oklahoma state line is approximately 480 square miles. The USGS gage on the Cimarron River near Elkhart, Kansas, is located

Figure 4.1-1

Baca County

Vicinity Map





- Rivers and Streams
- Canals and Ditches
- Primary Roads
- Secondary Roads
- Railroads
- Lakes and Reservoirs
- Municipal Boundaries

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Miles

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on the Cimarron River approximately 10 miles downstream of the Colorado-Kansas state line; it has a drainage area of 2,899 square miles. The elevation of Carrizo Creek ranges from 4,800 to 6,600 feet, while the Cimarron River's elevation at the state line is approximately 3,600 feet.

The headwaters of Two Butte Creek lie adjacent to those of Carrizo Creek upstream in Las Animas County. Further downstream in Las Animas County, the Bear Creek headwaters separate Carrizo and Two Butte creeks; Bear Creek eventually flows into the Arkansas River.

4.1.3 Local Flooding Problems

Tributaries in Baca County, including Carrizo Creek and Cimarron River, historically have experienced nuisance flooding during the summer months because of highly localized storms. However, Two Butte Creek flooded for the first time in 22 years during the storm events of 1997.

The incorporated areas seldom experience significant flooding problems. For example, the Town of Springfield is built near the divide between two creek channels within the Bear Creek watershed and rarely experiences any flooding.

4.1.4 Storm Characteristics

Although Baca County experienced widespread flooding during the summer of 1997, the type of storms in the southeastern region of Colorado were at a lower intensity than those observed in the northeastern counties. While counties in northeastern Colorado experienced bullseyes of extreme, short-duration precipitation, the summer storm pattern in Baca County produced numerous storms with moderately heavy rainfall over a few days. ***Table 4.1-1*** summarizes those storms that produced over 1 inch of rain in a 24-hour period in July and August of 1997.

Although the storms in the latter two dates caused damaging floods, limited information is available for these storms. Therefore, the primary focus of this discussion is on the storm that produced rainfall through the evening hours of August 5 and into the morning of August 6. While the entire county witnessed some rainfall, the precipitation intensity was greatest south of Walsh and down through Stonington.

The nearest weather station that recorded multiple types of atmospheric data is located 51 miles northwest of Walsh in the Prowers County Seat, Lamar. Daily data was collected at this station for each of the four events identified in ***Table 4.1-1***. A summary of this data is presented in ***Table 4.1-2***.

Table 4.1-1
Dates of Significant Precipitation
in Baca County During 1997

Date	Maximum Precipitation	Comments
July 29	1.13 inches	Heavy rain in central and southeastern portions of the county
August 5-6	3.5+ inches	The largest 24-hour precipitation event of the summer in eastern and southeastern areas of the county
August 9	1.52 inches	Widespread rains throughout the county
August 11	1.31 inches	Storm burst near Campo

Table 4.1-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches of Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
Lamar, CO	7/24	64	85	26.37	74	66	13.4	130
Lamar, CO	8/5	64	73	26.38	84	64	10.9	120
Lamar, CO	8/6	57	66	26.37	90	59	9.8	70
Lamar, CO	8/9	60	82	26.16	71	61	10.1	40
Lamar, CO	8/11	58	75	26.24	81	61	7.8	80

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + T_d}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C) (Linsley et al. 1992)
Source: National Climatic Data Center 1998a

Despite being the closest, most well-equipped gage near Baca County, the data presented in ***Table 4.1-2*** may not completely represent the local meteorological conditions south of Walsh. This is primarily because of the convective nature of thunderstorms on the eastern plains of Colorado, which produce significant spatial variability within a region.

4.1.4.1 Storm Duration and Rainfall Quantities

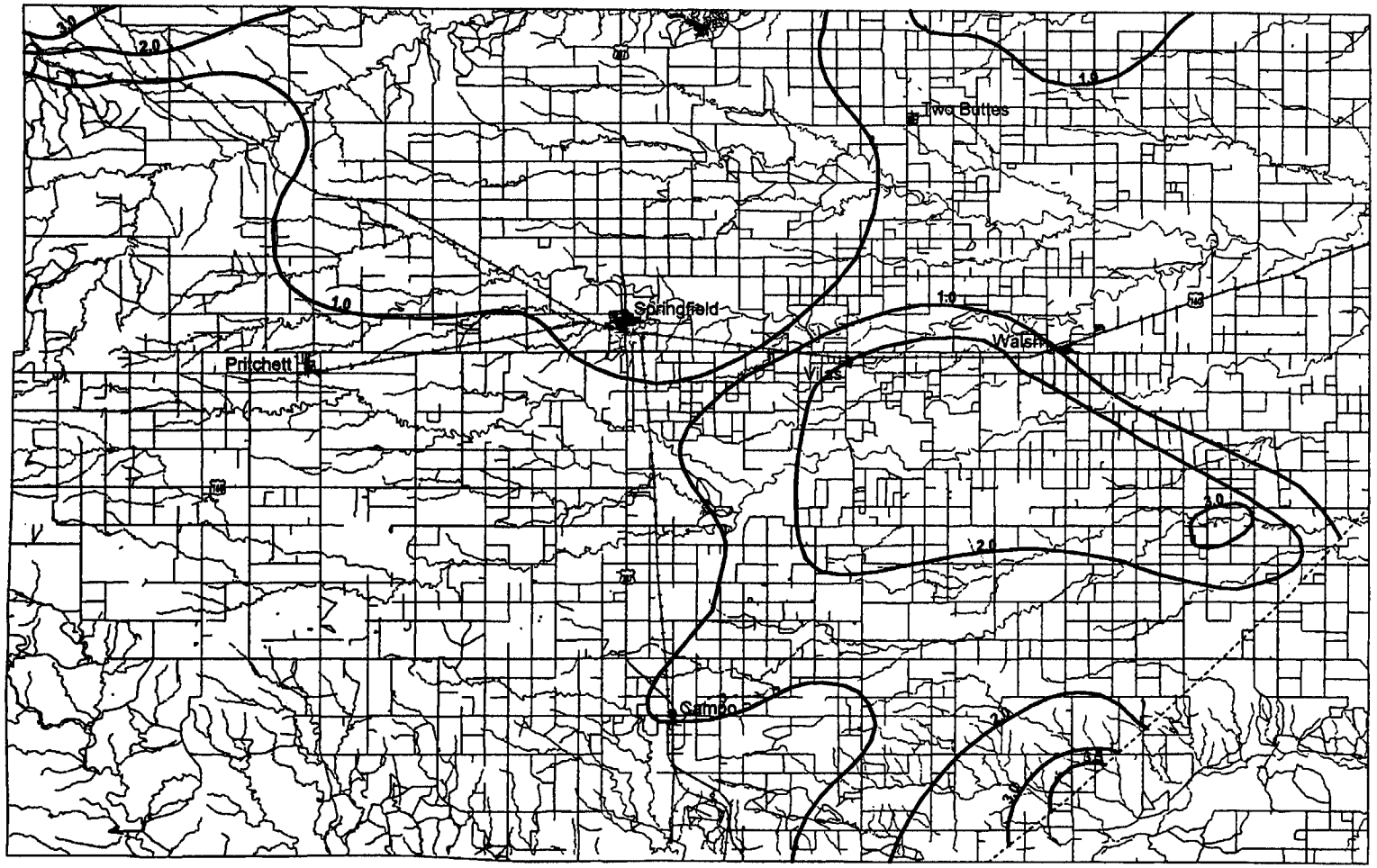
The storm duration for the August 5 and 6 rainfall shown in ***Table 4.1-1***, 26 hours, was based on NWS (National Weather Service) radar data taken from the Pueblo Weather Service Office (see Technical Addendum for radar images). A summary of the point precipitation collected for this storm event is presented in ***Table 4.1-3***. The radar data of precipitation totals and the NWS cooperative ground-level observations were converted to isohyets and are displayed in ***Figure 4.1-2***. As observed from this map, the largest pocket of rainfall, 3.5+ inches, fell over southeastern Baca County. Unfortunately, the complete spatial coverage of this storm event cannot be

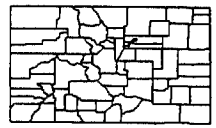
Figure 4.1-2

Baca County

Precipitation Map

8:09 a.m. August 5 -
9:54 p.m. August 6, 1997





Rivers and Streams
Canals and Ditches
Primary Roads
Secondary Roads
Railroads
Isohyetal Line (Inches)
Radar Limit
Lakes and Reservoirs
Municipal Boundaries

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Miles

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Table 4.1-3
Point Rainfall Amounts Recorded in Baca County for August 5 and 6, 1997

Source	Location	Amount	Recording Period
Colorado Climate Center (1998)	7 miles west-southwest of Springfield	0.65 inch	8/5/97 @ 5 p.m. to 8/6/97 @ 5 p.m.
NOAA (1997b)	North of Springfield	2.0 - 4.0 inches	8/5/97 @ 11:15 a.m. to 1:30 p.m.
Colorado Climate Center (1998)	Stonington	2.46 inches	8/5/97 @ 7 a.m. to 4 p.m.
Colorado Climate Center (1998)	Walsh	2.17 inches	8/5/97 @ 8 a.m. to 8/6/97 @ 8 a.m.
Colorado Climate Center (1998)	7 miles south of Campo	0.83 inch	8/5/97 @ 7 a.m. to 8/6/97 @ 7 a.m.

documented since the limit of the Pueblo radar's range occurs just northwest of the mainstem of the Cimarron River. For this reason, there is little available atmospheric information in this sparsely populated area, and the ability of the NWS' Pueblo office to provide detailed precipitation amounts and other meteorological characteristics is limited.

However, individual NWS spotter records verify the magnitude and spatial distribution of the rainfall estimates displayed in ***Figure 4.1-2***. According to the Stonington station, the majority of the rainfall that fell in this 26-hour period may be limited to an 8-hour duration in the afternoon.

The one significant difference between this point data and the radar estimates is the NOAA Storm Data report that described flash floods occurring north of Springfield following 2 to 4 inches of rain (NOAA 1997b). Since no additional information is provided in the NOAA report, the lower half (2 inches) of this estimated precipitation total appears more reasonable than the upper (4 inches) based on the radar data and other point and areal precipitation data recorded on this day.

Although storm totals are not very large for Baca County compared to other counties declared in the 1997 Presidential Disaster Declaration, the accumulated precipitation that fell during 1 week (August 5 through 12) in Stonington (6.10 inches) was over half of the average annual rainfall the county typically experiences (*Plainsman Herald* 1997).

4.1.4.2 Estimated Point Precipitation Return Periods

The estimated precipitation return periods in Baca County are presented in *Table 4.1-4*. The 6-hour, 12-hour, and 24-hour storm durations for the 10-year and 100-year return interval were taken from the maps and nomogram provided in NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado (1973).

Table 4.1-4
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation	100-yr Precipitation
6 hours	3.3 inches	5.2 inches
12 hours	3.8 inches	6.0 inches
24 hours	4.2 inches	6.8 inches

As noted earlier, the magnitude of precipitation that fell over Baca County in July and August of 1997 did not produce the damaging floods experienced in other counties; instead, the damage was the result of the frequency of storm events over a short time (August 5 through 12). Consequently, none of the rainfall totals exceeded the 100-year estimates. *Table 4.1-5* shows rainfall amounts, duration, and comparison with 10-year estimates for all four storm events that produced over one inch of rain.

Table 4.1-5
Summary of Storm Precipitation, Duration, and Return Period for Baca County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
Colorado Climate Center 1998	Springfield	July 29	1.13 inches	24 hours	<10-year, 24-hour event
Colorado Climate Center 1998	Stonington	August 5	2.46 inches	8 hours	<10-year, 6-hour event
Colorado Climate Center 1998	Walsh	August 5	2.17 inches	24 hours	<10-year, 24-hour event
Colorado Climate Center 1998	Walsh	August 9	1.52 inches	24 hours	<10-year, 24-hour event
Colorado Climate Center 1998	Campo	August 11	1.13 inches	24 hours	<10-year, 24-hour event

The August 5 through 6 event depicted in ***Figure 4.1-2*** produced a maximum isohyet of 3.5 inches. Assuming this storm duration was approximately 24 hours, this event corresponds to the 5-year, 24-hour rainfall in eastern Baca County (NOAA 1973).

4.1.5 Hydrology and Hydraulic Findings

No information was available to adequately describe the hydrologic or hydraulic characteristics associated with the July or August 1997 storm events in Baca County. A hydrograph was not developed for Baca County.

In general, however, Carrizo, Two Butte, and Bear Creek watersheds experienced flooding conditions along several reaches. Most information concerning the flooding extent in Baca County centers around areas where county roads and bridges traverse the channel.

In southwest Baca County, Carrizo Creek flowed out of its banks for approximately 36 to 48 hours (Stevenson 1998). During this time, the peak flow produced a water depth of approximately 15 to 20 feet in the channel. Along Cottonwood Canyon, a tributary of Carrizo Creek, an old cottonwood tree positioned approximately 12 feet above the channel bottom was washed away during the August storms. In addition, an 8-foot-square boulder located approximately 4 feet above the channel bottom washed away because of flood flows and shifting soils.

Water depths similar to those in Carrizo Creek were reported in the Two Butte watershed by the Baca County Road and Bridge Department. This watershed includes northern and central parts of the county. For example, water was running along Bear Creek north of Bartlett just underneath the county bridge, which is 15 feet above the creek bed. Two Butte Creek also experienced similar flooding conditions near Highway 287 and upstream.

4.1.6 Specific Flooded or Inundated Areas

The NWS Pueblo office reported flash flooding on county roads north of Springfield from 11:15 a.m. to 1:30 p.m. on August 5. In addition, newspaper photograph captions indicate that water had to be removed from Highway 287 a few miles north of Springfield on the morning of August 6 (*Plainsman Herald* 1997) (***Figure 4.1-3***). The same newspaper edition included a photograph of water overflowing Highway 287 at Two Butte Creek, approximately 18 miles north of Springfield (*Plainsman Herald* 1997). The newspaper suggests this flooding was caused by the rains that occurred on the evenings of August 9, 10, and 11.

The FEMA damage survey reports summarized the locations of the road and bridge damage that occurred on county roads during this period of flooding. ***Figures 4.1-4*** and ***4.1-5*** show damage to County Road C near Carrizo Creek,

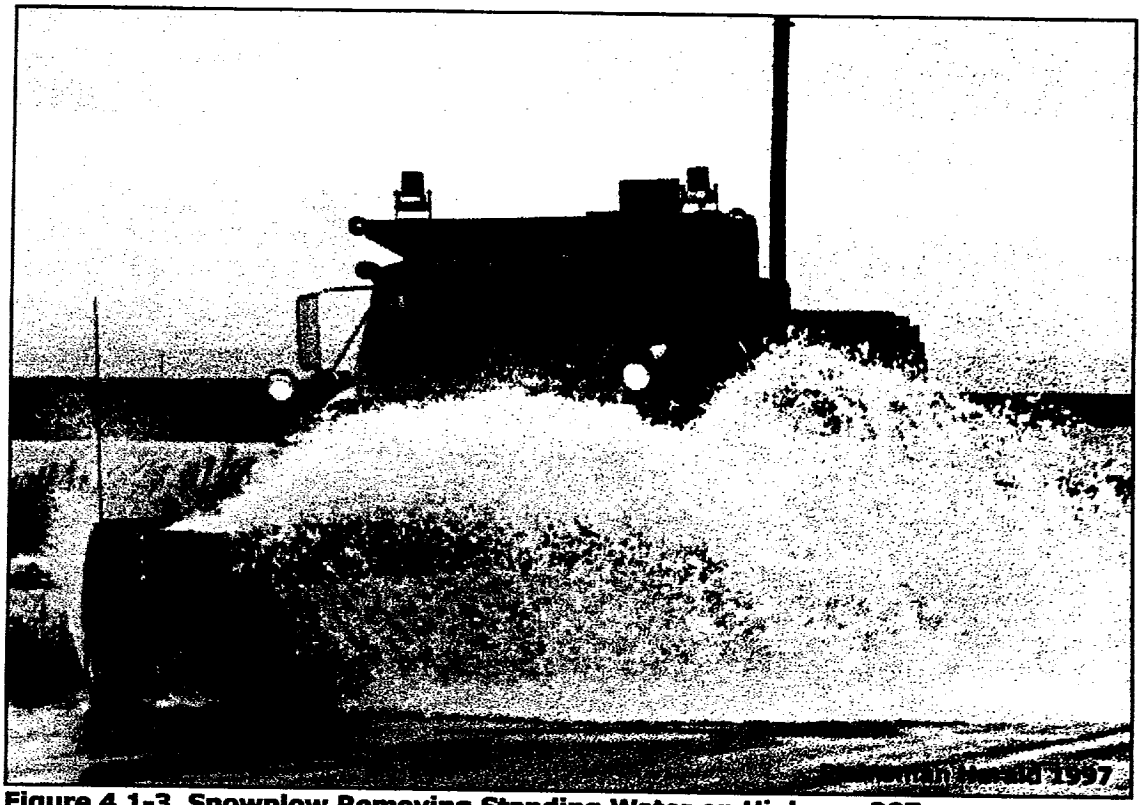


Figure 4.1-3 Snowplow Removing Standing Water on Highway 287

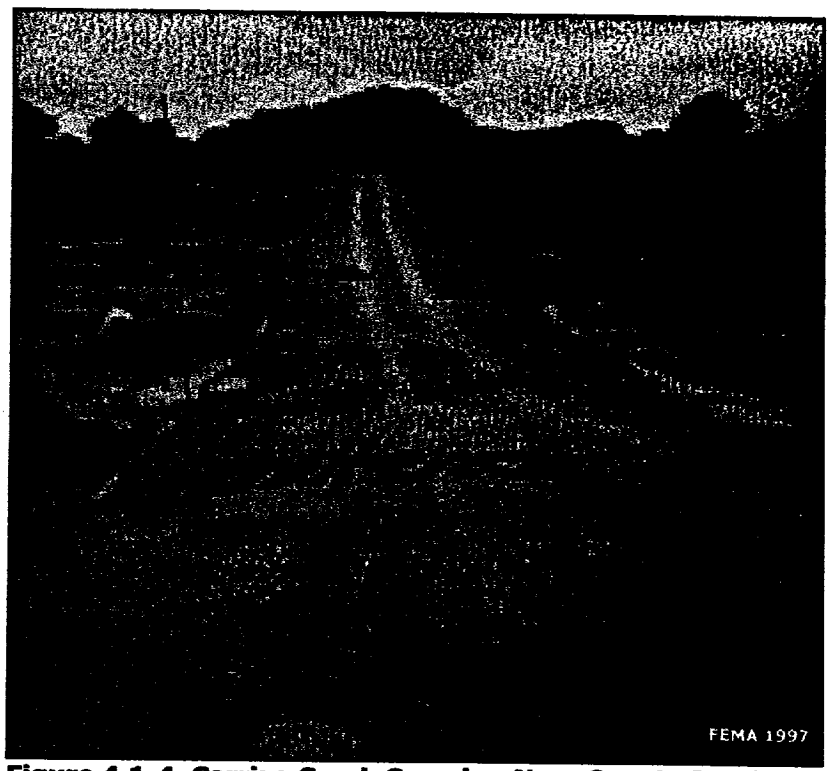


Figure 4.1-4 Carrizo Creek Crossing Near County Road C

Figure 4.1-5 Damage to County Road C Within the Carrizo Creek Watershed

while *Figure 4.1-6* depicts damage and inundated fields along County Road 39 in southeastern Baca County. *Figure 4.1-7* highlights where these FEMA damages occurred. Short-term flooding also was observed on Highway 160 near and within the Town of Walsh.

No additional information was available concerning flooding on state or federal highways or the extent of flooding in natural watersheds.

4.1.7 Emergency Response Effort

Since very little flooding occurred within incorporated areas, the potential damage to inhabited structures was minimal. Consequently, little information was available to describe the emergency response to the localized flooding. The August 14 edition of the *Plainsman Herald* does show the road crews plowing water off Highway 287 north of Springfield on August 6 following the rainfall that began on the 5th (see ***Figure 4-1.3***). In addition, highway crews positioned a digital sign on northbound Highway 287 south of Springfield to warn drivers of water on the roads (***Figure 4-1.8***). Neither the County Sheriff's Office nor the Commissioners' office indicated that other emergency response efforts occurred.

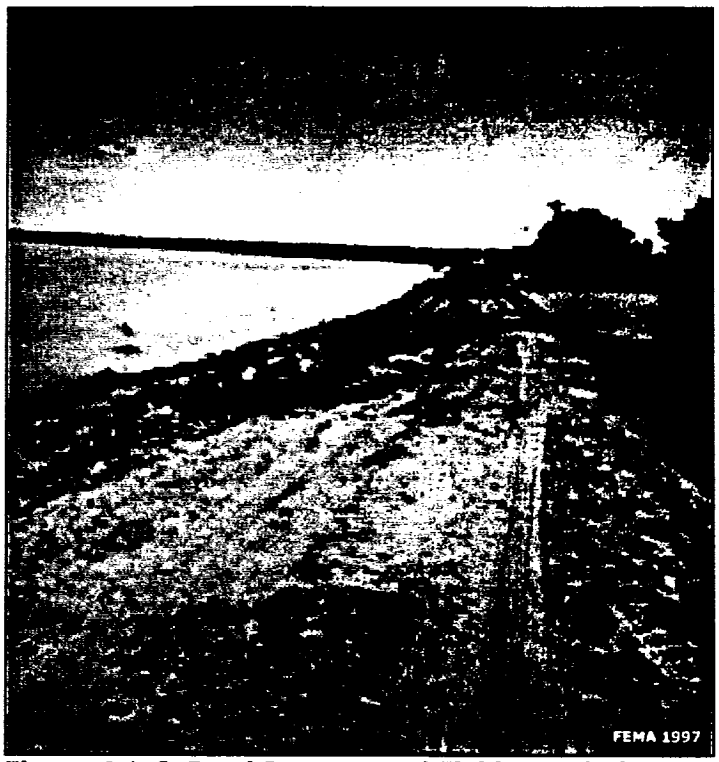


Figure 4.1-6 Road Damage and Field Inundation Along County Road 39

4.1.8 1997 Flood Damage

The available documentation indicates that damage from the 1997 floods in Baca County were primarily confined to county roads and bridges. Information obtained from the County Commissioners' Office (Waite and Self 1998) and the Baca County Road and Bridge Department (1998) provides some costs associated with these damages. In addition, the FEMA damage survey reports also provide cost estimates associated with these storm events. A summary of these damage estimates for Baca County are provided in *Table 4.1-6*.

The county road and bridge cost is an accumulated sum of material and equipment costs associated with damages on specific road sections; no labor costs are included in this value. The USDA-Farm Services Agency in Baca County did not indicate that any significant damage to agriculture occurred as a result of these floods (Lusk 1998); most of the inundation occurred over natural grasslands.

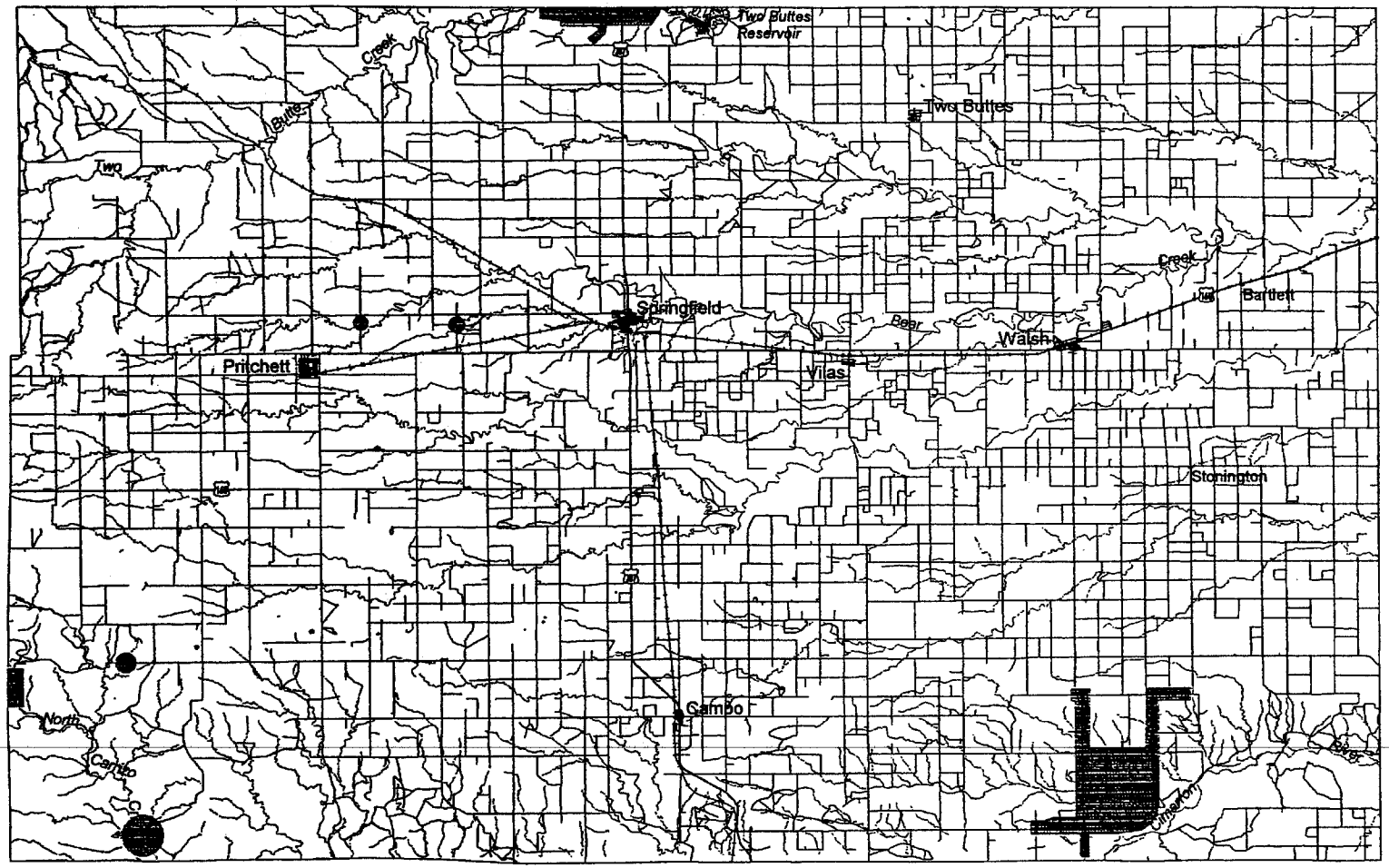
4.1.9 Flood Hazard Mitigation

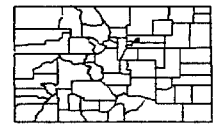
The County Commissioners' Office indicated that no formal flood mitigation efforts were or plan to be implemented as a result of the 1997 storm events

Figure 4.1.7

Baca County

Damage Areas





Rivers and Streams
Canals and Ditches
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries
Damage Areas

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Miles

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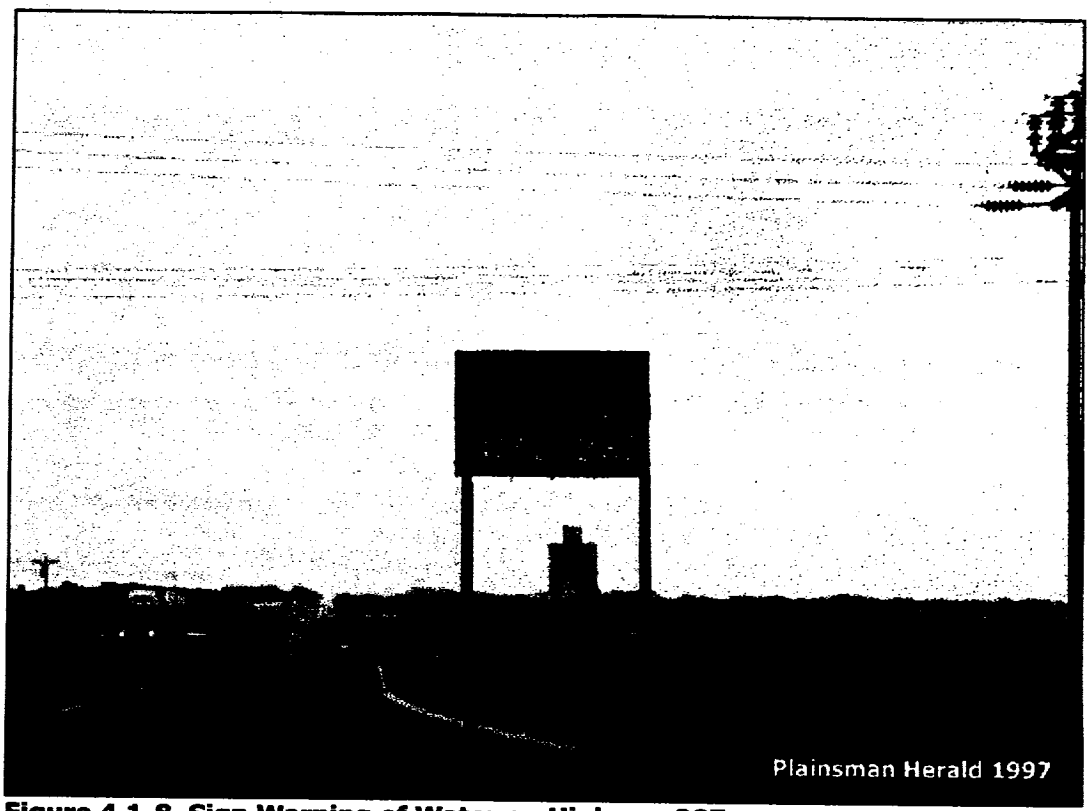


Figure 4.1-8 Sign Warning of Water on Highway 287

(Waite and Self 1998). The County Road and Bridge Department repairs any damage to its roads when damaging floods occur.

Table 4.1-6
Damage Estimates From the August 5-6, 1997, Storm Events

Description	Damage Estimate	Source
Baca County (includes roads and bridges for entire county)	$68,000[1,2]	Waite and Self (1998)
District 3 roads and bridges only	$22,900[1,2]	Baca County Road and Bridge Dept. (1998)
Agriculture	No dollar cost estimated	USDA-Farm Services Agency (Lusk 1998)
FEMA - countywide	$104,462[3]	FEMA Damage Survey Reports (1998)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

4.1.10 Special Circumstances

In general, all the tributaries in Baca County can experience flooding conditions along reaches where highway and railroad embankments transect the natural drainage paths. The criteria used to design these crossings were not investigated for this document. No other information was available to indicate that unique circumstances existed in Baca County to cause flooding as a result of the 1997 storm events.

4.2 Clear Creek County

4.2.1 Study Area

In August of 1997, Clear Creek County received intense thunderstorm-related precipitation, and rural parts of the county sustained considerable flood damage. The county is located along the Front Range of central Colorado, just east of the continental divide (see ***Figure 1.1-1***). The principle communities in the county are Idaho Springs, Empire, Georgetown, and Silver Plume. However, no flooding occurred in these communities during the August 1997 event. Flooding occurred primarily in the rural areas of Witter Gulch, Corral Creek, and Little Bear Creek. A general vicinity map of the county is provided in ***Figure 4.2-1***.

Primarily encompassing mountainous terrain, Clear Creek County spans 396.5 square miles. Much of the county lies within the Arapaho National Forest and is densely vegetated with spruce, pine, and aspen, and has a dense undercover with a thick duff (organic leaf litter) layer (Jarrett 1997). The mean annual precipitation for the area ranges from approximately 19 to 25 inches.

4.2.2 Watershed Description

The primary drainage in Clear Creek County is Clear Creek, which flows east toward Golden, Colorado, and the Denver metroplex. However, the watershed that experienced the most flooding in August of 1997 was Bear Creek. According to the Clear Creek County Road Supervisor, tributaries to Bear Creek that experienced flooding include Witter Gulch, Corral Creek, Indian Creek, and Yankee Creek (Cannady 1998a). Witter Gulch and Corral Creek are left bank tributaries to Bear Creek. The Indian Creek and Yankee Creek watersheds drain northward and are right bank tributaries to Bear Creek.

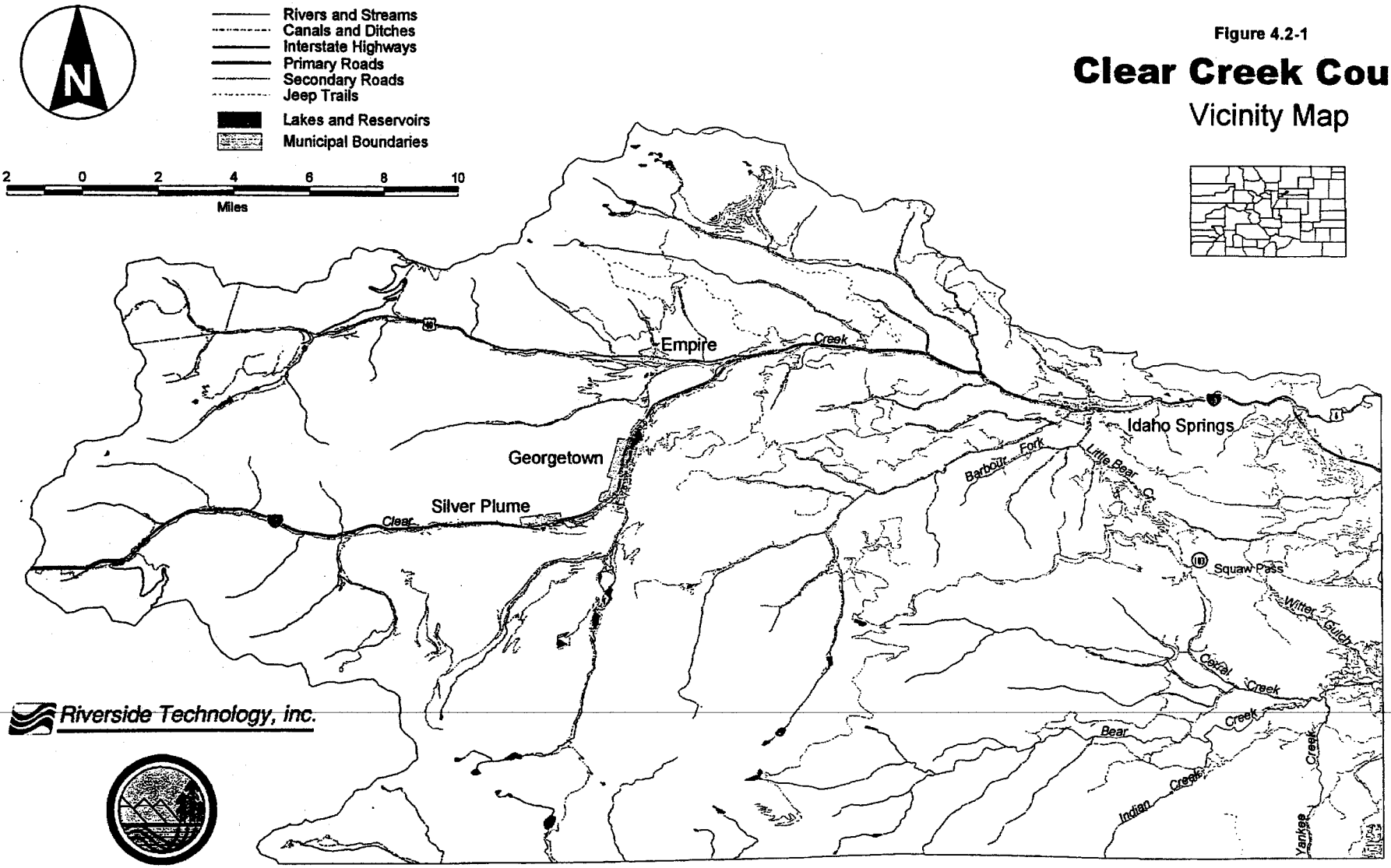
Colorado State Highway 103 runs along the crest dividing Corral Creek and Witter Gulch to the south from Little Bear Creek and the Clear Creek drainage to the north. Little Bear Creek drains to the north and is a right bank tributary to Barbour Fork Creek and Clear Creek.

These watersheds are located in mountainous terrain with elevations ranging from approximately 7,400 to over 10,000 feet. The closest town to the watersheds of interest is Idaho Springs, located at the confluence of Barbour Fork Creek and Clear Creek. Given the nature of the flooding and the damage sustained, Witter Gulch is the primary focus of this discussion. Its watershed has an area of approximately 4.9 square miles, and it contains several hundred homes. Most of the roads in this area are gravel (Jarrett 1997). ***Figure 4.2-2*** shows the Witter Gulch watershed and surrounding study area. The nearest reservoir is Evergreen Lake, which is located on Bear

Figure 4.2-1

Clear Creek County

Vicinity Map



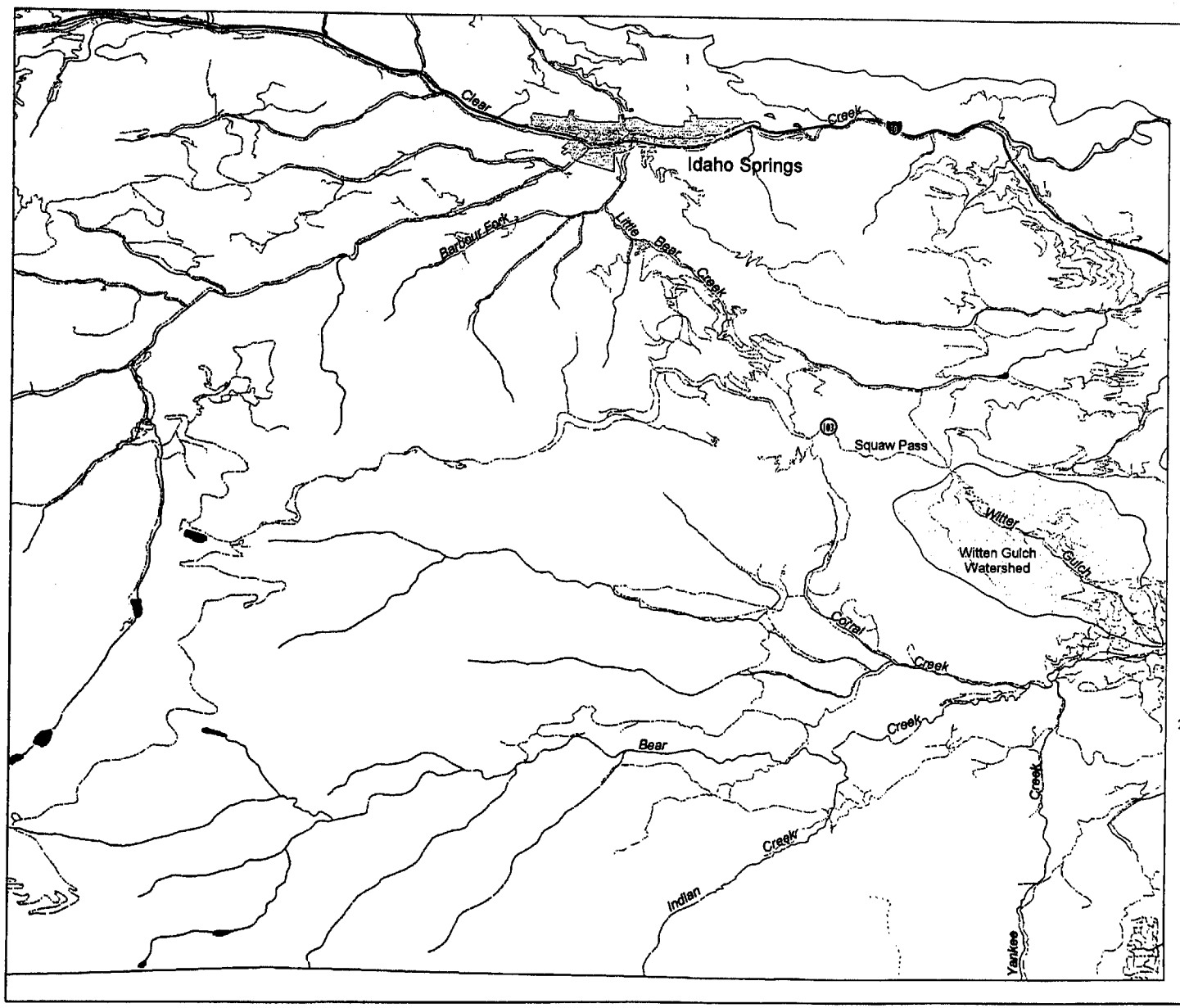
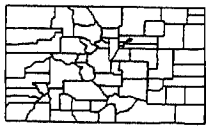


Figure 4.2-2

Clear Creek County

Affected Watershed



Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Jeep Trails
Lakes and Reservoirs
Municipal Boundaries
Watershed

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Creek in Jefferson County approximately 4 miles downstream from Witter Gulch.

4.2.3 Local Flooding Problems

Local flooding is not uncommon in Clear Creek County. The relatively high elevation of the county makes it prone to flooding from snowmelt and thunderstorms. Every summer during the 1990s, flooding has occurred in at least one location in the county. During the 1980s, there also were several flooding events (Cannady 1998b). In the spring of 1995, considerable damage occurred in the Town of Georgetown from flooding caused by snowmelt. That winter the snowpack was approximately 240 percent of normal. Flooding occurred primarily along Leavenworth Creek and Clear Creek (Cannady 1998b).

4.2.4 Storm Characteristics

Heavy rains in eastern and central Colorado, including very heavy localized precipitation in August of 1997, caused significant flooding in several areas within Clear Creek County. The dates of these events are shown in ***Table 4.2-1.***

Table 4.2-1
Dates of Significant Precipitation in Clear Creek County During 1997

Date	Maximum Precipitation	Comments
August 3	1 - 2.5 inches	Unconfirmed reports of up to 10 inches in Witter Gulch
August 30	2 inches (unconfirmed)	Corral Creek and Little Bear Creek areas (unconfirmed reports of up to 7 inches in Bear Creek)

On August 3, 1997, a severe thunderstorm settled over the Witter Gulch area. According to the Clear Creek County Office of Emergency Management Director, this storm dropped up to 11 inches of rain in a matter of 1 to 3 hours (Oman 1998). The Bear Creek area foreman for the Clear Creek County Road Department also reported up to 10 inches of rain for this event (Cannady 1998a). The intense rainfall caused flooding in Witter Gulch and damaged several county roads. On August 30, 1997, another thunderstorm hit the area, this one situated near Squaw Pass a couple of miles to the west of the first storm. This last storm also released a large amount of rainfall in a short time, causing flood damage along both Corral Creek to the south and Little Bear Creek to the north. These two storm events were the worst seen by local residents in at least 25 years (Oman 1998) and resulted in a presidential disaster declaration for Clear Creek County.

Table 4.2-2 presents meteorological data from Denver on August 3 and August 30, 1997. Denver is the closest site to Clear Creek County that has reasonably complete archived weather data. However, these data are probably not representative of conditions in the Witter Gulch area of Clear Creek County because the elevation at this Denver weather station is 5,414 feet and the Denver area is more exposed to Great Plains weather patterns.

Table 4.2-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches of Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
Denver, CO	8/3	59	87	24.81	57	57	8.3	170
Denver, CO	8/30	54	83	24.64	53	51	8.7	170

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C)

(Linsley et al. 1992)
Source: National Climatic Data Center 1998a

4.2.4.1 Storm Duration and Rainfall Quantities

The severe thunderstorm on August 3 lasted from approximately 6:15 p.m. until 10:30 p.m. (Cannady 1998a), and most of the flooding problems associated with this storm were in the Witter Gulch area. This storm event produced very heavy localized precipitation and was accompanied by nearly continuous lightning (Oman 1998). The CWCB did not conduct a bucket survey for this event, but precipitation data were recorded by the UDFCD (Urban Drainage and Flood Control District) at its Rosedale gage (Stewart 1997). Rainfall at this station totaled approximately 0.6 inch between 8:00 p.m. and 9:00 p.m. on August 3. No other precipitation was measured at this site on this date. Apparently, the Rosedale gage is located outside the area of maximum precipitation because it measured much less precipitation than was estimated to have fallen at Witter Gulch.

Rainfall estimates for the August 3 storm were made from geomorphic indicators, including the amount of sediment mobilized on hillslopes, distance transported, width and depth of rill/gully development, and peak discharge estimates (Jarrett 1997). On unvegetated, steep hillslopes, rills were generally less than 1 inch deep and 2 inches wide, suggesting moderately intense rainfall during the August 3 event. Along roadsides, gullies generally were less than 1 foot deep, and small sediment deposits typically only developed in areas draining gravel roads.

Areas in Witter Gulch that have the greatest concentration of homes, driveways, and gravel roads exhibited the most notable runoff deposits. Based on these observations, the peak discharges for this event were

generated by 1 to 2 inches of very localized rain that fell in less than an hour. These are characteristic of large thunderstorms at this elevation. *Figure 4.2-3* is an isohyetal map of Clear Creek County for August 3-4 made from a radar image. It also indicates that the Witter Gulch area experienced approximately 2 inches of rainfall during this event.

Table 4.2-3 summarizes point rainfall estimates for the August 3, 1997, event.

Table 4.2-3
Point Rainfall Amounts Recorded in Clear Creek County for August 3, 1997

Source	Location	Amount	Recording Period
UDFCD (Stewart 1997)	Approximately 1 mile below the mouth of Witter Gulch on Bear Creek	0.6 inch	8/3/97 8p.m. - 9p.m.
USGS (Jarrett 1997)	Witter Gulch	1 - 2 inches	8/3/97; less than 1 hour

Larger rainfall amounts reported by some local residents may reflect total amounts of rainfall accumulated over longer periods (a day or more) (Jarrett 1997). However, several residents in Witter Gulch said the thunderstorm on August 3 moved up and down the valley several times, releasing intense rainfall before moving away from the area. According to some eyewitnesses, this intense rainfall prompted car-sized boulders to be washed down Witter Gulch (Ryman 1998).

4.2.4.2 Estimated Point Precipitation Return Periods

The point precipitation totals for Witter Gulch for storm durations of 6 hours, 12 hours, and 24 hours for return periods of 10 and 100 years (as developed from the NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado [1973]) are shown in ***Table 4.2-4.***

Table 4.2-5 summarizes the storm precipitation duration and return period for the rainfall amounts shown in ***Table 4.2-3***.

Table 4.2-4
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation	100-yr Precipitation
6 hours	1.9 inches	2.9 inches
12 hours	2.4 inches	3.7 inches
24 hours	2.9 inches	4.4 inches

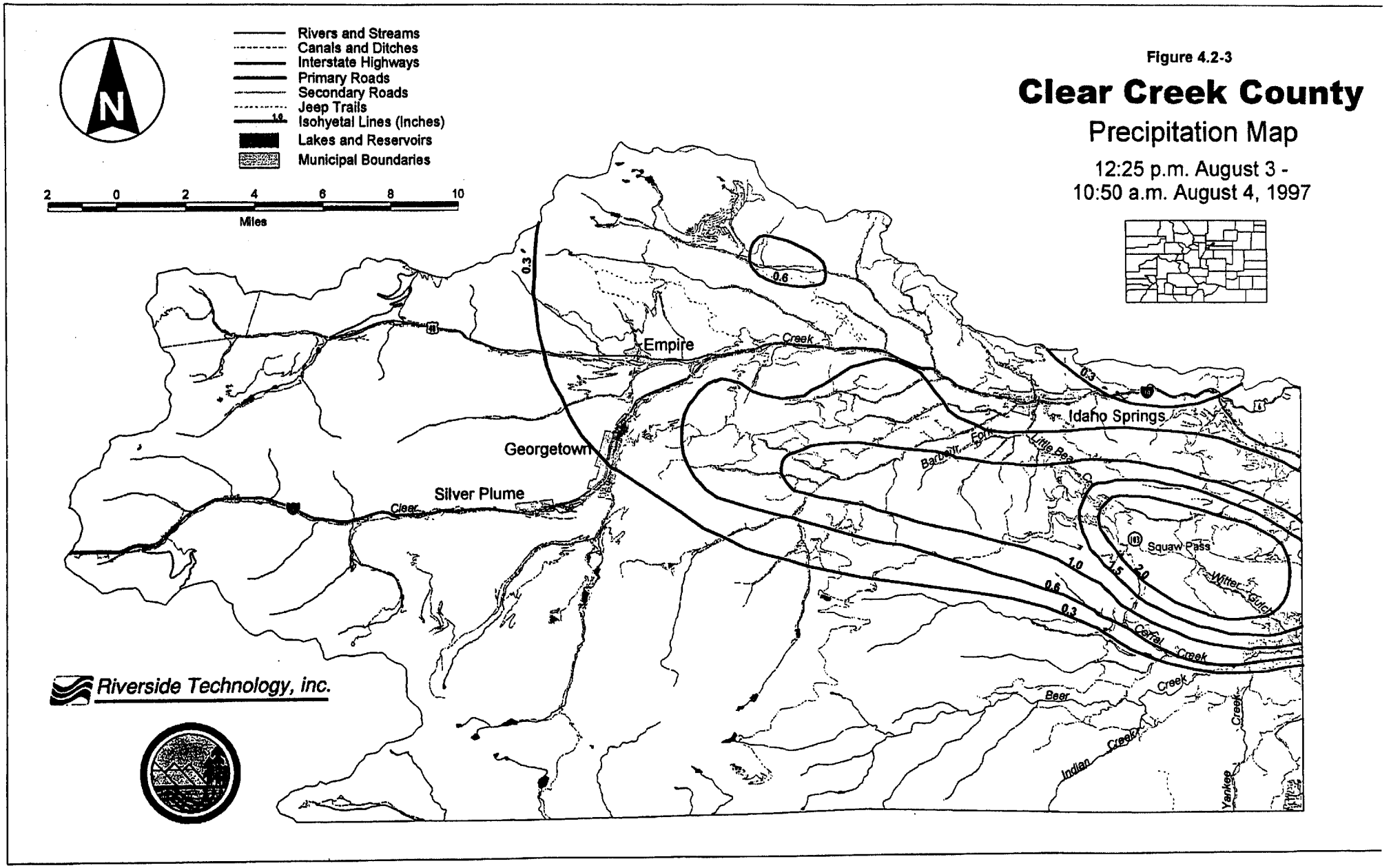

Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Jeep Trails
Isohyetal Lines (Inches)
Lakes and Reservoirs
Municipal Boundaries
2 0 2 4 6 8 10
Miles
Figure 4.2-3
Clear Creek County
Precipitation Map
12:25 p.m. August 3 -
10:50 a.m. August 4, 1997
Empire
Georgetown
Silver Plume
Idaho Springs
Squaw Pass
Clear Creek
Little Beaver Creek
Witter Gulch
Beaver Creek
Indian Creek
Yankee Creek
0.3
0.6
1.0
1.5
2.0
Riverside Technology, inc.

Table 4.2-5
Summary of Storm Precipitation, Duration, and Return Period for Clear Creek County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
NOAA (1973)	Witter Gulch	Aug. 3, 1997	0.6 inches	1 hour	Less than 2 years
NOAA (1973)	Witter Gulch	Aug. 3, 1997	2 inches	less than 1 hour	Approximately 80 years

4.2.5 Hydrology and Hydraulic Findings

4.2.5.1 Locations/Reaches of Flooded Streams

Flood damage from the August 3, 1997, event was primarily generated from runoff on gravel roads and driveways in the Witter Gulch area; natural areas had minimal (less than 5 cfs) runoff within the area of maximum rainfall (Jarrett 1997). Flooding evidence in the form of small sediment deposits was observed half way up Witter Gulch approximately 0.5 mile upstream from the intersection of Stagecoach, Circle K, and Witter Gulch Road. This is the area with the greatest concentration of homes, driveways, and gravel roads. Downstream, the Bear Creek channel is sufficiently large from annual snowmelt runoff that no overbank flooding occurred. It is likely that Bear Creek probably had a peak discharge of less than 175 cfs during this event (Jarrett 1997).

4.2.5.2 Channel Characteristics

The natural channel of Witter Gulch drains undeveloped forestland and residential areas. It is irregular in nature with varying cross-sectional geometries and has a relatively steep slope. The channel has an average depth of approximately 2 to 5 feet, an average width ranging from approximately 3 to 10 feet, and an average slope ranging from approximately 6 to 10 percent. The channel consists of a primary stream cross section with overbank flood plains. The natural channel is generally well defined.

4.2.5.3 Peak Flows and Estimated Return Periods

A hydrologic/hydraulic assessment was prepared for the flooding that occurred in Witter Gulch as a result of the storm event on August 3, 1997 (Jarrett 1997). As part of this effort, stream cross sections were made at five locations along Witter Gulch (***Figure 4.2-2***), and high water marks were recorded. High water marks were primarily fine leaf/needle litter, slack-water (sediment) deposits, wash lines, and bent grass. Local channel slopes and Manning "n" values were estimated for each cross section, and

photographs were taken. Peak discharge was computed using both the slope-conveyance method and critical-depth method at each cross section, and the discharge estimate was taken as the average of these two methods. The two methods generally agreed within 10 percent (Jarrett 1997). The computed peak discharge estimates for Witter Gulch are presented in ***Table 4.2-6***. The 100-year peak flow was estimated for Witter Gulch at the confluence with Bear Creek only and not for locations within Witter Gulch upstream of the mouth.

Table 4.2-6
Computed Peak Discharge for the Storm Event of August 3, 1997 – Witter Gulch

Location[1] (arranged from upstream to downstream	Drainage Areas (square miles)	Estimated Peak Flow[1] (cfs)	Estimated 100-year Peak Flow[2] (cfs)
1 mile below Colorado State Hwy 103	approx. 1.4	55	--
0.5 mile upstream from intersection of Stagecoach, Circle K, and Witter Gulch Roads	approx. 3.0	150	--
Upstream from Oak Way	approx. 4.6	210	--
Upstream from the first crossing of Witter Gulch Road	approx. 4.7	135	--
Near confluence of Witter Gulch and Bear Creek (entire Witter Gulch watershed)	approx. 4.9	130	135

[1]Source: Jarrett 1997 (locations are shown in ***Figure 4.2-2***)
[2]Source: CWCB 1997b

Less than 5 cfs of runoff occurred in the undeveloped parts of the study area. Dense vegetation and thick duff on the undisturbed hillslopes of Witter Gulch helped to minimize runoff and erosion (Jarrett 1997).

4.2.5.4 Flood Hydrograph

The hydrograph of the Rosedale gage, located near the county line and the confluence of Witter Gulch and Bear Creek, is shown in ***Figure 4.2-4***.

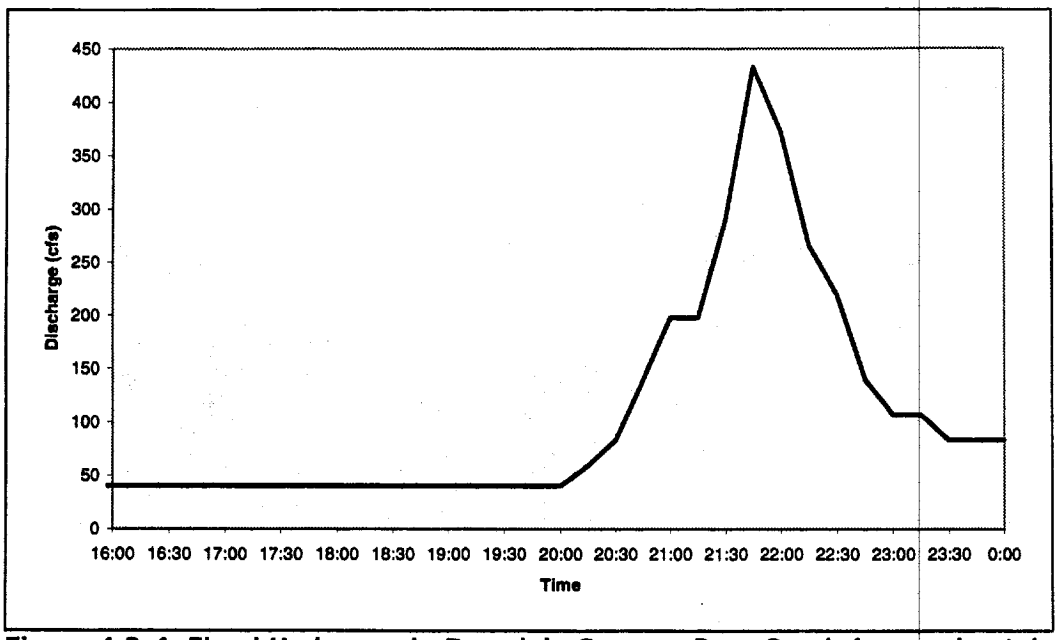


Figure 4.2-4 Flood Hydrograph, Rosedale Gage on Bear Creek (approximately 1 mile below Witter Gulch), August 3, 1997 (Stewart 1997)

4.2.6 Specific Flooded or Inundated Areas

Virtually all of the flooding that occurred in Witter Gulch on August 3, 1997, was confined to areas with residential development. Homes, driveways, and gravel roads reduced infiltration in these areas resulting in more runoff and flooding. In undeveloped parts of the watershed, dense vegetation and thick duff helped minimize runoff and erosion (Jarrett 1998). The lower 2 miles of Witter Gulch down to Bear Creek experienced the most flooding during this event. There is a greater concentration of homes and development in this area, and the canyon becomes narrower and the channel more defined. In addition, some structures are built within the floodplain in this area (Cannady 1998b).

4.2.7 Emergency Response Effort

The only emergency response efforts that were required for the August 3 storm event in Witter Gulch were road and culvert repairs by the Clear Creek County Road and Bridge Department. These emergency activities helped to provide access for residents in the area. No emergency rescues or evacuations were required (Cannady 1998b).

4.2.8 1997 Flood Damage

Flood waters in Witter Gulch damaged utilities, bridges, and county roads. Damage to public utilities resulted more from moderate erosion on steep slopes than from flows in natural stream channels. Woody debris obstructed

many culverts in Witter Gulch. These obstructions, coupled with the low flow capacities (100 to 200 cfs) of some culverts, caused them to overtop. These waters then flowed along roads and further contributed to erosion and the deposition of flood sediments. However, this process also helped to attenuate the peak flows (Jarrett 1997).

Because this storm event was located in rural and relatively undeveloped areas of Clear Creek County, most of the costs associated with flooding were incurred to repair roads and ditches. Also, one small man-made pond washed out and several ditches and embankments failed. Repairs included replacing culverts, regrading gravel roads, repairing ditches, and repairing pavement. Total damage costs were estimated to be over $400,000 (Cannady 1998a). This estimate does not include damage to private property. ***Table 4.2-7*** summarizes these costs.

Table 4.2-7
Damage Estimates From the August 3, 1997, Storm Event

Description	Damage Estimate	Source
County Roads	$250,000[1,2]	Clear Creek County (Cannady 1998a)
Utilities (gas and telephone lines)	Up to $10,000[1,2]	Colorado Public Service Co. (Ryman 1998) and US West Telephone Co. (Alvers 1998)
Clean-up Efforts	$15,400 (local) [1,2]	Clear Creek County (Cannady 1998a)
	$10,800 (state) [1,2]	Clear Creek County (Cannady 1998a)
	$104,740 (federal) [1,2]	Clear Creek County (Cannady 1998a)
Emergency Operations	Less than $10,000[1,2]	Clear Creek County (Cannady 1998a)
Residential Properties	$100,000	Oman (1998b)
FEMA - countywide	$207,339[3]	FEMA Damage Survey Reports (1998)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include some overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

4.2.9 Flood Hazard Mitigation

Clear Creek County had implemented an infrastructure improvement plan in 1995 that included installing culverts in strategic locations. These

improvements may have reduced the overall damage caused by the August 3 storm by as much as 80 percent. In addition, the county has plans to install more drainage improvements in Witter Gulch in the future (Cannady 1998a).

4.2.10 Special Circumstances

The flooding that occurred in Clear Creek County in August of 1997 would have been much more costly if it had occurred in more densely populated parts of the county. Much of the area that saw intense rainfall was protected from intense runoff and erosion by dense vegetation and a thick duff covering the ground. In addition, the overall intensity of the rainfall events was much less than what was seen in other lower-elevation counties during the summer of 1997.

Residential development, driveways, and gravel roads intensified runoff and erosion in the more developed parts of Witter Gulch. The areas that experienced the most flooding were those with the most development. As floodplain encroachment continues, flooding from severe storm events will likely increase.

4.3 Crowley County

4.3.1 Study Area

Numerous localized thunderstorms produced several inches of rainfall over rural areas of Crowley County during the first 2 weeks of August 1997. Crowley County, composed primarily of agricultural land, is located on the eastern plains of Colorado, north of the Arkansas River and east of Pueblo County (see ***Figure 1.1-1***). Both northern and southern portions of the county were significantly affected by the 1997 flooding, but most of the communities escaped serious damage. While damages were wide-spread in the unincorporated lands in the county, some of the heaviest rain was observed north of Olney Springs and Sugar City (see ***Figure 4.3-1***).

In Crowley County, county roads and bridges sustained the most serious damage as a result of the runoff generated in the Black Draw, Horse Creek, Breckenridge Creek, and Bob Creek drainages. Ordway, the county seat (population of approximately 1,100), is located between the Horse and Bob Creek watersheds, and its runoff drains into Lake Meredith. Although this lake received a large volume of inflow via Bob Creek and other tributary runoff, the City of Ordway was not significantly affected by the storm events.

Land use in Crowley County is predominantly agricultural and includes grazing livestock and cultivating corn, alfalfa, and several types of fruit (e.g., cantaloupe and watermelon).

The topography of Crowley County is relatively flat with low hills dividing watersheds. The mean annual precipitation for Crowley County is approximately 11 inches.

4.3.2 Watershed Description

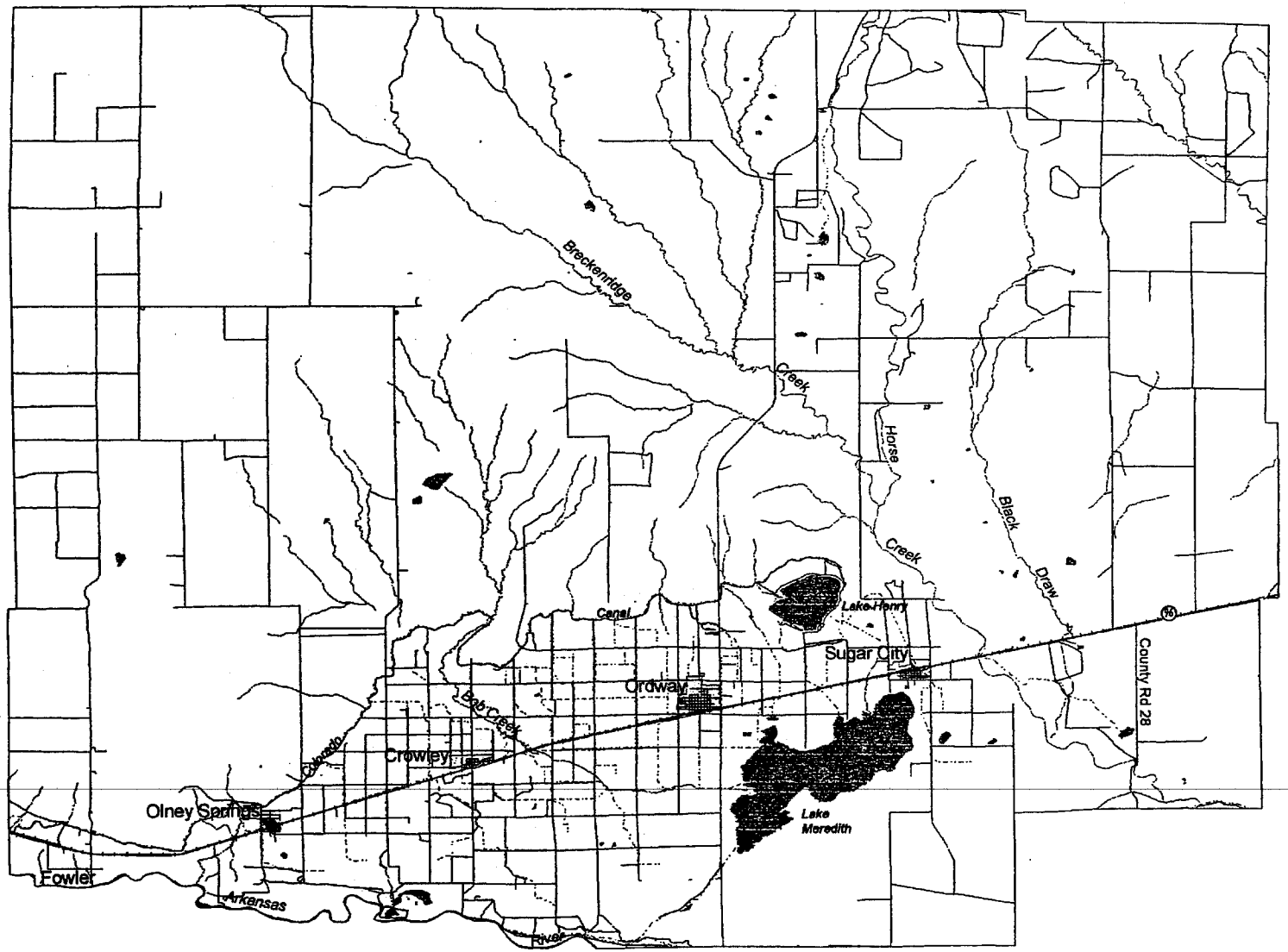
The watersheds of interest in Crowley County include Horse Creek, Bob Creek, and Black Draw. Water in Horse Creek flows south through Crowley County, meets Breckenridge Creek approximately 5 miles north of Sugar City, and eventually drains into the Arkansas River a few miles west of Las Animas, located in Bent County. Black Draw also is a tributary to Breckenridge Creek, whose confluence lies southeast of Sugar City, just upstream of the Crowley-Otero county line. Bob Creek, located in the central part of the county, flows southeast between the towns of Crowley and Ordway, and eventually drains into Lake Meredith.

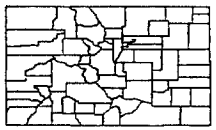
The headwaters of Horse Creek are located within El Paso County near Calhan (***Figure 4.3-2***). Additional events in the Horse Creek watershed are described in the Lincoln County flood documentation, Section 5.7. The USGS gage at Horse Creek near Sugar City, located approximately 8 miles

Figure 4.3-1

Crowley County

Vicinity Map





Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries

1 0 1 2 3 4 5 6 7 8 9 10
Miles

Riverside Technology, inc.

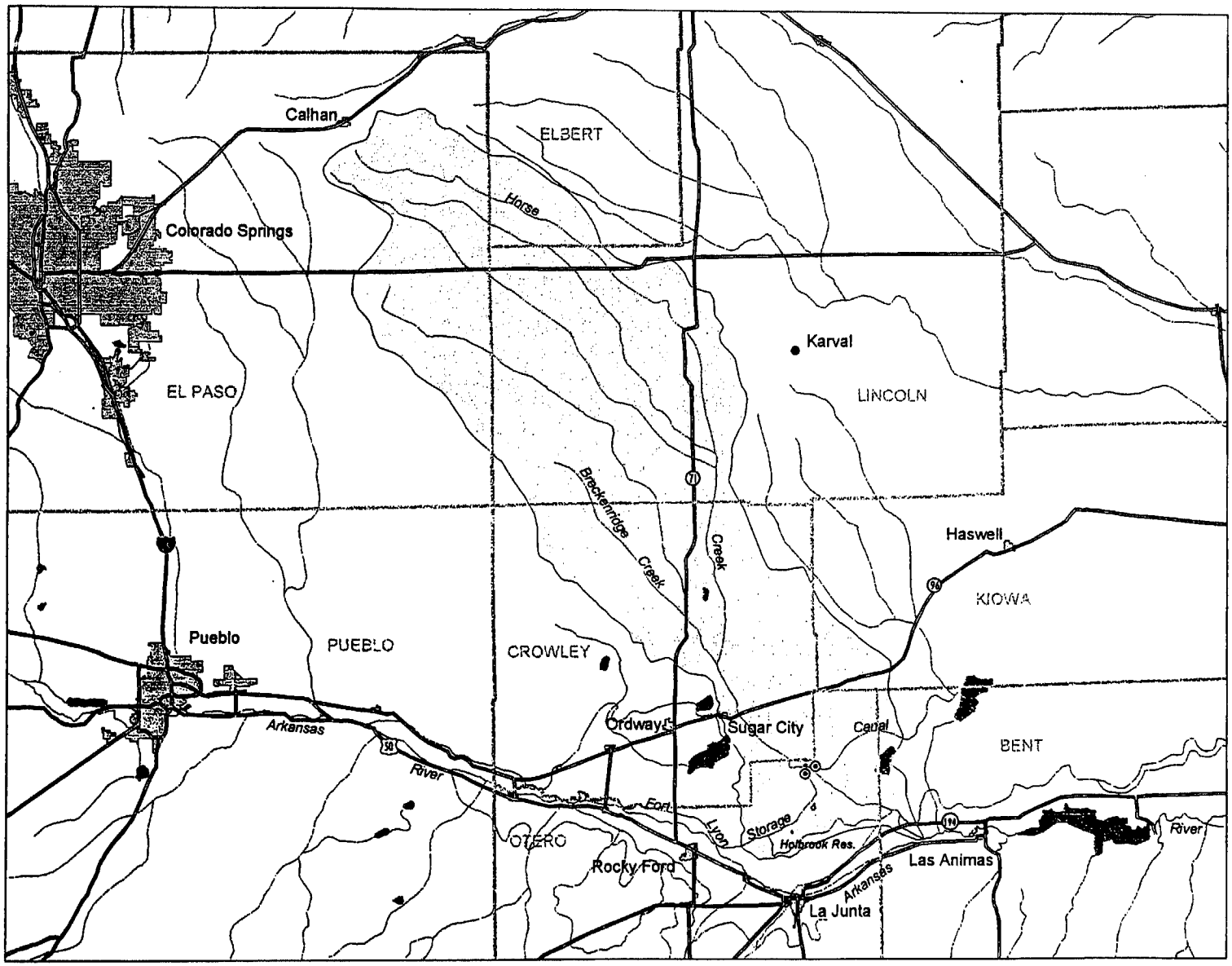


Figure 4.3-2

Horse Creek Watershed

5 0 5 10 15 20

Miles

- Rivers and Canals
- Highways
- Lakes and Reservoirs
- Municipal Boundaries
- County Boundaries
- Watershed
- Approximate Location of Fort Lyon Storage Canal Breaches

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upstream of the Crowley County line, measures flows from a drainage area of 1,026 square miles (USGS ID 07123500). The elevation of the Horse Creek drainage ranges from 6,600 to 4,200 feet.

The entire basin of Bob Creek is contained in Crowley County, and its headwaters originate approximately 15 miles northeast of Olney Springs. This local watershed has a drainage area of 110 square miles and an elevation ranging from approximately 4,800 feet at its headwaters to 4,440 feet at Lake Meredith.

4.3.3 Local Flooding Problems

Drainages in Crowley County, particularly those in the northern part of the county, historically have experienced flash flooding during the summer months because of highly localized storms (Mumm 1998). Because of the extensive drainage system used by current and former farmers in Crowley County south of Highway 96, flood problems are minimized in this region. Significant runoff is typically routed around the communities located in this area and into Lake Meredith.

4.3.4 Storm Characteristics

While other counties described in this report experienced damaging storm events throughout the summer, heavy rainfall in Crowley County was concentrated during early August of 1997. ***Table 4.3-1*** summarizes the intense storms that produced over 1 inch of rain recorded at two or more NWS cooperative or spotter stations during a 24-hour period in July and August of 1997.

Table 4.3-1
Dates of Significant Precipitation in Crowley County During 1997

Date	Maximum Precipitation	Comments
August 4-5	3.0 inches	Heavy rains south of Highway 96 near Ordway and Crowley
August 5-6	3.0+ inches	Storms over the northern half of the county, with the area north of Crowley experiencing the peak
August 13	1.8 inches	Heavy rain recorded in Ordway

Although the NWS cooperative station at Ordway recorded nearly 2 inches of precipitation in no more than 24-hours on August 13, no additional information is available for this storm. Therefore, the primary focus of this discussion is on the storms that produced rainfall over the first few days of August, specifically the evenings of August 4 and 5. While the entire county

witnessed some rainfall, the strongest precipitation intensity on the evening of August 4 occurred south of Highway 96, between Ordway and Crowley. From NWS spotter reports and radar images for the evening hours of August 5, the heaviest rainfall fell northwest of Crowley.

The nearest weather station that recorded multiple types of atmospheric data is located in La Junta, approximately 20 miles southeast of Ordway. Daily data was collected at this station for each of the three events identified in ***Table 4.3-1***. A summary of this meteorological data is presented in ***Table 4.3-2***.

Table 4.3-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches of Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
LaJunta, CO	8/4	64	91	25.97	60	63	9.4	40
LaJunta, CO	8/5	64	73	25.91	84	64	13.0	120
LaJunta, CO	8/6	58	66	25.93	84	57	11.0	30
LaJunta, CO	8/13	62	87	25.60	62	61	10.4	180

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T} \right)^8$ where T = average air temperature (°C), T_d = average dew point (°C)

(Linsley et al. 1992)
Source: National Climatic Data Center 1998a

Despite being the closest, most well-equipped gage near Crowley County, the data from the LaJunta Gage that is presented in ***Table 4.3-2*** may not completely represent the local meteorological conditions in the areas described earlier. This is primarily because of the convective nature of thunderstorms on the eastern plains of Colorado, which produce significant spatial variability within a region.

4.3.4.1 Storm Duration and Rainfall Quantities

The storm duration for the evening of August 5 shown in ***Table 4.3-1***, 38 hours, was based on NWS radar data (see Technical Addendum for radar images) taken from the Pueblo Weather Service Office. The radar data of precipitation totals and the NWS ground-level, 24-hour observer data (***Table 4.3-3***) were converted to isohyets which are displayed in ***Figure 4.3-3***. As can be observed on this map, the largest pocket of rainfall (3.0+ inches) fell over western and extreme northeastern regions of Crowley County. A summary of the point precipitation collected for all storm events greater than 1 inch is presented in ***Table 4.3-3***.

Table 4.3-3
Point Rainfall Amounts Recorded in Crowley County for August 4-6, 1997

Source	Location	Amount	Recording Period
Colorado Climate Center (1998)	21 miles north of Ordway	1.80 inches	7/29/97 @ 7 a.m. to 7/30/97 @ 7 a.m.
Colorado Climate Center (1998)	21 miles north of Ordway	1.12 inches	8/4/97 @ 7 a.m. to 8/5/97 @ 7 a.m.
Colorado Climate Center (1998)	Ordway	1.55 inches	8/4/97 @ 7 a.m. to 8/5/97 @ 7 a.m.
Erickson (1997)	Ordway and Crowley	3.0 inches	evening hours 8/5/97 - 8/6/97
Colorado Climate Center (1998)	21 miles north of Ordway	1.52 inches	8/5/97 @ 7 a.m. to 8/6/97 @ 7 a.m.
Colorado Climate Center (1998)	Ordway	0.34 inch	8/5/97 @ 7 a.m. to 8/6/97 @ 7 a.m.
Magnuson (1998a)	Sugar City	2.90 inches	evening hours 8/5/97 - 8/6/97
Colorado Climate Center (1998)	21 miles north of Ordway	1.80 inches	8/12/97 @ 7 a.m. to 8/13/97 @ 7 a.m.

During the evening of August 5 and into the morning hours of August 6, radar estimates indicate that only a trace of precipitation fell along the corridor of towns along Highway 96, despite significantly greater rainfall observed by NWS spotters in the Sugar City area (2.9 inches) (Magnuson 1998a). In addition, a station north of Ordway reported that 1.52 inches fell during a 24-hour period between August 5 and 6.

Assuming the periods from the radar and spotter information overlap, several factors could be responsible for this inconsistency in total rainfall between the data sources. First, the radar beam may not pick up low-level precipitation formations in the atmosphere at locations far from the radar facility (Magnuson 1998b). Second, human errors reading gage data, calibrating radar parameters, or both are possible. Third, the ground data are accurate, but the averaging process to produce a radar image reduces the peak rainfall amounts.

Although the isohyets in ***Figure 4.3-3*** are approximate delineations of precipitation totals, the NWS Cooperative 24-hour station data presented in the table above confirms the magnitude of the rainfall. Even though spatial inconsistencies exist between the point data and radar estimates on August 5 and 6, both data sources agree that an area of intense precipitation occurred in northeast Crowley County, north of Ordway and Sugar City.

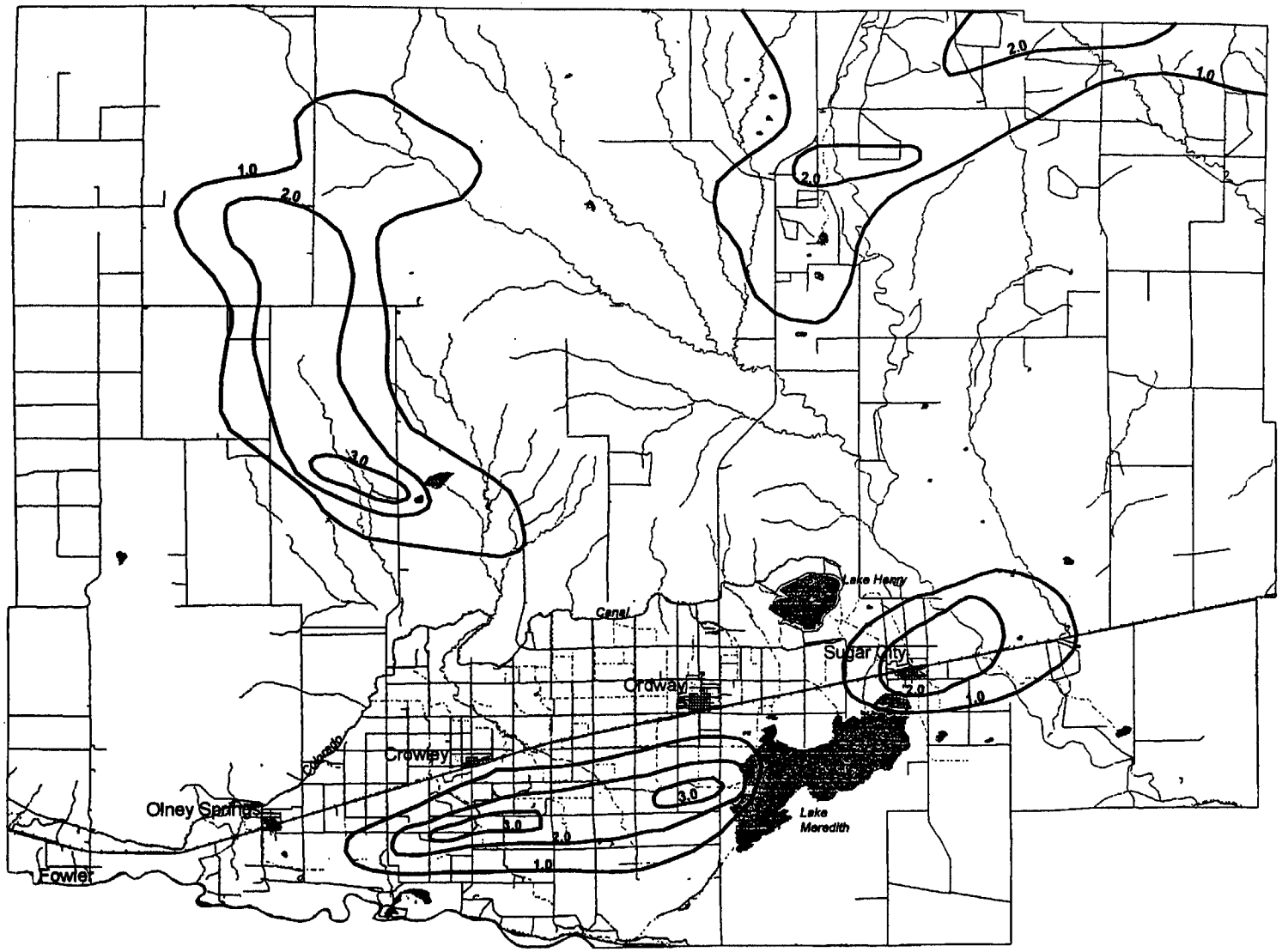
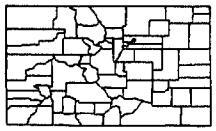


Figure 4.3-3

Crowley County

Precipitation Map

8:09 a.m. August 5 -
9:54 p.m. August 6, 1997



- Rivers and Streams
- Canals and Ditches
- Interstate Highways
- Primary Roads
- Secondary Roads
- Railroads
- 3.0 Isohyetal Line (Inches)
- Lakes and Reservoirs
- Municipal Boundaries

1 0 1 2 3 4 5 6 7 8 9 10

Miles

Riverside Technology, inc.

On the previous evening, approximately 3.0 inches of rain fell south of Ordway and Crowley during a 12-hour period, according to the *La Junta Tribune-Democrat* (Erickson 1997). NWS radar data during this time supports this observation, both in location and magnitude of rainfall.

4.3.4.2 Estimated Point Precipitation Return Periods

The estimated precipitation frequencies in Crowley County are presented in ***Table 4.3-4***. The 6-hour, 12-hour, and 24-hour storm durations for the 10-year and 100-year return periods were taken from the maps and nomogram provided in NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado (1973).

Table 4.3-4
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation	100-yr Precipitation
6 hours	2.5 inches	3.7 inches
12 hours	2.8 inches	4.1 inches
24 hours	3.0 inches	4.5 inches

The magnitude of precipitation that fell over Crowley County in August of 1997 produced damaging floods; however, the flooding in this county resulted not from a single large storm but from several storm events over several days (primarily August 4 through 6). Consequently, none of the individual rainfall totals exceeded the 100-year recurrence interval estimates. ***Table 4.3-5*** shows rainfall amounts and durations compared with 10-year and 100-year estimates for all four storm events that produced over 1 inch rain.

Rainfall on August 4 and 5 produced the highest amount of rain in the shortest time [approximately 12 hours, as reported by the *La Junta Tribune-Democrat* (Erickson 1997). According to the NOAA Atlas 2 (1973), the August 12 event was approximately equal to or greater than the 2-year, 24-hour rainfall in central Crowley County (1.8 inches).

4.3.5 Hydrology and Hydraulic Findings

4.3.5.1 Locations/Reaches of Flooded Streams

A description of the locations and reaches of flooded streams within Crowley County is only presented for those locations affected by the storm events that occurred between August 4 through 6. Little information regarding the hydrologic response of the watersheds as a result of the storms occurring later in the month is available.

Table 4.3-5
Summary of Storm Precipitation, Duration, and Return Period for Crowley County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
La Junta Tribune-Democrat (Erickson 1997)	Southern Crowley County	August 4	3.0 inches	12 hours	> 10-year, 12-hour event
Magnuson (1998a)	Sugar City	August 5	2.90 inches	12 hours	> 10-year, 12-hour event
National Climatic Data Center (1998a)	North of Crowley	August 5	3.00+ inches	38 hours	Approx. 10-yr, 24-hr event
Colorado Climate Center (1998)	21 Miles North of Ordway	August 12	1.80 inches	24 hours	Approx. 2-year, 24-hour event

In general, Horse Creek and Bob Creek experienced flooding conditions along several reaches. The flooding situation was complicated by the presence of county road embankments that transect these drainages.

Flood waters in the Horse Creek watershed began north of Crowley County in Lincoln County, near Karval, and propagated south toward the Arkansas River in Bent County (see ***Figure 4.3-2***). Photographs taken on August 5 and 6 indicate flood waters continued to inundate land along the mainstem of Horse Creek near Ordway, the confluence with Black Draw, and at the Fort Lyons Storage Canal (see ***Figures 4.3-4, 4.3-5,*** and ***4.3-6***). Flooding also occurred along Breckenridge Creek, at a minimum, between Highway 71 and its confluence with Horse Creek, located approximately 2 miles northeast of Lake Henry (see ***Figure 4.3-7***).

Although no specific photographs or anecdotes provide information concerning the flooded reaches of Bob Creek, FEMA damage reports indicate that substantial road damage occurred throughout this watershed (see Section 4.3.6).

4.3.5.2 Channel Characteristics

The natural channels in Crowley County drain agricultural lands and undeveloped rangeland. These channels are typically irregular in nature, have sandy bottoms and relatively mild slopes, and are only well-defined for low-flow conditions (Kipple 1998). For floods greater than the annual event, the water leaves these small channels and spreads out over the floodplain usually several hundred feet wide.

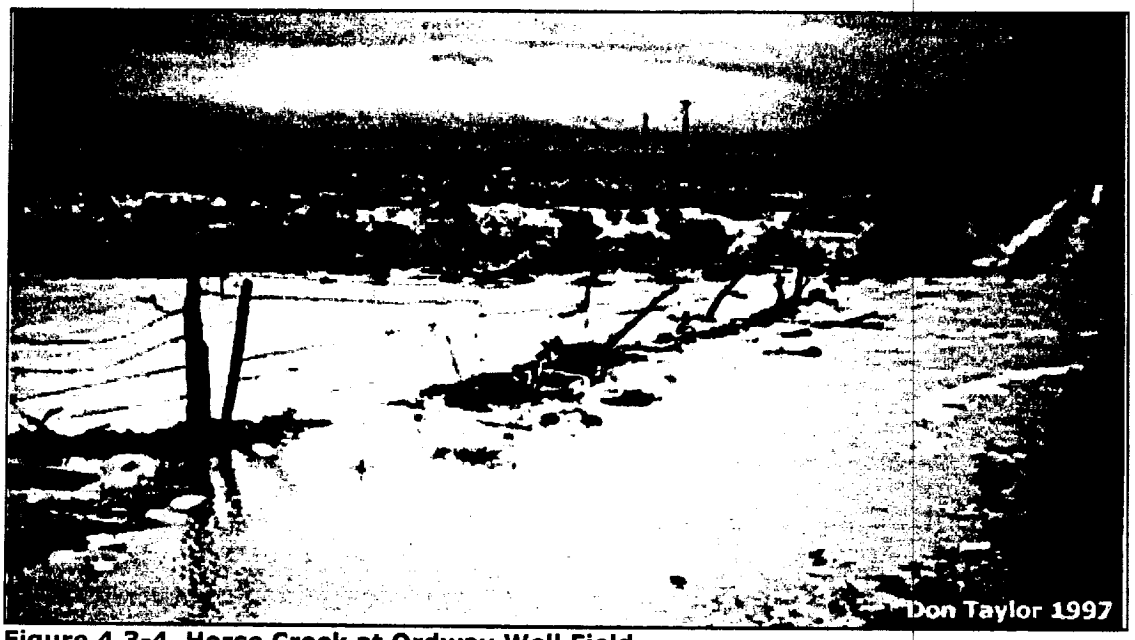


Figure 4.3-4 Horse Creek at Ordway Well Field

Figure 4.3-5 Horse Creek Confluence With Black Draw

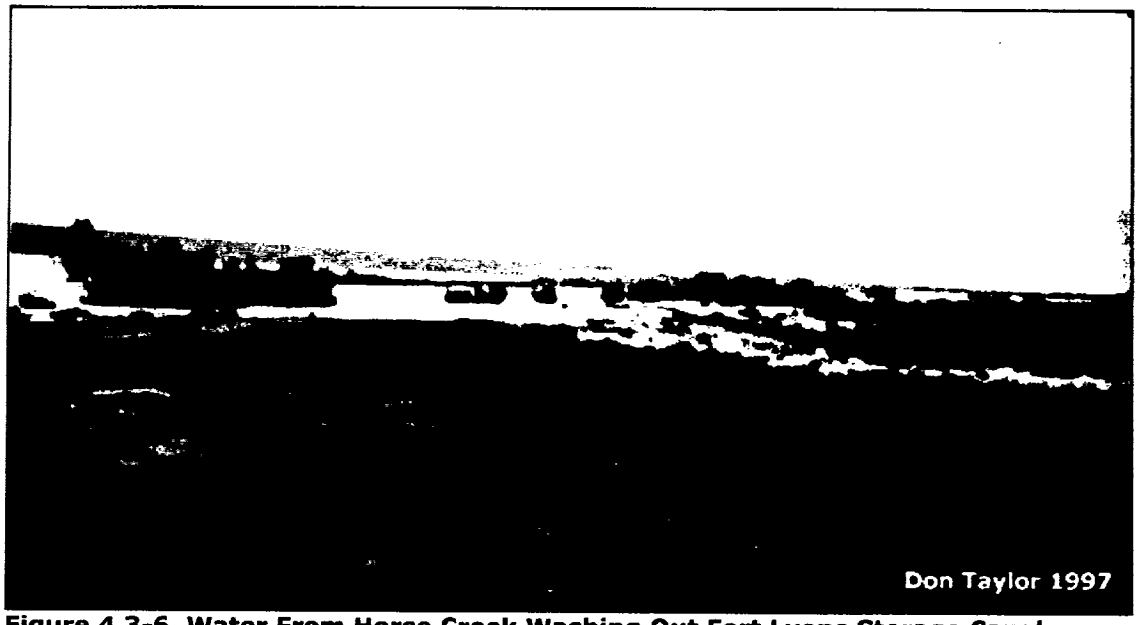


Figure 4.3-6 Water From Horse Creek Washing Out Fort Lyons Storage Canal

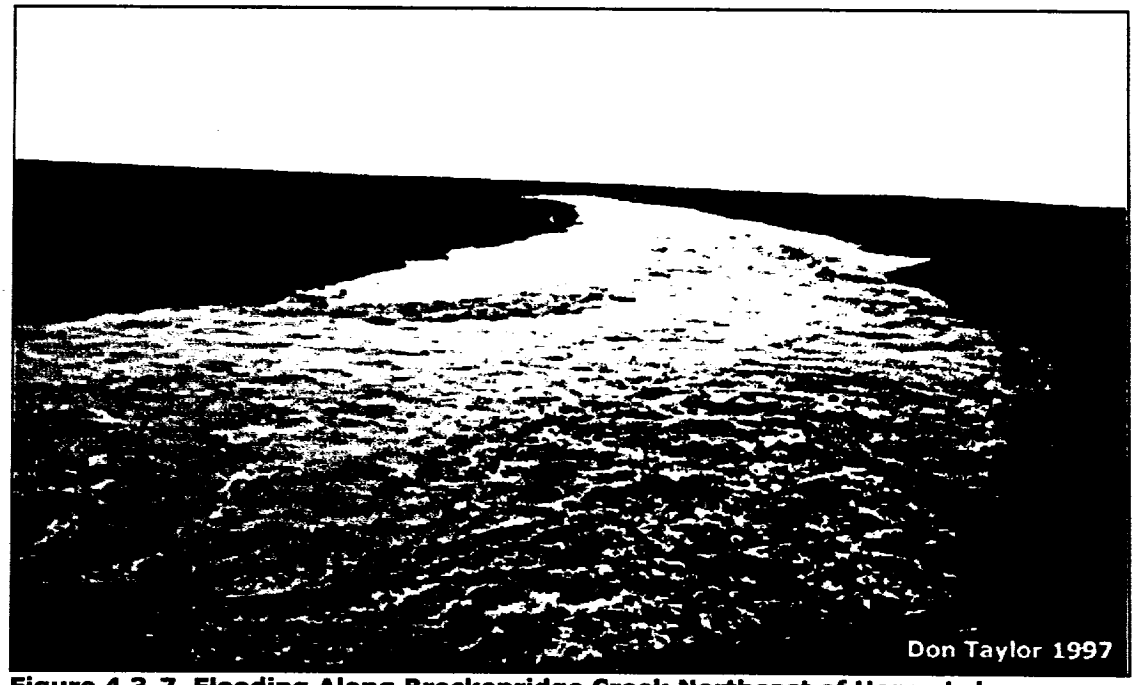


Figure 4.3-7 Flooding Along Breckenridge Creek Northeast of Henry Lake

The Horse Creek channel near Sugar City is approximately 2 feet wide and 8 to 10 inches deep on average. At this location, a number of salt cedar and willows are present, along with omnipresent sagebrush. Normal flows in this reach are typically less than 1 cfs.

4.3.5.3 Peak Flows and Estimated Return Periods

Streamflow records are available for the Horse Creek watershed from the Colorado Department of Natural Resources gage for Horse Creek at Highway 194 (ID # HRC194CO), located near the Town of Las Animas in Bent County.

During the August 1997 storm events, the Horse Creek gage recorded an estimated instantaneous peak discharge of 2,236 cfs on August 7 at 2:30 p.m. Although the CWCB has developed a procedure to compute the 100-year streamflow frequency for the eastern plains within the Arkansas River basin, the maximum drainage basin size that is valid for this procedure is 1,125 square miles (CWCB 1997b). The drainage area for Horse Creek is 1,403 square miles; therefore, the CWCB procedure may not be appropriate.

To compute the peak discharge, the USGS PEAKFQ program was used to compute the Log Pearson III estimate (USGS 1998b). Annual peak flows from 1980 through 1993 were obtained from the USGS, which formerly maintained the Horse Creek gage site as USGS ID # 07123675, and the Colorado Department of Natural Resources. Using this procedure, the 100-year and 500-year estimates at the Horse Creek gage are shown in ***Table 4.3-6.*** Based on a relatively short period of gage records for this statistical analysis, the peak flow in 1997 was between the 100- and 500-year events. Although the total drainage peak flow has an estimated return period of between 100 and 500 years, it is important to note that the tributary area to this gage includes portions of El Paso, Lincoln, and Crowley counties. For this reason, the measured discharge is a function of precipitation in those counties as well.

Table 4.3-6
Computed Peak Discharge for the Storm Events of August 1997

Location	Drainage Area (square miles)	Estimated Peak Flow (cfs)	Estimated 100-Year Peak Flow[1] (cfs)	Estimated 500-Year Peak Flow[1] (cfs)
Horse Creek Gage at Highway 194	1,403	2,236	1,643	2,745

[1]Source: USGS 1998b

4.3.5.4 Flood Hydrograph

The Colorado Department of Natural Resources office in Pueblo provided daily streamflow data during the first week of August 1997 for the Horse Creek gage. On the basis of information provided by the Colorado Department of Water Resources' Water Commissioner in this region, the irrigation ditches were not diverting water from Horse Creek during the flooding period in early August (Taylor 1998). The lack of a second gage upstream of the Horse Creek gage makes computing the natural runoff from the August storm events difficult.

Since streamflow information on Horse Creek is limited to this gage, its data provides the closest estimate of the natural runoff in the Horse Creek watershed that was produced from the August storms. *Figure 4.3-8* depicts Horse Creek's response in average daily flows to the early August storms.

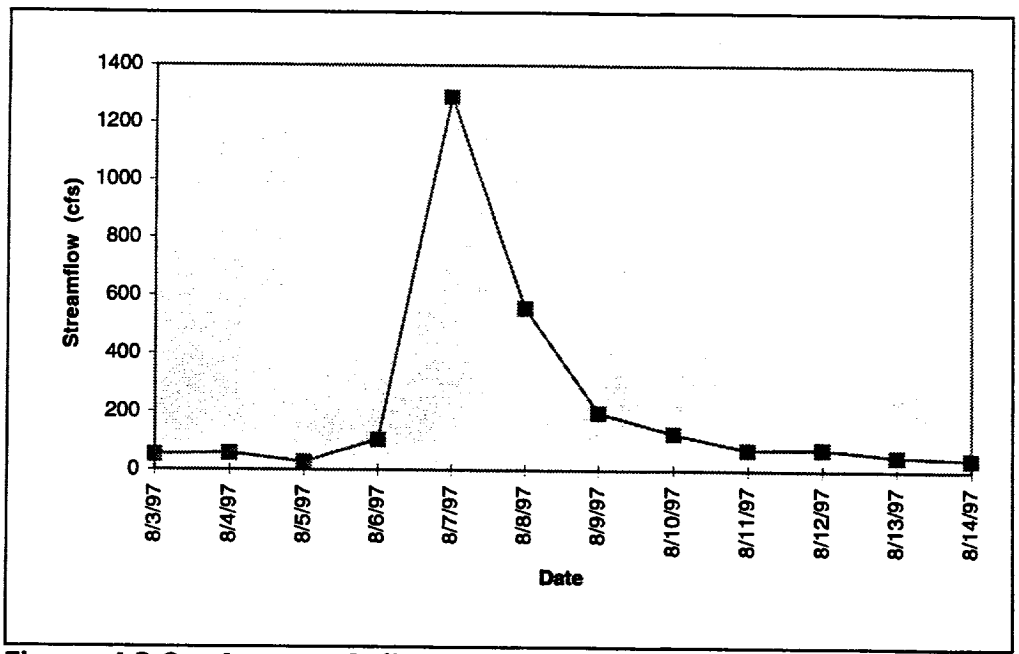


Figure 4.3-8 Average Daily Flows for Horse Creek at Highway 194 (Instantaneous peak was 2,236 cfs)

While this streamflow response to rainfall events between August 4 through 6 is a direct result of the storm events that occurred during this period, not all of the rain fell in Crowley County. However, no other streamflow records are available in the other counties within the Horse Creek watershed that could separate their contribution to the gage readings at Highway 194.

4.3.6 Specific Flooded or Inundated Areas

Specific flooded or inundated areas are documented only for the flooding resulting from the early August storm events. While individual flood areas

have been located, little information regarding specific flood inundation boundaries is available.

The FEMA damage survey reports summarize the locations of the road and bridge damage that occurred on county roads during this period of flooding. An overview of these damaged areas is presented in ***Figure 4.3-9.***

One of the most damaged areas occurred as a result of flood waters near County Road 21. ***Figure 4.3-10*** shows the aftermath of the Horse Creek flows that washed out this road crossing. ***Figure 4.3-11*** shows water in Horse Creek near the Crowley-Otero County line washing over a section of County Road 28. Additional damage was reported within the Bob Creek watershed, low-lying areas south of Highway 96, along the Crowley-Pueblo county line, and north of Olney Springs.

Flooding also was reported along State Highway 96 between the towns of Olney Springs and Crowley (Mumm 1998). No additional information was available concerning potential flooding on other sections of state highways or the flooding extent in natural watersheds.

4.3.7 Emergency Response Effort

Since most flooding occurred in areas with limited population, the potential damage to inhabited structures was minimal. Consequently, little information was available to describe the emergency response to the localized flooding. Crowley County officials indicate that the county road and bridge crew erected detour signs and closed roads soon after the floods occurred (Mumm 1998).

Along State Highway 96, the employees from the Colorado Department of Transportation were present to help with traffic control and warn drivers about the possibility of hydroplaning. In addition, the Town of Olney Springs experience localized flooding.

4.3.8 1997 Flood Damage

The available documentation indicates that damages from the 1997 floods in Crowley County were mainly confined to county roads and bridges. The primary sources of damage costs associated with the August storms are the FEMA damage survey reports. A summary of these damage estimates for Crowley County is provided in ***Table 4.3-7.***

Although no dollar figures were determined for the damage sustained by agricultural crops, the USDA-Farm Services Agency in Otero County (Hammer 1998), which oversees activities in Crowley County as well, did estimated unofficial damages, which are summarized in ***Table 4.3-8.***

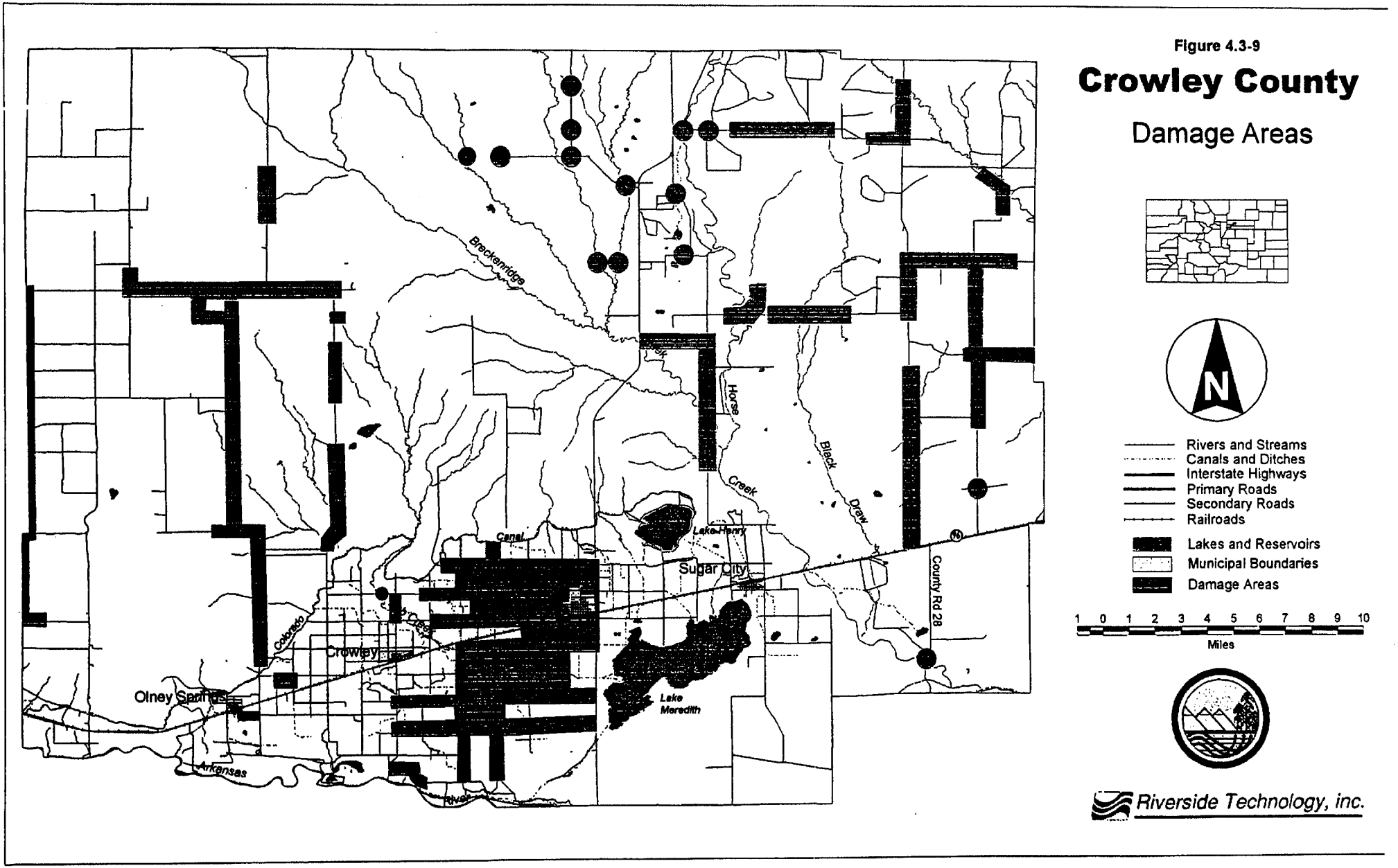


Figure 4.3-9
Crowley County
Damage Areas
Breckenridge
Horse
Black
Creek
Draw
Canal
Lake Henry
Sugar City
County Rd 28
Colorado
Crowley
Olney Springs
Arkansas
River
Lake
Meredith
N
Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries
Damage Areas
1 0 1 2 3 4 5 6 7 8 9 10
Miles
Riverside Technology, inc.

Figure 4.3-10 Breckenridge Creek Near County Road 21

Figure 4.3-11 Horse Creek Washing Over County Road 28

Table 4.3-7
Damage Estimates From the August 1997 Storm Events

Description	Damage Estimate	Source
Town of Olney Springs	$3,771[1]	Crowley County Commissioners (Mumm 1998)
Agriculture	No dollar cost estimated	USDA-Farm Services Agency (Hammer 1998)
FEMA-countywide	$577,705[2]	FEMA Damage Survey Reports (1998)

[1]Value is unofficial; it is a best estimate at the time of the study.
[2]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

Table 4.3-8
Unofficial Crop Damage in Crowley County Associated with July 28 - August 12, 1997, Storm Events

Crop	Affected Acres	Percent Loss
Alfalfa	4,800	20
Cantaloupe	35	75
Watermelon	300	80

In addition to depositing silt in the fields, the flood waters caused crops to rot or diminished their quality such that they were not marketable (Hammer 1998).

4.3.9 Flood Hazard Mitigation

The County Commissioner's Office indicated that no formal flood mitigation efforts were implemented or are planned as a result of the 1997 storm events (Mumm 1998). The County Road and Bridge Department repairs any damage to its roads when damaging floods occur. As a result of the 1997 floods, roads were re-built and some drainage systems were enlarged to allow more water to pass through.

4.3.10 Special Circumstances

In general, all the tributaries in Crowley County can experience flooding conditions along reaches where highway and railroad embankments transect the natural drainage paths. The criteria used to design these crossings were not investigated for this document. The flooding problems that occurred in the southern portions of the county were partly caused by culverts plugged from lack of maintenance and use (Mumm 1998).

No other information was available to indicate that unique circumstances existed in Crowley County to cause flooding as a result of the 1997 storm events.

4.4 Elbert County

4.4.1 Study Area

Severe thunderstorms occurred in Elbert County from early June through early August of 1997, producing localized floods and damage to agricultural lands. Elbert County is in east-central Colorado on the eastern slopes of the Front Range. Located approximately 40 miles southeast of Denver, the Town of Kiowa is the county seat (see ***Figure 1.1-1***).

The major structural damages occurred to roads, culverts, and bridges in unincorporated areas of central and southeastern Elbert County as a result of successive, intense precipitation events on July 28 and July 29, 1997. Severe storms also occurred on these dates and on July 31 in the Kiowa and Elizabeth vicinities. Relatively minor flooding occurred in the towns of Elizabeth, Kiowa, and Simla. The major storms were centered over the headwaters of the Bijou Creek and Big Sandy watersheds in the south-central part of the county and along the Middle and South forks of Rush Creek in the extreme southeastern part of the county. Additional storm events occurred in the Rush Creek and Simla area in mid-June and again during the first week of August north of Elizabeth. The towns of Elizabeth, Kiowa, and Simla have populations of 820, 280, and 480 people, respectively. Although a number of rural subdivisions are becoming established near Elizabeth, the major land uses in the county remain agricultural. Ranching activities occur extensively throughout Elbert County, and wheat is grown in the eastern portions. ***Figure 4.4-1*** is a general vicinity map of the county.

The topography in the county ranges from steep forested foothills on the west to gently rolling high plains on the east. Elevations in the county range from approximately 7,000 feet along the western edge of the county to approximately 5,300 feet along on the eastern boundary. The mean annual precipitation is approximately 12 inches but varies with elevation, being somewhat higher to the west and lower to the east.

4.4.2 Watershed Description

The major drainages of interest in Elbert County include Kiowa Creek in the west, West Bijou and East Bijou Creek draining northward through the central part of the county, the Big Sandy watershed draining eastward through the southern and eastern parts of the county, and the Horse Creek and Rush Creek watersheds in the southeast. Kiowa Creek and the Bijou Creek tributaries flow generally northward, joining the South Platte near Fort Morgan, Colorado, approximately 55 miles north of the Elbert County line. Horse Creek flows generally southeast within the county, and then turns southward to join the Arkansas River near Las Animas, Colorado. Rush Creek joins Big Sandy Creek approximately 100 miles to the southeast, just north of where Big Sandy Creek itself joins the Arkansas River near Lamar,

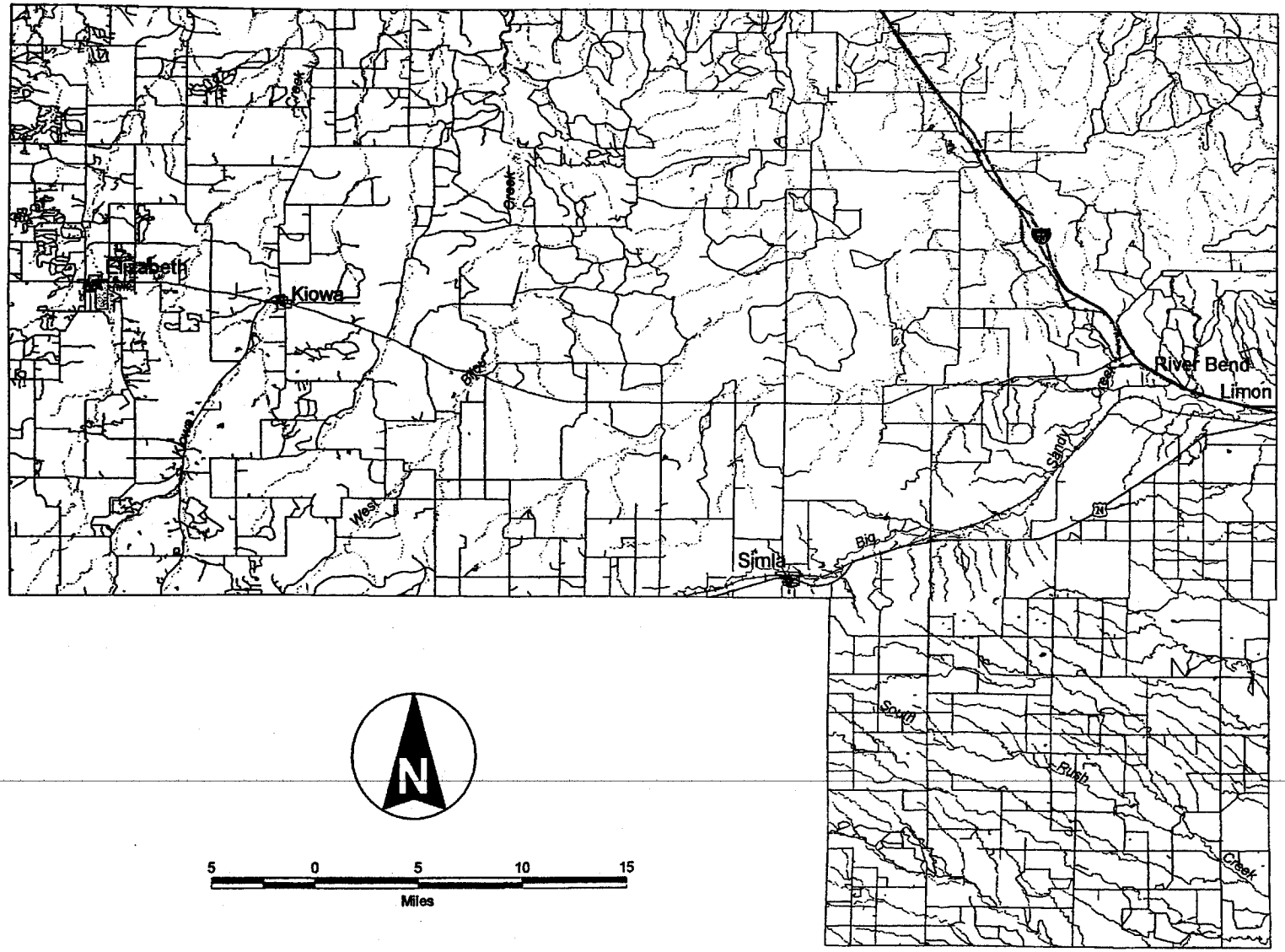


Figure 4.4-1

Elbert County

Vicinity Map

Riverside Technology, inc.

Colorado (*Figure 4.4-1*). In the headwaters, all of these streams have well-defined channels within confining valleys or draws. The valleys widen as they open onto the plains downstream.

A USGS streamgage is located on Big Sandy Creek just upstream of the Arkansas River, approximately 110 miles from the Elbert County line. No gages occur on the streams within Elbert County. Although all of these drainages extend further into surrounding counties, their headwaters occur in southern Elbert County or just over the line in El Paso County to the south. Intensive thunderstorm activity in the Kiowa, Bijou, Big Sandy, and Rush Creek headwaters during the last few days of July 1997 contributed to high streamflows both in Elbert County and in other areas immediately downstream of the county.

4.4.3 Local Flooding Problems

The major streams in Elbert County that historically have experienced flooding problems include South Rush Creek, Middle Rush Creek, and Big Sandy Creek. Damages from flooding usually affect county roads, related road drainage structures, and agricultural lands. Flows in East Bijou Creek in the vicinity of Agate, Colorado, in northeastern Elbert County also have caused similar flood damage on occasion.

Floods on upper Big Sandy Creek are attenuated by the dam at Ramah Reservoir State Recreation Area, approximately 7 miles west-southwest of Simla. The reservoir controls the flow from 50 square miles of Big Sandy watershed by means of a zoned earthfill dam and a concrete drop inlet principal spillway. The dam is owned by the Double El Soil Conservation District in Simla. The reservoir has a storage capacity of 1,400 acre-feet at the crest of the principal spillway. Additional smaller flood control dams also exist on Big Sandy tributaries in the Simla area. All of these structures are maintained by the Natural Resources Conservation Service and help to attenuate flood peaks along Big Sandy Creek.

4.4.4 Storm Characteristics

Thunderstorms are common occurrences in east-central Colorado during the summer months. In 1997, particularly severe thunderstorms occurred in the Elbert County area in mid-June, the last week of July, and the first week of August. During these periods, portions of Elbert County experienced significant amounts of precipitation, as shown in ***Table 4.4-1***. ***Table 4.4-2*** summarizes available meteorological data for the major storm events in Elbert County.

Table 4.4-1
Dates of Significant Precipitation in Elbert County During 1997

Date	Maximum Precipitation	Comments
June 13-14	4 inches over 2 nights; up to 8 inches of hail	General storm over southeastern Elbert County; hail along Rush Creek on June 13
July 27	3.5 inches	Near River Bend
July 28	9.7; and 2-3.5 inches	West of Simla; in Rush Creek area
July 29	7.5; and 4.5-6 inches	West of Simla; in Rush Creek area
July 31	1-2 inches	Kiowa-Elizabeth area
August 5	3.5 inches	North of Elizabeth

Table 4.4-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
Limon, CO	6/13	50-	69	24.36	54	51	9.8	11
Limon, CO	6/14	56	78	24.38	59	55	15.4	15
Limon, CO	7/27	60	90	24.54	54	57	8.6	340
Limon, CO	7/28	58	77	24.66	78	61	9.3	100
Limon, CO	7/29	59	79	24.64	76	61	14.4	150
Limon, CO	7/30	60	83	24.62	68	61	13.9	160

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C)

(Linsley et al. 1992)
Source: National Climatic Data Center 1998a

4.4.4.1 Storm Duration and Rainfall Quantities

Available information for the storm of June 13 through 14 is shown in ***Table 4.4-3***.

Table 4.4-3
Point Rainfall Amounts Recorded in Elbert County for June 13-14, 1997

Source	Location	Amount	Recording Period
Atwater (1998)	Southeast of Simla	~2 inches	unknown
Ashcraft (1997)	Southeast of Simla	~3.5 inches of rain and 8 inches of hail	unknown

Intense localized storms formed over Elbert County on July 25, 27, 28, and 29, 1997. The events on the 25th through the 28th carried significant rainfall amounts by themselves, but more importantly, they sequentially developed high moisture conditions over several watershed areas prior to events on July 29. Areas notably affected were along Big Sandy Creek, Middle and South Rush Creek, and west of Simla at the headwaters of East and West Bijou Creek. CWCB rainfall bucket surveys in the area indicate that approximately 3.5 inches fell in the River Bend area of extreme eastern Elbert County on July 27. Rainfall reports in Limon varied from 1.5 to 3 inches for July 27, as reported by the *Eastern Colorado Plainsman* (1997). This particular storm was short, lasting an hour or so, but produced high flows in Big Sandy Creek and its tributaries in the River Bend area, as well as immediately downstream in Lincoln County.

Individual rain gages in these areas and supplemental NWS radar data indicate that a maximum rainfall amount of approximately 9.7 inches of rain fell in the Bijou Creek headwaters on the night of July 28 - 29. Radar images confirm the location of this storm (see Technical Addendum for radar images). The most intense precipitation was limited in extent, but was accompanied by more widespread precipitation totaling 2 to 5 inches from approximately 18 miles west of Simla over a locale extending 6 to 8 miles to the north and northeast. Also on the night of July 28 - 29, radar imagery indicates that approximately 2 inches of rain fell in the Middle and South Rush Creek watersheds in the southeastern part of the county. No significant flood damages were reported for the storms of July 27 through 28 in Elbert County.

Late in the evening of July 29, extremely heavy rains again fell in the Bijou Creek/Big Sandy Creek headwaters west of Simla and in northern El Paso County. Approximately 7.5 inches of rain were reported at an individual rain gage surveyed by CWCB approximately 16 miles west of Simla. At the same time, intense rainfall occurred again on the Middle and South Rush Creek drainages. The maximum reported rainfall total in the latter area was 6 inches, with 3.5 to 4.5 inches commonly reported from individual rain gages in the area. Using NWS radar data, the rainfall bucket survey conducted by CWCB, and reports from other observers, an isohyetal map was generated for the Bijou/Big Sandy storm and for the Rush Creek storm for the night of July 29, 1997. This isohyetal map is shown in ***Figure 4.4-2***. Extensive flood damages occurred from these storms, particularly to roads and agricultural lands in the south-central and southeastern parts of the county.

Approximately 4.8 inches of rain fell along the eastern boundary of Elbert County in the vicinity of Limon on the night of July 29 and on the morning of the 30th. This storm occurred over the Big Sandy watershed and created substantial damage to fields, roads, and fences in the area (Hass 1997).

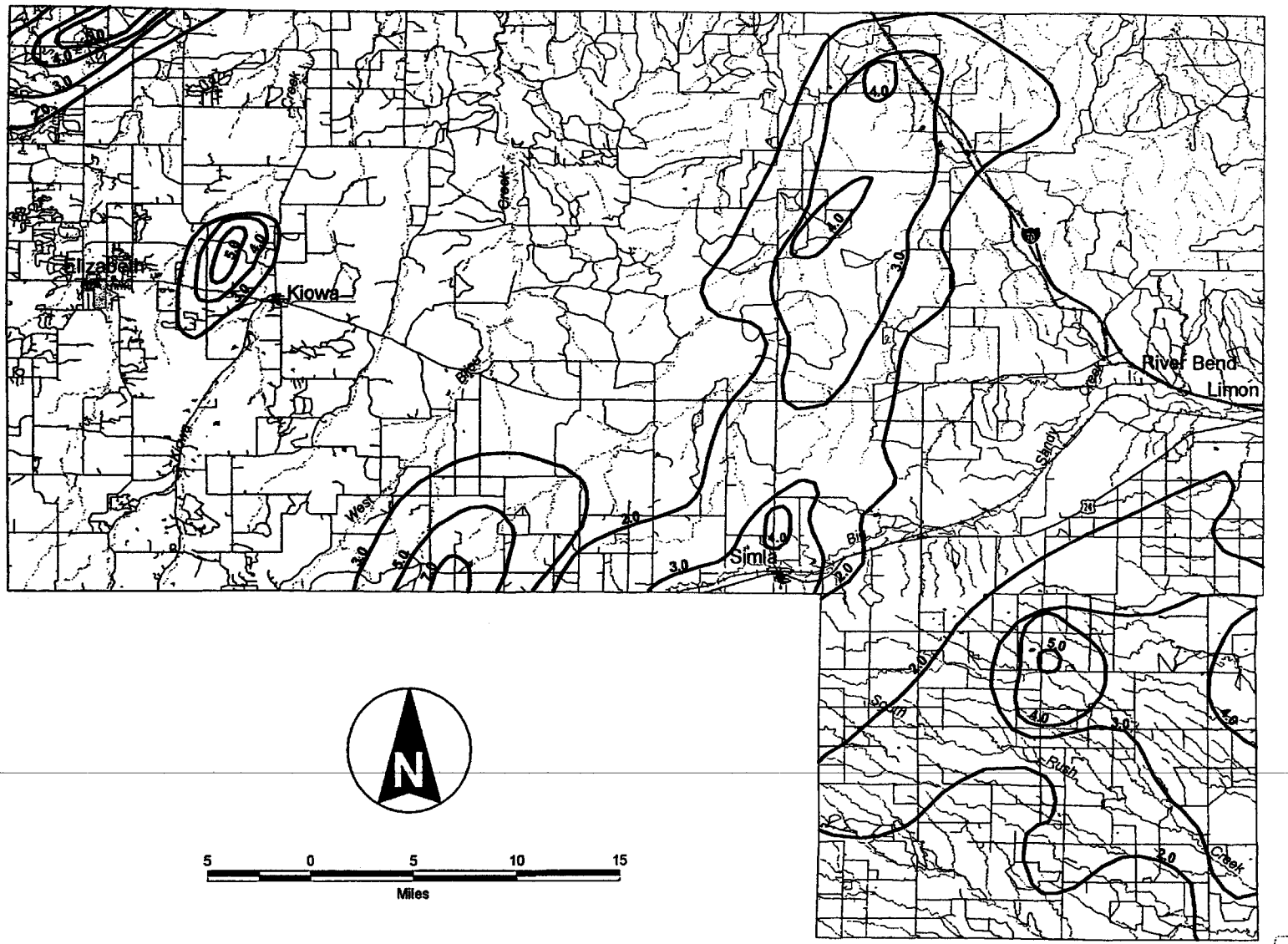


Figure 4.4-2

Elbert County

Precipitation Map

7:18 a.m. July 29-
6:21 a.m. July 30, 1997

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Available information for the storms of July 28 through 30 is shown in ***Table 4.4-4***.

Table 4.4-4
Point Rainfall Amounts Recorded in
Elbert County for July 28-30, 1997

Source	Location	Amount	Recording Period
Alexander (1997)	18 miles west of Simla	9.73 inches	7/28/97 times unknown
Alexander (1997)	18 miles west of Simla	7.7 inches	7/29/97 times unknown
Ashcraft (1997)	22 miles southeast of Simla	6+ inches	7/29/97 7:30 p.m. to 11:00 p.m.
Atwater (1998)	25 miles southeast of Simla	4.5 inches	7/29/97 7:30 p.m. to 11:00 p.m.
Dennis Stone (1997)	30 miles southeast of Simla	4.0 inches	7/29/97 7:30 p.m. to 11:00 p.m.
NOAA/ NWS (1997c)	Immediately south of Limon	4.79 inches	7/29/97 @ 8:00 p.m. to 7/30 at 5:30 a.m.

4.4.4.2 Estimated Point Precipitation Return Periods

As summarized from NOAA information, the point precipitation totals for storm durations of 6 hours, 12 hours, and 24 hours for 10-year and 100-year return periods are shown in ***Table 4.4-5*** below for the Bijou Creek area west of Simla and for the Middle and South Rush Creek area (NOAA 1973).

Table 4.4-5
10-year and 100-year Point Precipitation Values
for Various Storm Durations

Storm Duration	10-yr. Precipitation		100-yr. Precipitation	
	Upper Bijou Creek	Upper Rush Creek	Upper Bijou Creek	Upper Rush Creek
6 hours	2.3 inches	2.4 inches	3.5 inches	3.6 inches
12 hours	2.6 inches	2.7 inches	4.0 inches	4.0 inches
24 hours	3.0 inches	3.0 inches	4.4 inches	4.6 inches

A summary of the precipitation for the major Elbert County storm events of July 29, 1997, are shown in ***Table 4.4-6***.

Table 4.4-6
Summary of Storm Precipitation, Duration, and Return Period for Elbert County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
Alexander (1997)	18 miles west of Simla	July 29	7.7 inches	unknown	>100-year
Ashcraft (1997)	22 miles southeast of Simla	July 29	6 inches	3.5 hours (approx.)	>100-year
Atwater (1998)	25 miles southeast of Simla	July 29	4.5 inches	3.5 hours (approx.)	>100-year
Dennis Stone (1998)	30 miles southeast of Simla	July 29	4.0 inches	3.5 hours (approx.)	>100-year
NOAA/NWS (1997c)	Limon vicinity	July 29	4.8 inches	10 hours	>100-year

4.4.5 Hydrology and Hydraulic Findings

4.4.5.1 Locations/Reaches of Flooded Streams

Flooded areas occurred in the Bijou Creek headwaters (East and West Bijou creeks), along Middle and South Rush creeks, Kiowa Creek, and along Big Sandy Creek. The major flooding occurred on July 28, 29, and 30, 1997. Particularly high flows occurred in West Bijou Creek south of Colorado Highway 86 and in South Rush Creek between Simla and Punkin Center in Lincoln County (***Figure 4.4-3*** shows the West Bijou and South Rush Creek watersheds). Stream levels in both of these channels rose and subsided swiftly according to local witnesses (Atwater 1998, Dennis Stone 1998) and county road officials that were responding to calls throughout the county (Craven 1998). Flows in upper Big Sandy Creek were higher than normal for several weeks after the July 29 event. Throughout the county, numerous other channels contained high flow rates relative to their normal condition in late July.

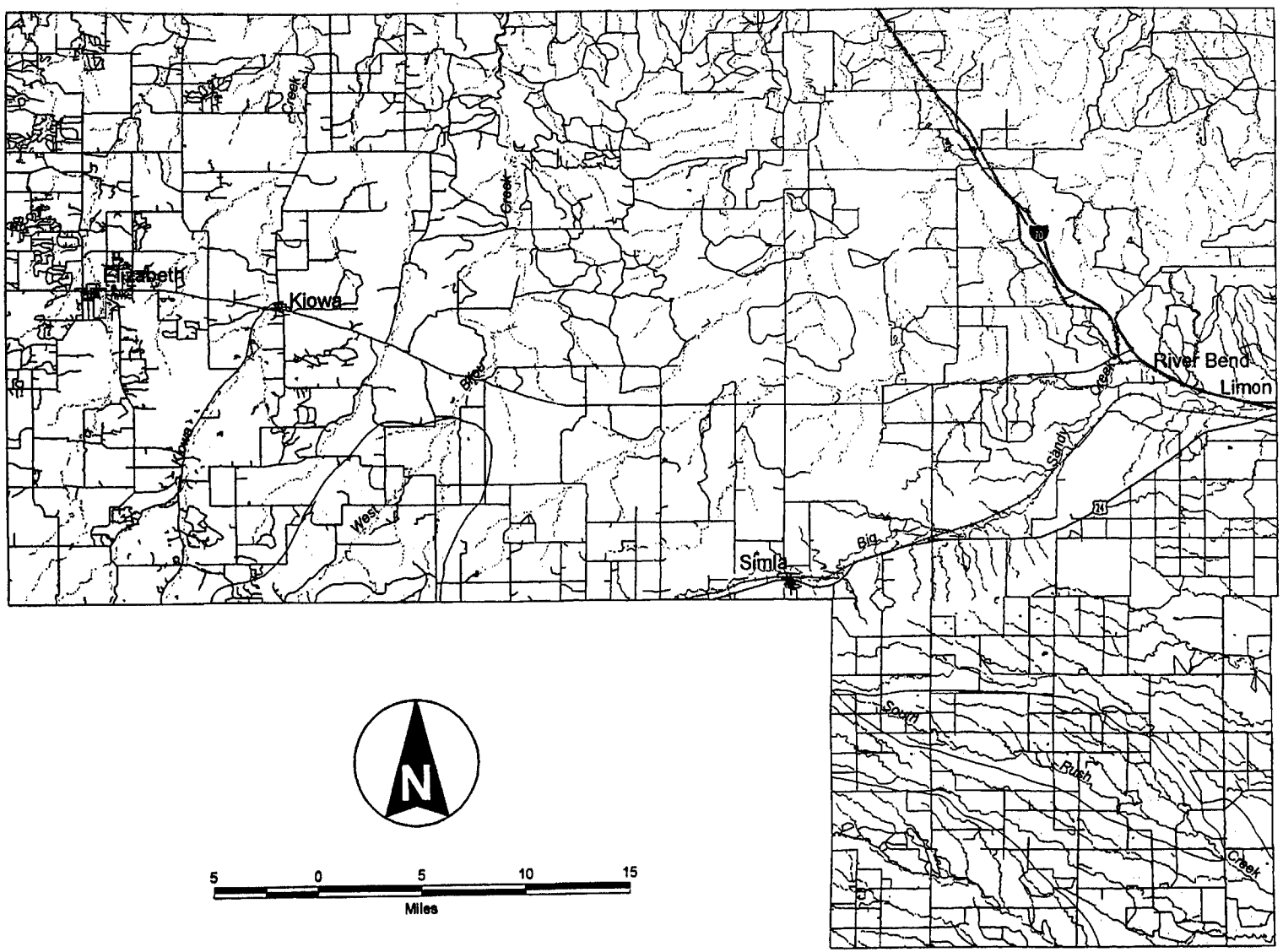
4.4.5.2 Channel Characteristics

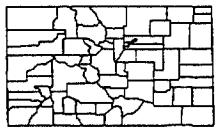
Natural channels in Elbert County drain undeveloped rangelands and croplands. An RTi flood documentation team visited specific stream reaches to investigate conditions in particular flood-damaged areas. The areas visited included upper West Bijou Creek just south of the Kiowa-Limon Road (Highway 86) and South Rush Creek in the extreme southeastern corner of

Figure 4.4-3

Elbert County

Affected Watersheds





- Rivers and Streams
- Canals and Ditches
- Interstate Highways
- Primary Roads
- Secondary Roads
- Railroads
- Lakes and Reservoirs
- Municipal Boundaries
- Watersheds

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the county. These channels generally have sandy beds and transport considerable amounts of sand during high flow events. They are meandering channels in the reaches that were examined for this study, but braided conditions (where a number of small subsidiary channels intertwine to form the overall stream) are known to occur downstream on West Bijou Creek and Big Sandy Creek.

In its upper reaches, West Bijou Creek is an incised channel that migrates within a fairly narrow flood zone, cutting through older stream terraces and depositing sand bars. Flow occurs intermittently during the year. The stream width is typically 5 to 10 feet, and the width of the overbank area is approximately 80 feet. West Bijou Creek has a channel slope of approximately 0.0035 feet per foot of length (18.5 feet per mile).

In the area studied, South Rush Creek passes through a gentler V-shaped valley. It is a perennial stream that flows in a well-defined meandering channel 15 to 25 feet wide. It is lined with mature cottonwood trees along a narrow floodplain approximately 200 feet wide. South Rush Creek has a channel slope of 0.0019 feet per foot of length (10 feet per mile).

Both creeks are shallow, having depths of 1 to 3 feet during normal flows in early summer. Native grasses and shrubs occur in the overbank areas of both streams. The drainages open into considerably wider valleys and broader floodplains as they transition from their headwaters onto the plains.

4.4.5.3 Peak Flows and Estimated Return Periods

Runoff from the July 29 storm caused South Rush Creek to overflow its banks in the extreme southeastern part of the county. Where the creek is crossed by Elbert County Road 197, the rising flood wave and the accompanying debris clogged a 6-foot diameter culvert and washed out the entire 8- to 10-feet high earthfill section of the county road crossing the creek (***Figures 4.4-4*** and ***4.4-5***). Culvert sections on the order of 20 feet long were deposited approximately 1/4 mile downstream (***Figure 4.4-6***). At its maximum height, the stage in South Rush Creek rose approximately 14 feet above its normal level (Atwater 1998). Eyewitness reports estimated the flow width at the peak to be on the order of 100 yards (this was later verified by an on-site survey). Agricultural lands along the creek were flooded and substantial erosion occurred (***Figures 4.4-7*** and ***4.4-8***) (Atwater 1998).

West Bijou Creek also rose rapidly under the runoff conditions of July 29. At the bridge on County Road 112, high water and debris impacts severely damaged the middle set of pilings and threatened the integrity of the bridge deck (***Figure 4.4-9***). Flow filled the entire width between the incised banks, and the flood stage reached a height of approximately 13 feet above the normal flow level and a width of approximately 100 yards. A significant amount of sediment was transported in the flow and deposited along the

Figure 4.4-4 County Road 197 at South Rush Creek After the Night of July 29-30, 1997

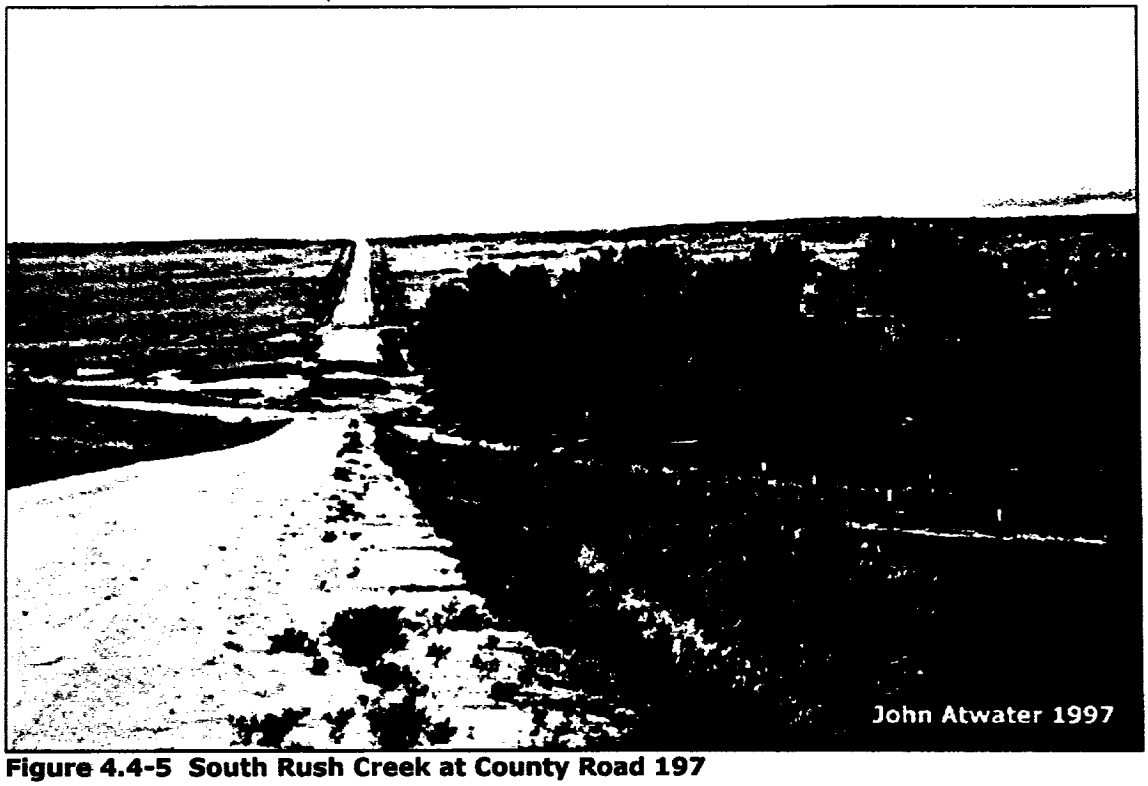


Figure 4.4-5 South Rush Creek at County Road 197

Figure 4.4-6 Culvert Sections Left by Flood Water Downstream of Rush Creek-County Road 197 Crossing

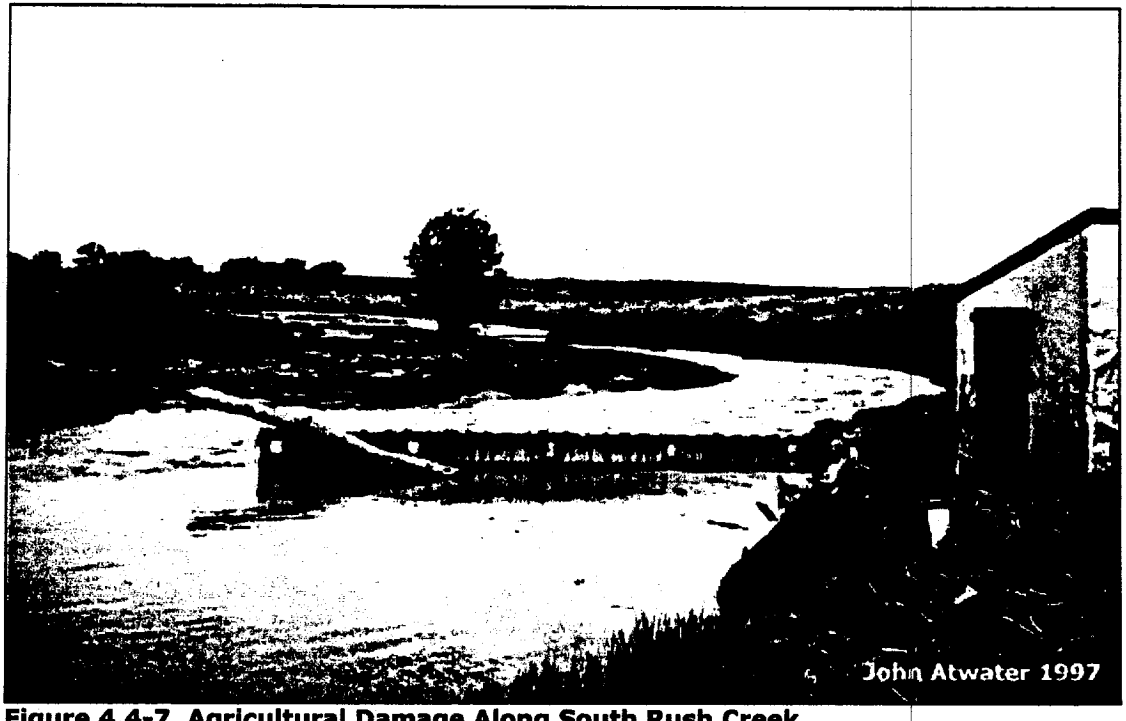


Figure 4.4-7 Agricultural Damage Along South Rush Creek

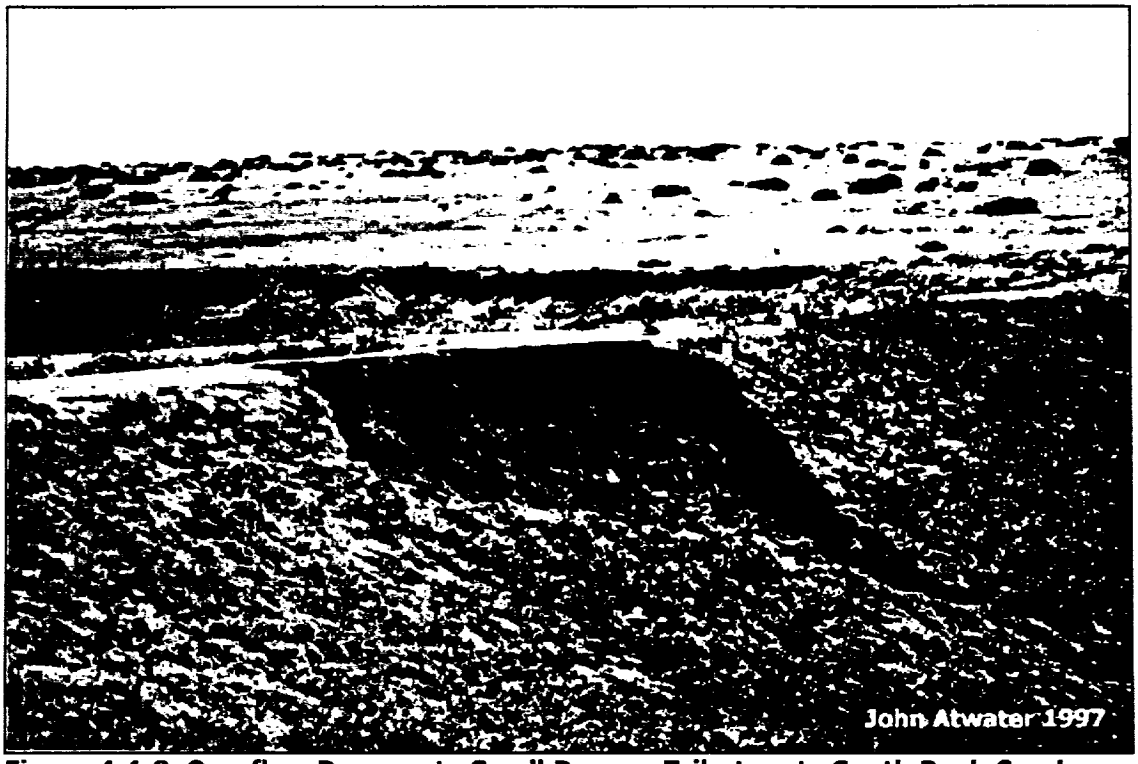


Figure 4.4-8 Overflow Damage to Small Dam on Tributary to South Rush Creek

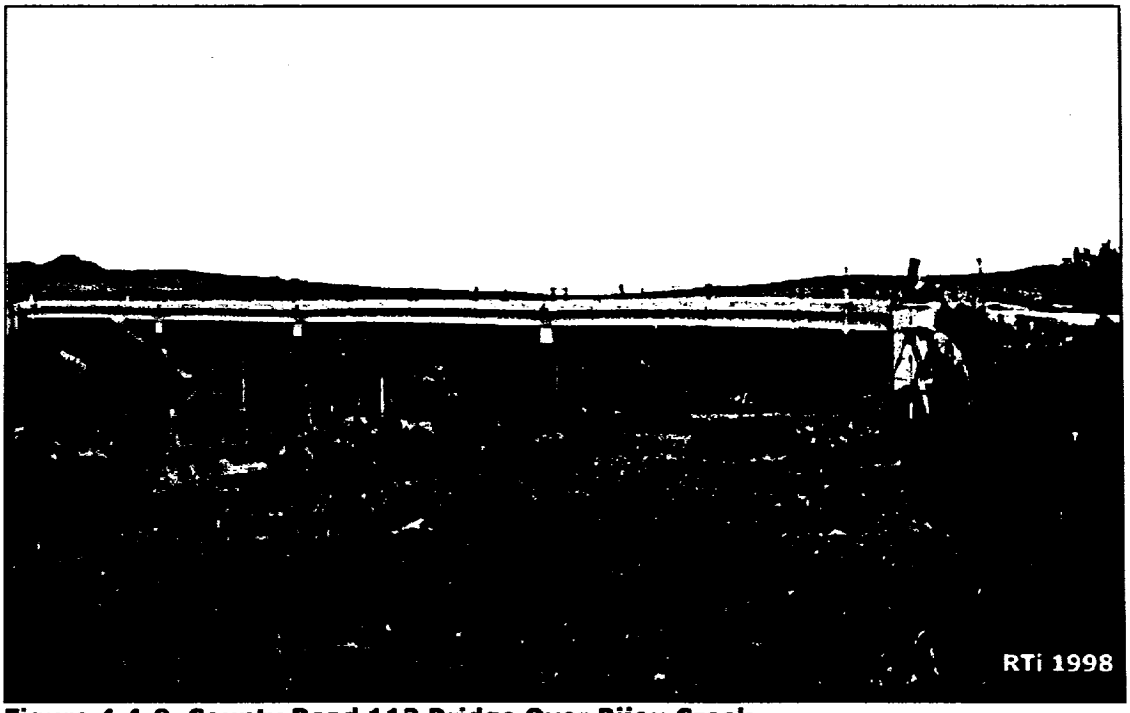


Figure 4.4-9 County Road 112 Bridge Over Bijou Creek

sides of the channel and in overbank areas. The lower portions of the bridge pilings were subsequently reinforced with concrete pier sections.

An RTi flood documentation team visited West Bijou Creek and South Rush Creek in early June of 1998 at the same time the road was being reconstructed and two new culverts were being installed on South Rush Creek. The team surveyed the channels, noted high water marks, and measured channel slopes. Flood debris lines were evident at both locations at the time of the site visits. Peak discharges were then estimated using Manning's equation under the assumption of steady to gradually-varied flow. The computed peak discharges for the sites are presented in ***Table 4.4-7***. A range of flows is presented because of the uncertainty in estimating peak discharges.

Table 4.4-7
Computed Peak Discharge for the Storm Event of July 29, 1997

Location	Drainage Area (square miles)	Estimated Peak Flow (cfs)	Estimated 100-year[1] Peak Flow (cfs)
South Rush Creek at CR197	54	14,000 to 18,000	13,900
West Bijou Creek at CR112	88	8,000 to 10,000	13,200

[1]Source: CWCB 1997b

4.4.5.4 Flood Hydrograph

Residents living along South Rush Creek were able to describe the events of July 29 in sufficient detail to allow a streamflow hydrograph to be estimated and related to the storm event (Atwater 1998, Dennis Stone 1998). The storm itself was of relatively short duration, compared to the 6- to 24-hour events for which data are published. Rains were fairly steady throughout the storm's approximately 3.5-hour duration, which began near 7:30 in the evening. South Rush Creek rose significantly (the flow width was about one-third of its peak width) within 3 hours from the onset of precipitation. The flood peaked approximately 5.5 hours after the start of precipitation, and the height of flow dropped substantially within approximately 12 hours after the start of precipitation. Higher than normal flows occurred in the channel for an additional week or so (Atwater 1998, Dennis Stone 1998). The approximate flood hydrograph is shown in ***Figure 4.4-10***.

Based on observer accounts, the approximate storm and flooding chronology in the South Rush Creek area is shown in ***Table 4.4-8***.

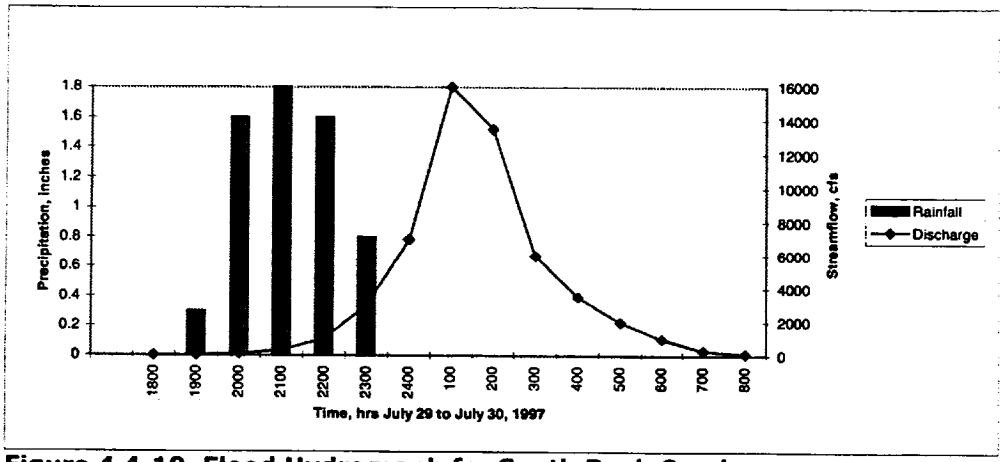


Figure 4.4-10 Flood Hydrograph for South Rush Creek

Table 4.4-8
Chronology of Flooding Along South Rush Creek

Date/Time	Description of Event
July 29, 6:30 p.m.	Severe storm observed at a distance, moving into the area (observer checked weather radar via computer)
July 29, 7:30 p.m.	Rain begins, much thunder and lightning
July 29, 7:30 to 10:30 or 11:00 p.m.	Extreme rainfall (4.5 inches at gage)
July 29, 11:15 p.m.	Rain lessens significantly; South Rush Creek is approximately 100 feet wide; severe overland flow in yard and nearby pastures are flooded; basement floods through window wells
July 30, 12:30 a.m.	South Rush Creek approximately 100 yards wide and 15 to 20 feet deep
July 30, 1:00 a.m.	South Rush Creek at steady level, then begins to drop
July 30, 1:30 a.m. to after daybreak	Emergency activities at road washouts in area
July 30, after daybreak	South Rush Creek drops significantly, running approximately 4 feet deep; continues to drop, but flows above normal rates for 5 to 6 days

Source: Atwater 1998

Because of the remoteness of the West Bijou site, no observations were available to estimate the timing of the flood hydrograph. Observers at downstream county road crossings indicated that the peak flow duration was short, and that within a day or so the stream level had dropped significantly (Craven 1998).

4.4.6 Specific Flooded or Inundated Areas

No areas of long-term flooding or inundation are documented for Elbert County. Most of the flooding that did occur was limited to the stream channels that rose up out their banks on the nights of July 28, 29, and 30. High waters in these areas typically receded rapidly. Other areas, such as nearby agricultural fields or areas where drainage was obstructed, were inundated for a longer period (particularly along South Rush Creek), but detailed descriptions of these occurrences were not available for the county in general.

4.4.7 Emergency Response Effort

Emergency activities were carried out by the Elbert County Sheriff's Office, the Kiowa Fire Department, the county road department, and numerous individuals under their own initiatives. Since most of the structural damage occurred to county roads, typical emergency responses consisted of barricading, monitoring, or otherwise marking road washouts to the extent that materials and personnel for these activities were available. This involved a considerable amount of travel at night under hazardous conditions, particularly for county road staff responding to emergency calls in remote rural areas. Road personnel in the eastern part of Elbert County were busy around the clock for several days after the July 29 storm.

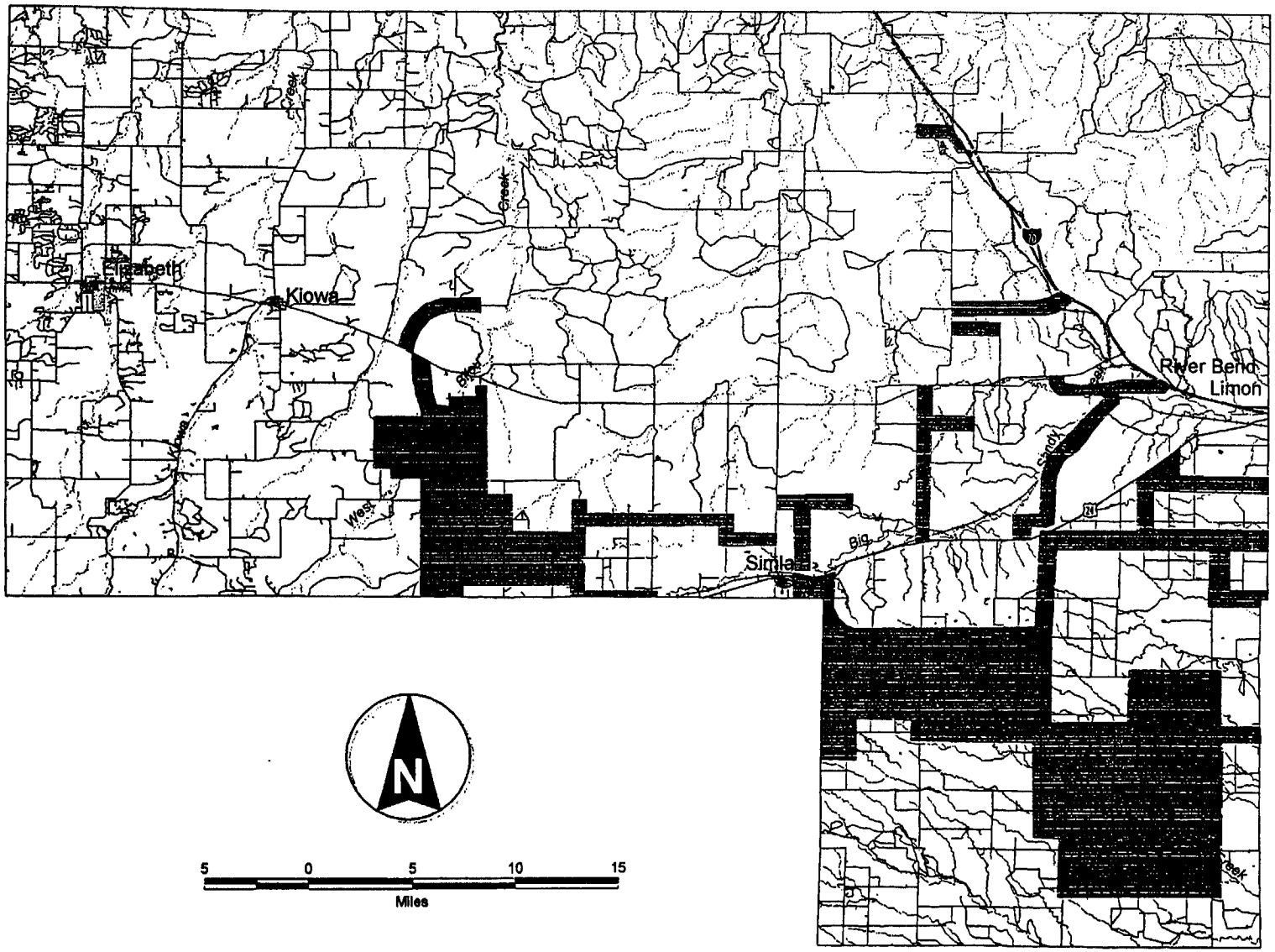
4.4.8 1997 Flood Damage

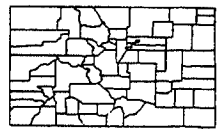
Within Elbert County itself, the major storm damages to structures occurred in the West Bijou Creek watershed and along Middle and South Rush Creek on July 29 and 30, 1997. Additional damages occurred throughout the county, such as on roads crossing Kiowa Creek north of Kiowa and Big Sandy Creek west of Limon. Flooding caused road washouts and damaged or destroyed road drainage structures (predominantly culverts). Areas of major flood damages are shown in ***Figure 4.4-11***. Damage costs were estimated by county and federal personnel; these estimates are shown in ***Table 4.4-9***.

Crops and a significant amount of agricultural land were damaged by storm events in Elbert County during the summer of 1997. In addition to the destruction of crops in the fields, there was extensive field erosion, damage to drainage controls and conservation structures (small dams and irrigation features, terraces, and diversions), and destruction of fences. Although no dollar values were determined, the USDA-Farm Service Agency did make unofficial estimates of the acreage damaged in Elbert County by summer storms in 1997.

Figure 4.4-11

Elbert County
Damage Areas





- Rivers and Streams
- Canals and Ditches
- Interstate Highways
- Primary Roads
- Secondary Roads
- Railroads
- Lakes and Reservoirs
- Municipal Boundaries
- Damage Areas

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Table 4.4-9
Damage Costs From the July 29, 1997, Storm Event

Description	Damage Estimate	Source
General County Road Surfaces	$185,471	FEMA Damage Survey Reports (1998)
Culverts, Bridges, and Roads at Major Drainages	$213,330	FEMA Damage Survey Reports (1998)
Public Buildings	$1,165	FEMA Damage Survey Reports (1998)
Private Property	No dollar cost estimated	NA
FEMA - countywide	$424,261[1]	FEMA Damage Survey Reports (1998)

[1]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

Approximately 20,500 acres of croplands were severely damaged by the storms of June 14, according to preliminary agricultural reports. On June 24 and 25, 4 to 6 inches of hail fell southwest of Kiowa and elsewhere in southwestern Elbert County, as well as in the extreme eastern part of the county near Limon. Preliminary assessments indicate that approximately 5,000 acres of croplands were severely damaged. On July 28, the storm in the Bijou Creek headwaters washed out a small dam. Preliminary reports indicate that approximately 2,300 acres of crops were affected by the storms on July 29, with approximately 10 small dams and 5 miles of terraces and diversions damaged. Approximately 600 acres of lands were damaged by erosion during that event.

Estimates for damage to agricultural crops from June through July 1997 are shown in ***Table 4.4-10***.

4.4.9 Flood Hazard Mitigation

4.4.9.1 Previous Efforts

Previous efforts for mitigating flood hazards in Elbert County have consisted of building the dam at Ramah Reservoir and numerous smaller flood control embankments throughout the county, particularly along Big Sandy Creek and its tributaries. Controlled releases occurred at Ramah Reservoir in late July 1997, but the emergency spillway was not used. The flow over the principal spillway was approximately 34 inches deep. Drainage structures (primarily culverts and bridges) along county roads were regularly maintained or replaced as necessary. The Natural Resources Conservation Service regularly maintains the dam at Ramah Reservoir and other flood control structures in the county.

Table 4.4-10
Unofficial Crop Damage Associated with June and July 1997 Storm Events

Crop	Affected Acres	Percent Loss
Wheat	18,000	50
Alfalfa/hay mix	2,500	50
Wheat	4,100	40
Oats	40	80
Forage hay	860	50
Alfalfa/hay mix	100	80
Millet	1,000	20
Alfalfa/hay mix	1,300	minimal

Source: Meyer 1997

4.4.9.2 Future Needs

No specific future flood mitigation projects have been identified in Elbert County as a result of the late July 1997 storms. Maintenance schedules for road structures and flood control dams in the county are ongoing as they were previous to the 1997 events. The capacities of road drainage structures, such as the culvert at County Road 197 on Rush Creek, are being enlarged as time and budget allow.

Flood-borne debris was a problem at West Bijou Creek, where the bridge pilings sustained impacts from logs carried in the flow. The pilings have been reinforced with a concrete pier around them to a height of approximately 5 feet. Scour at bridge piers and abutments was not investigated for this document but may be of concern for some locations in the county. Regular inspections and a program of reviewing historical designs for adequacy could be of benefit if bridge scour concerns exist.

4.4.10 Special Circumstances

In general, all of the streams in Elbert County can experience flooding where they are crossed by county or state roads. The culvert at South Rush Creek obviously was undersized for the event on July 29; but this was an exceptional event, and the culvert performance was seriously affected by debris that significantly reduced its flow capacity. A secondary relief culvert has been installed slightly off-channel at this location to mitigate the problem. The design criteria for culvert crossings were not investigated for this document. Bridges generally performed well during the high flows.

4.5 Kiowa County

4.5.1 Study Area

Thunderstorms that occurred in late July through late August of 1997 produced localized flooding throughout Kiowa County, located on the eastern plains of Colorado, adjacent to the Kansas state line (see ***Figure 1.1-1***). Both unincorporated and incorporated areas were affected by the flooding, which was concentrated in the western and central portions of the county. While damages were wide-spread, a majority of the inundated areas were located northeast of the Town of Eads and south of the Kiowa-Lincoln county line. ***Figure 4.5-1*** is a general vicinity map of the county.

Additional flooding also occurred within the Town of Eads, which has a population of 820 people. Eads is located approximately 40 miles west of the Colorado-Kansas state line and 35 miles northwest of Lamar, Colorado.

In Kiowa County, county roads and bridges sustained the most serious damage as a result of the runoff generated in the Mustang, Adobe, Rush, and Big Sandy Creek drainages. Eads, the county seat, is located between the Adobe and Rush Creek watersheds, in the Kiowa Creek drainage. The latter drainage was relatively unaffected by the 1997 summer storm events.

Land use in Kiowa County is predominantly agricultural and includes cultivating wheat and corn and grazing livestock. The topography of Kiowa County is relatively flat with low hills dividing watersheds. The mean annual precipitation for Kiowa County is approximately 13 inches.

4.5.2 Watershed Description

The watersheds of interest in Kiowa County include Adobe Creek and Big Sandy Creek. Water in Adobe Creek flows south through Kiowa County, meets Mustang Creek just north of Arlington, and eventually drains into the Arkansas River a few miles west of the Town of Las Animas, located in Bent County. Big Sandy Creek, located in the central part of the county, flows southeast, joins Rush Creek approximately 5 miles southwest of the Town of Brandon, and eventually flows into the Arkansas River approximately 10 miles downstream (east) of Lamar.

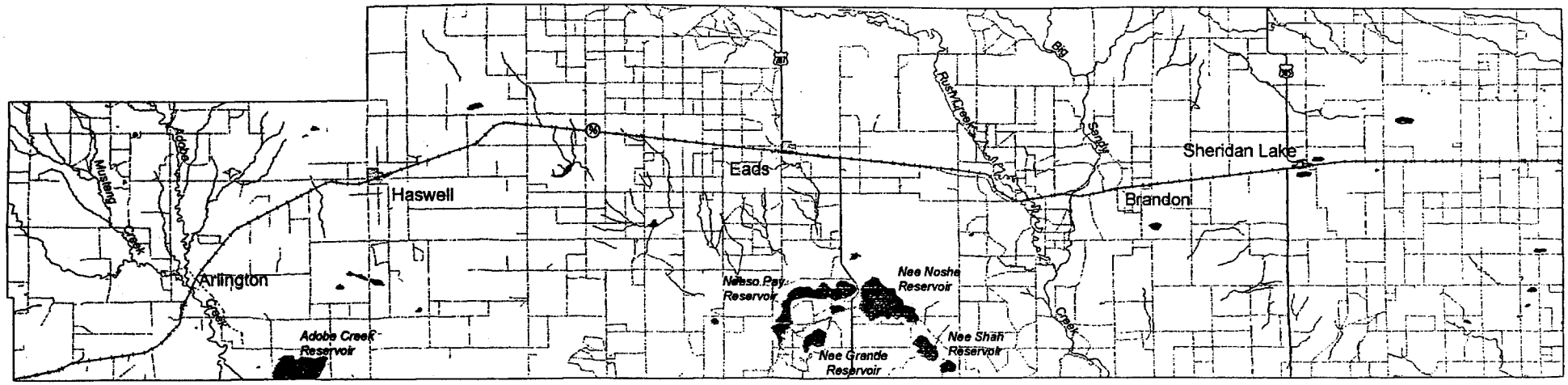
The headwaters of Adobe Creek are located within Lincoln County near the Town of Karval. The total drainage area of Adobe Creek at the southern boundary of Kiowa County is approximately 430 square miles. The elevation of Adobe Creek ranges from 4,200 to 4,800 feet.

The headwaters of Big Sandy Creek start in El Paso County approximately 5 miles northeast of Peyton. The USGS gage for Big Sandy Creek near Lamar, Colorado is located approximately 18 miles south of the Kiowa-Prowers

Figure 4.5-1

Kiowa County

Vicinity Map



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County line near Highway 196, and measures flows from a drainage area of 3,248 square miles. Within Kiowa County, the elevation of the Big Sandy Creek watershed ranges from approximately 4,000 to 4,200 feet.

4.5.3 Local Flooding Problems

Drainages in Kiowa County, including those in the central and western portions of the county, historically have experienced nuisance flooding during the summer months because of highly localized storms (Frederick 1998). The last major event in the Big Sandy Creek watershed occurred in August of 1965, when the stage level reached 9.93 feet (USGS 1998b).

Flooding problems are common along the east side of Eads, where low elevation and poor drainage are the primary culprits (Peck 1998). Rainfall in this area flows southeast toward a single culvert, which passes water underneath the Missouri Pacific railroad embankment. This sole culvert is not large enough to pass significant rainfall amounts; consequently, nearby residences are subject to backwater effects.

4.5.4 Storm Characteristics

Kiowa County experienced widespread flooding during the summer of 1997. ***Table 4.5-1*** summarizes the intense storms that produced over 1 inch of rain recorded at two or more NWS cooperative or spotter stations during a 24-hour period in July and August of 1997.

Table 4.5-1
Dates of Significant Precipitation in Kiowa County During 1997

Date	Maximum Precipitation	Comments
July 29	1.24 inches	Heavy rain from Haswell through Brandon
August 2	2.51 inches	4-hour storm duration reported at Haswell
August 4-5	3.0+ inches	Widespread storm events blanketing all areas of the county, with the heaviest precipitation north of Haswell and south of Brandon
August 5-6	6.0 inches	Peak 24-hour rainfall during the summer according to NWS spotter reports at Sheridan Lake and the Brandon areas
August 30	1.42 inches	Rains near the Haswell and Eads areas

Although the storms occurring in the final days of July most likely flooded some region of the county, no information is available for these storms. Therefore, the primary focus of this discussion is on the storms that produced rainfall over the first week of August, specifically the evenings of August 4 and 5. While the entire county witnessed some rainfall, the strongest precipitation intensity on the evening of August 4 ranged from north of Haswell through the area south of Sheridan Lake. From NWS spotter reports and radar images during the evening hours of August 5, the heaviest rainfall fell north of Brandon and Sheridan Lake.

The nearest weather station that recorded multiple types of atmospheric data is located in Lamar. Daily data was collected at this station for each of the four events identified in ***Table 4.5-1***. A summary of this data is presented in ***Table 4.5-2***.

Table 4.5-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (°F)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
Lamar, CO	7/29	64	85	26.37	74	66	13.4	130
Lamar, CO	8/2	66	92	26.36	65	66	8.5	320
Lamar, CO	8/4	66	90	26.43	64	65	6.5	90
Lamar, CO	8/5	64	73	26.38	84	64	10.9	120
Lamar, CO	8/6	57	66	26.37	90	59	9.8	70
Lamar, CO	8/30	57	89	29.90	62	59	6.6	290

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C) (Linsley et al. 1992)
Source: National Climatic Data Center 1998a

Despite being the closest, most well-equipped gage near Kiowa County, the data from the Lamar Gage that is presented in ***Table 4.5-2*** may not completely represent the local meteorological conditions in the areas described earlier. This is primarily because of the convective nature of thunderstorms on the eastern plains of Colorado, which produce significant spatial variability within a region.

4.5.4.1 Storm Duration and Rainfall Quantities

The storm precipitation estimates for the evening of August 4 are based on NWS radar data taken from the Pueblo Weather Service Office (see Technical Addendum for radar images). The radar data of precipitation totals and the NWS cooperative 24-hour station data (***Table 4.5-3***) were converted to isohyets, which are displayed in ***Figure 4.5-2***. As observed from this map,

the largest pocket of rainfall, 3.0+ inches, fell over northwestern and southern portions of Kiowa County.

Table 4.5-3
Point Rainfall Amounts Recorded in Kiowa County
for August 4 - 6, 1997

Source	Location	Amount	Recording Period
Colorado Climate Center (1998)	Eads	2.49 inches	8/4/97 @ 7 a.m. to 8/5/97 @ 7 a.m.
Colorado Climate Center (1998)	Brandon	0.72 inch	8/4/97 @ 7 a.m. to 8/5/97 @ 7 a.m.
Colorado Climate Center (1998)	Haswell	0.75 inch	8/4/97 @ 7 a.m. to 8/5/97 @ 7 a.m.
Colorado Climate Center (1998)	Brandon	2.74 inches	8/5/97 @ 7 a.m. to 8/6/97 @ 7 a.m.
Magnuson (1998a)	Brandon	2.75 - 5.0 inches	evening hours 8/5/97 - 8/6/97
Colorado Climate Center (1998)	Haswell	1.3 inches	8/5/97 @ 7 a.m. to 8/6/97 @ 7 a.m.
Magnuson (1998a)	Sheridan Lake	5.0 - 6.0 inches	evening hours 8/5/97 - 8/6/97

During the evening of August 5 and into the morning hours of August 6, approximately 3.0 to 5.0 inches fell across the county. A summary of the point precipitation collected for this storm event is presented in ***Table 4.5-3***.

Although the isohyets in ***Figure 4.5-2*** are approximate delineations of precipitation totals, they show that one of the most intense areas of precipitation was a band trending generally from the northwest corner of the county to the southeast corner.

4.5.4.2 Estimated Point Precipitation Return Periods

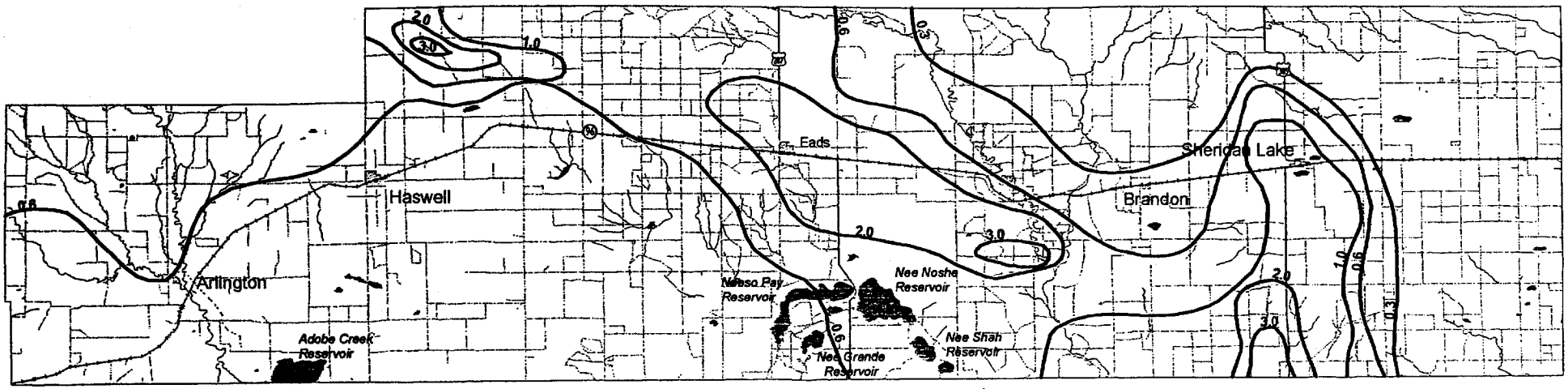
The estimated point precipitation totals for storm durations of 6 hours, 12 hours, and 24 hours are presented in ***Table 4.5-4***. The 10-year and 100-year return period events were taken from the maps and nomogram provided in NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado (1973).

Figure 4.5-2

Kiowa County

Precipitation Map

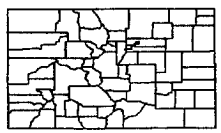
11:59 a.m. August 4 -
7:16 a.m. August 5, 1997



Rivers and Streams
Canals and Ditches
Primary Roads
Secondary Roads
Isohyetal Lines (Inches)
Railroads
Lakes and Reservoirs
Municipal Boundaries

N

5 0 5 10 15 20
Miles



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The magnitude of precipitation that fell over Kiowa County in July and August of 1997 produced damaging floods. However, these floods were not produced by a single, large-magnitude precipitation event as in other counties. Rather, damages in Kiowa County resulted from repeated events of smaller magnitudes over a short period of time. Consequently, none of the individual rainfall totals exceeded the 100-year estimates. ***Table 4.5-5*** shows rainfall amounts and durations compared with 100-year estimates for all five storm events that produced over 1 inch rain.

Table 4.5-4
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation	100-yr Precipitation
6 hours	3.0 inches	4.3 inches
12 hours	3.3 inches	4.8 inches
24 hours	3.6 inches	5.3 inches

Table 4.5-5
Summary of Storm Precipitation, Duration, and Return Period for Kiowa County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
Colorado Climate Center (1998)	Eads	August 4	2.49 inches	24 hours	< 10-year, 24-hour event
National Climatic Data Center (1998a)	Kiowa County	August 4	3.0 inches	19 hours	< 10-year, 24-hour event
Colorado Climate Center (1998)	Brandon	August 5	2.74 inches	24 hours	< 10-year, 24-hour event
Magnuson (1998a)	Brandon	August 5	5.0 inches	12 hours	> 100-year, 12-hour event
Magnuson (1998a)	Sheridan Lake	August 5	6.0 inches	12 hours	> 100-year, 12-hour event

The rainfall total at Sheridan Lake and Brandon on August 5 exceeded the 100-year estimate. The remaining 24-hour values fall below the 10-year level; but according to the NOAA Atlas (1973), they are approximately equal to the 5-year, 24-hour rainfall in central Kiowa County of 3.0 inches.

4.5.5 Hydrology and Hydraulic Findings

4.5.5.1 Locations/Reaches of Flooded Streams

In general, Adobe and Big Sandy Creek watersheds experienced flooding conditions along several reaches. The flooding situation was complicated by the presence of county road embankments that transect these drainages. *Figure 4.5-3* shows Adobe Creek overflowing just downstream of Arlington.

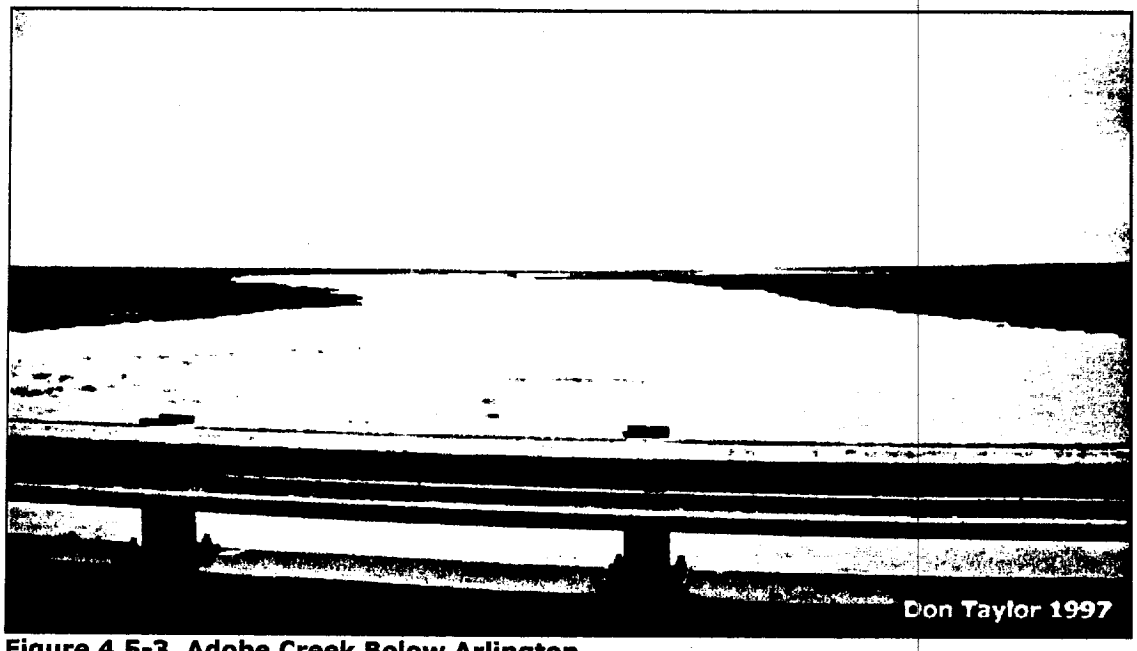


Figure 4.5-3 Adobe Creek Below Arlington

4.5.5.2 Channel Characteristics

No information was available to adequately describe the channel characteristics for the Adobe Creek or Big Sandy Creek watersheds. However, a COE study of the 1965 flood indicates that intermittent tributaries of the Arkansas River, entering from the north side (including Adobe and Big Sandy creeks) have high infiltration rates and large valley storage capacities (COE 1974).

4.5.5.3 Peak Flows and Estimated Return Periods

Streamflow records are available for the Big Sandy Creek watershed from the USGS gage, Big Sandy Creek Near Lamar, Colorado (ID # 07134100). This gage reasonably represents the Big Sandy watershed area for Kiowa County. However, no gages record streamflow data from runoff generated in the Adobe Creek basin.

During the August 1997 storm events, the Big Sandy Creek gage recorded an instantaneous peak discharge of 531 cfs on August 6 at 5:00 p.m., which is approximately equal to the 5-year return period. Although the CWCB has developed a procedure to compute the 100-year streamflow frequency for the eastern plains within the Arkansas River basin, the maximum drainage basin size that is valid for this procedure is 1,125 square miles (CWCB 1997b). The drainage area for the Big Sandy Creek gage, as recorded by the USGS, is 3,248 square miles.

To compute the streamflow frequency, the USGS PEAK FQ program was used to compute the Log Pearson III estimate (USGS 1998b). Annual peak flows from 1968 through 1982 and 1996 were obtained from the USGS gage (ID # 07134100). Using this program, the computed 100-year streamflow was 2,577 cfs. Using the relatively short period of record as a basis for this statistical analysis, the 1997 peak flow was significantly smaller than the 100-year event (see ***Table 4.5-6***).

Table 4.5-6
Computed Peak Discharge for the Storm Events of August 1997

Location	Drainage Area (square miles)	Estimated Peak Flow (cfs)	Estimated 100-year[1] Peak Flow (cfs)
Big Sandy Creek gage near Lamar	3,248	531	2,577

[1]Source: USGS 1998b

4.5.5.4 Flood Hydrograph

The USGS office in Pueblo provided 1-hour streamflow data during the first week of August 1997 for the Big Sandy Creek gage. On the basis of information provided by the Colorado Department of Water Resources' Water Commissioner in this region, no significant diversion headgates exist on Big Sandy Creek that would require adjustments in the gage records during this period (Neuhold 1998). Consequently, the streamflow data at the Big Sandy Creek gage represents the closest approximation of the natural runoff produced by the August 4 through 6 storm events in Kiowa and upstream counties (Cheyenne, Lincoln, Elbert, and El Paso). ***Figure 4.5-4*** depicts the Big Sandy Creek's response to the early August storms.

While this streamflow response to rainfall events between August 4 through 6 is a direct result of the storm events that occurred during this period, not all of the rain fell in Kiowa County. However, no other streamflow records are available in the other counties within the Big Sandy Creek watershed that could separate their contribution to the gage readings near Lamar.

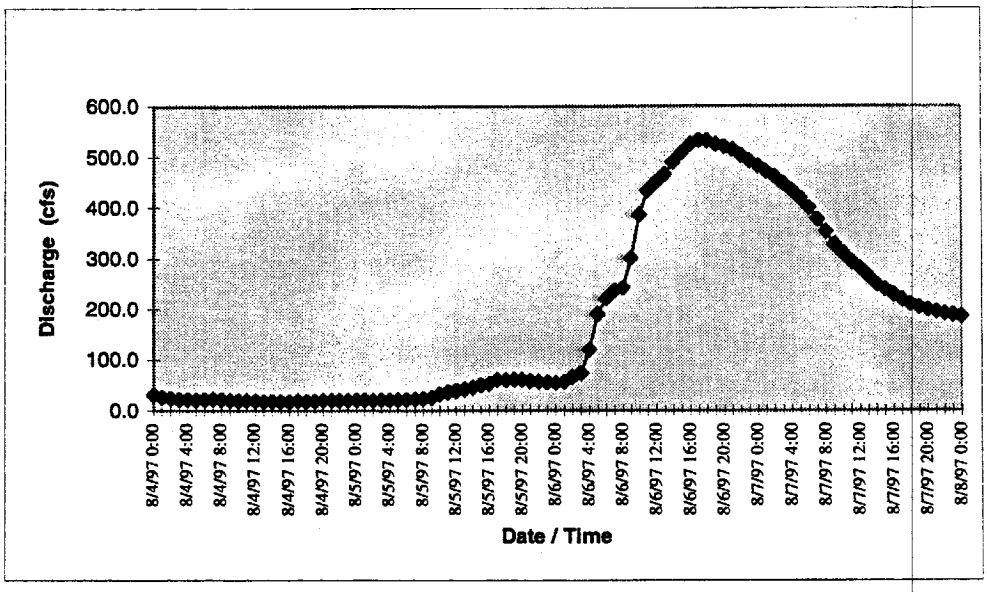


Figure 4.5-4 Flood Hydrograph for Big Sandy Creek Near Lamar, Colorado (USGS ID 07134100)

4.5.6 Specific Flooded or Inundated Areas

The FEMA damage survey reports summarized the locations of the road and bridge damage that occurred on county roads during late July and August from flooding. ***Figure 4.5-5*** shows the washed out section of County Road 2 crossing the south fork of Mustang Creek, while ***Figure 4.5-6*** shows a twisted culvert that was damaged along with County Road L in western Kiowa County. ***Figure 4.5-7*** highlights where these damages occurred. Additional damage was reported within the Rush and Big Sandy Creek watersheds. Flooding also was experienced on the east side of Eads where county roads crossed these channels.

No additional information was available concerning potential flooding on state or federal highways or the flooding extent in natural watersheds.

4.5.7 Emergency Response Effort

Since most flooding occurred in areas with limited population, the potential damage to inhabited structures was minimal. Consequently, little information was available to describe the emergency response to the localized flooding. Kiowa County officials indicate that the county road and bridge crew erected warning signs and closed roads soon after the floods occurred (Frederick 1998).

In Eads, the streets department closed East 13th Street and cut a trench across it to divert water away from some structures. Local residents in this area of Eads used pumps to evacuate water from their homes.

Figure 4.5-5 County Road 2 Crossing the South Fork of Mustang Creek

4.5.8 1997 Flood Damage

The available documentation indicates that damage from the 1997 floods in Kiowa County was primarily confined to county roads and bridges. Information obtained from the County Commissioners' Office (Frederick 1998) provides some costs associated with these damages. In addition, the FEMA damage survey reports also provide costs estimates associated with these storm events. A summary of these damage estimates are provided in *Table 4.5-7*.

The local county costs provided by the Kiowa County Commissioners' office included labor, equipment, and materials (Frederick 1998). The USDA-Farm Services Agency in Kiowa County did not indicate that any significant damage to agriculture occurred as a result of these floods (Johnson 1998). On the contrary, farmers welcomed the moisture provided by the storm events.

4.5.9 Flood Hazard Mitigation

The County Commissioners' Office indicated that no formal flood mitigation efforts were implemented or are planned as a result of the 1997 storm events (Frederick 1998). The County Road and Bridge Department repairs any damage to its roads when damaging floods occur.

Figure 4.5-6 Damaged Culvert Under County Road L in Western Kiowa County

The Town of Eads has obtained recommendations for drainage improvements within the city limits (The Engineering Company 1996). In the northeast region of town, proposed flood mitigation measure include channel bypasses, retention ponds, cross-pans, curb and gutter enhancements, and borrow ditch re-grading. Additional mitigation measures were recommended in the northwest region that include expanding the storm sewer system. Presently, the town is searching for funding sources to implement some of these projects.

4.5.10 Special Circumstances

In general, all the tributaries in Kiowa County can experience flooding conditions along reaches where highway and railroad embankments transect the natural drainage paths. The criteria used to design these crossings were not investigated for this document. According to county officials, limited funds force the installation of culverts in areas where bridges would be more adequate (Frederick 1998). No other information was available to indicate that unique circumstances existed in Kiowa County to cause flooding as a result of the 1997 storm events.

Table 4.5-7
Damage Estimates From the August 5-6, 1997, Storm Events

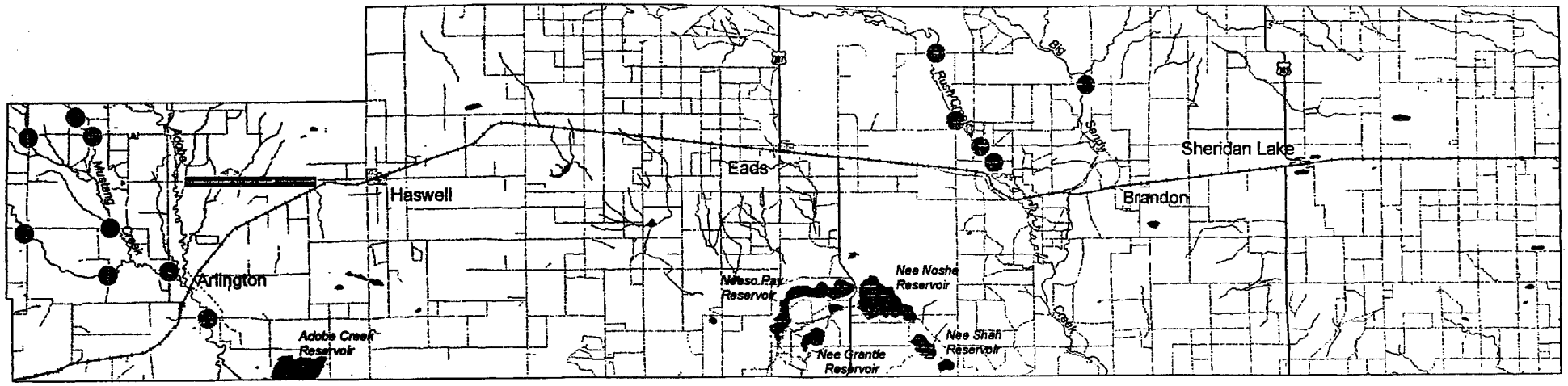
Description	Damage Estimate	Source
Kiowa County - total damages	$108,000[1,2]	Kiowa County Commissioners (Frederick 1998)
Kiowa County - cleanup costs	$69,075[1,2]	Kiowa County Commissioners (Frederick 1998)
Kiowa County	$74,936[1,2]	FEMA (1998)
Town of Eads	$312[1,2]	FEMA (1998)
Agriculture	No dollar cost estimated	USDA-Farm Services Agency (Johnson 1998)
FEMA - countywide	$103,274[3]	FEMA Damage Survey Reports (1998)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include some overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

Figure 4.5-7

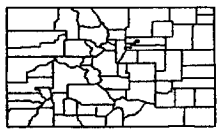
Kiowa County

Damage Areas



Rivers and Streams
Canals and Ditches
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries
Damage Areas

5 0 5 10 15 20
Miles



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4.6 Larimer County

4.6.1 Study Area

Larimer County was one of the first counties to be declared a disaster area by the President during the 1997 flood season. From early June through early August, the county (shown in ***Figure 4.6-1***) sustained some of the most severe damage from flooding in the state, including five deaths. Both incorporated and unincorporated areas were affected by the flooding; however, the City of Fort Collins sustained the greatest impacts from the flooding events of this season.

The population of Larimer County in 1997 was 228,423 (Larimer County 1998b). Fort Collins is the largest community in the county, with a 1997 population of approximately 106,000 (City of Fort Collins 1998a). Loveland is the second largest community, with more than 48,000 residents. Wellington and Berthoud are significantly smaller communities. During the 1997 flood season, Fort Collins experienced the most severe flooding; therefore, the subsequent discussions in this section are focused primarily within Fort Collins city limits, which encompass approximately 44 square miles (City of Fort Collins 1998a).

Larimer County covers approximately 2,640 square miles of northern Colorado directly east of the Continental Divide (see ***Figure 1.1-1***). From the Continental Divide, the county spans eastward just a few miles beyond Interstate 25. From north to south, the county stretches from approximately 35 miles north of Denver to the Wyoming border (Larimer County 1998a).

The terrain in the western part of the county includes foothills, mountainous regions, and canyons. Western Larimer County is home to Rocky Mountain National Park, the Cache la Poudre Canyon, and the Big Thompson Canyon. The eastern portion of the county is typified by gently rolling ranchland and farmland, as well as developed urban areas, including Wellington, Fort Collins, Loveland, and Berthoud (Larimer County 1998a). The climate for the area is semi-arid with approximately 300 days of sunshine a year. The average annual precipitation for Fort Collins is 14.5 inches (City of Fort Collins 1998a).

Land use in Larimer County consists of agriculture, including wheat, corn, alfalfa, and sugar beet farming; ranching; and growing commercial, industrial and residential development.

4.6.2 Watershed Description

The major watershed of interest in Larimer County is the Cache la Poudre River basin; the community of Fort Collins lies within this watershed. The Cache la Poudre River basin comprises approximately 1,129 square

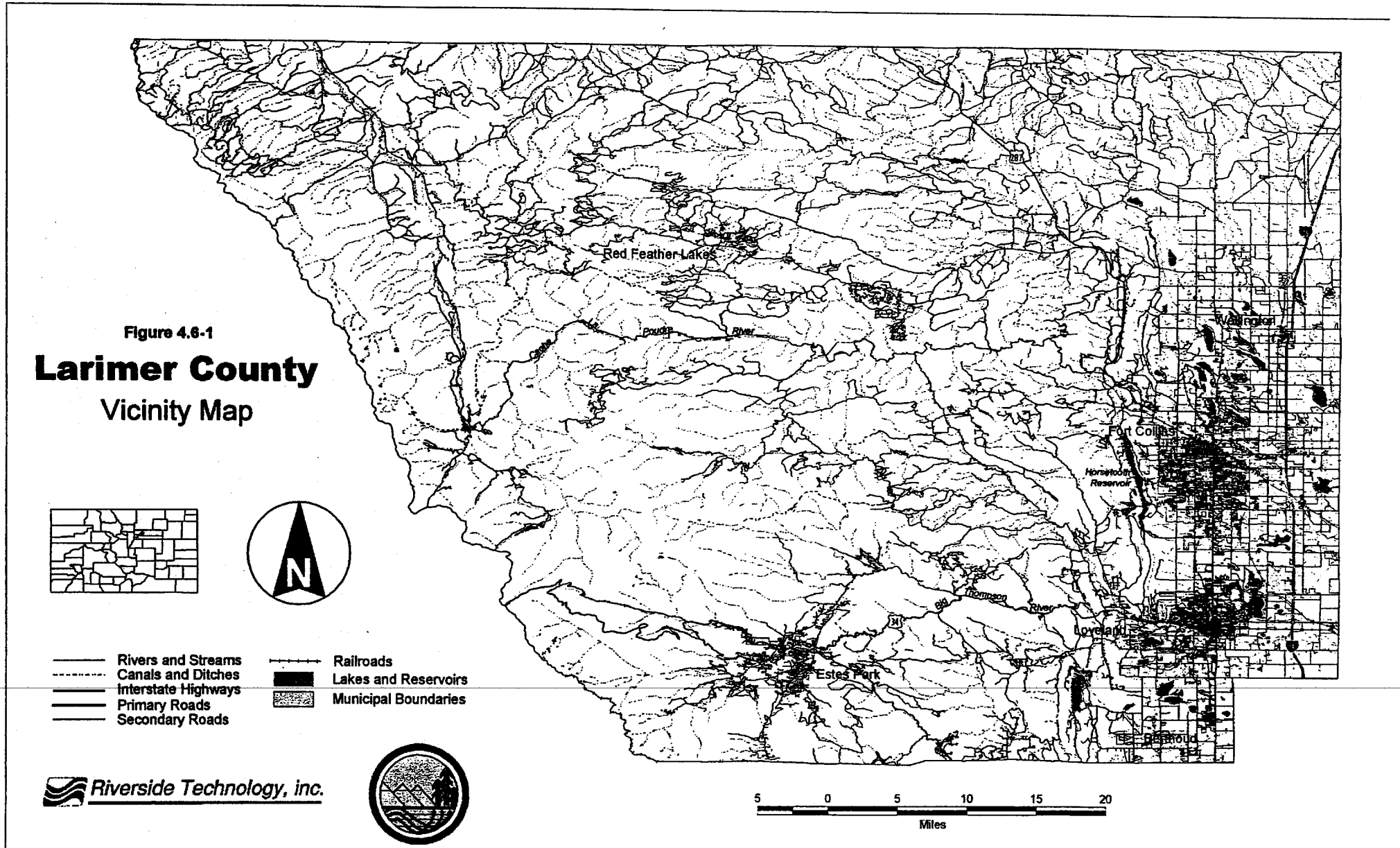

Figure 4.6-1

Larimer County

Vicinity Map

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miles of contributing drainage above Fort Collins (City of Fort Collins 1998a). The watershed elevation ranges from 5,000 to 13,500 feet throughout the basin. The annual precipitation for the basin averages 12 inches on the plains to 30 inches at the headwaters.

Within the Fort Collins city boundaries, there are several subwatersheds of the Cache la Poudre River basin. These subwatersheds are illustrated in *Figure 4.6-2* and are listed below:

- Spring Creek basin
- Dry Creek basin
- Fossil Creek basin
- Boxelder Creek basin
- Greenbriar/Evergreen basin
- Cooper Slough basin
- Old Town North Tributary sub-basin
- West Vine basin
- Old Town basin
- Canal Importation basin (including Fairbrooke, Clearview, and Plum irrigation channels)
- Foothills basin
- Fox Meadows basin
- McClellands/Mail Creek basin

Of these subwatersheds, four were significantly affected by the flooding in 1997: Spring Creek, West Vine, Old Town, and Canal Importation.

4.6.3 Local Flooding Problems

The physical characteristics of the Cache la Poudre River watershed, the location of farms and ranches, and urbanization all have contributed to historical flooding problems within the basin. The watershed and channels within the Cache la Poudre River basin are steep and subject to flash flooding (City of Fort Collins 1998a). Once the Cache la Poudre River reaches the plains in eastern Larimer County, its flood waters have damaged crops, livestock, and transportation structures that lie in the floodplain. In addition, commercial and residential structures in the cities adjacent to the river channel also are subject to flooding.

Tributaries of the Cache la Poudre River also contribute to flooding problems. Historical floods in Dry Creek and Boxelder Creek basins have caused considerable damage in these undeveloped areas over the years. However, the flooding problems in these basins have been heightened in recent years because of increased urbanization within these basins. Irrigation canals that historically captured large portions of the excess

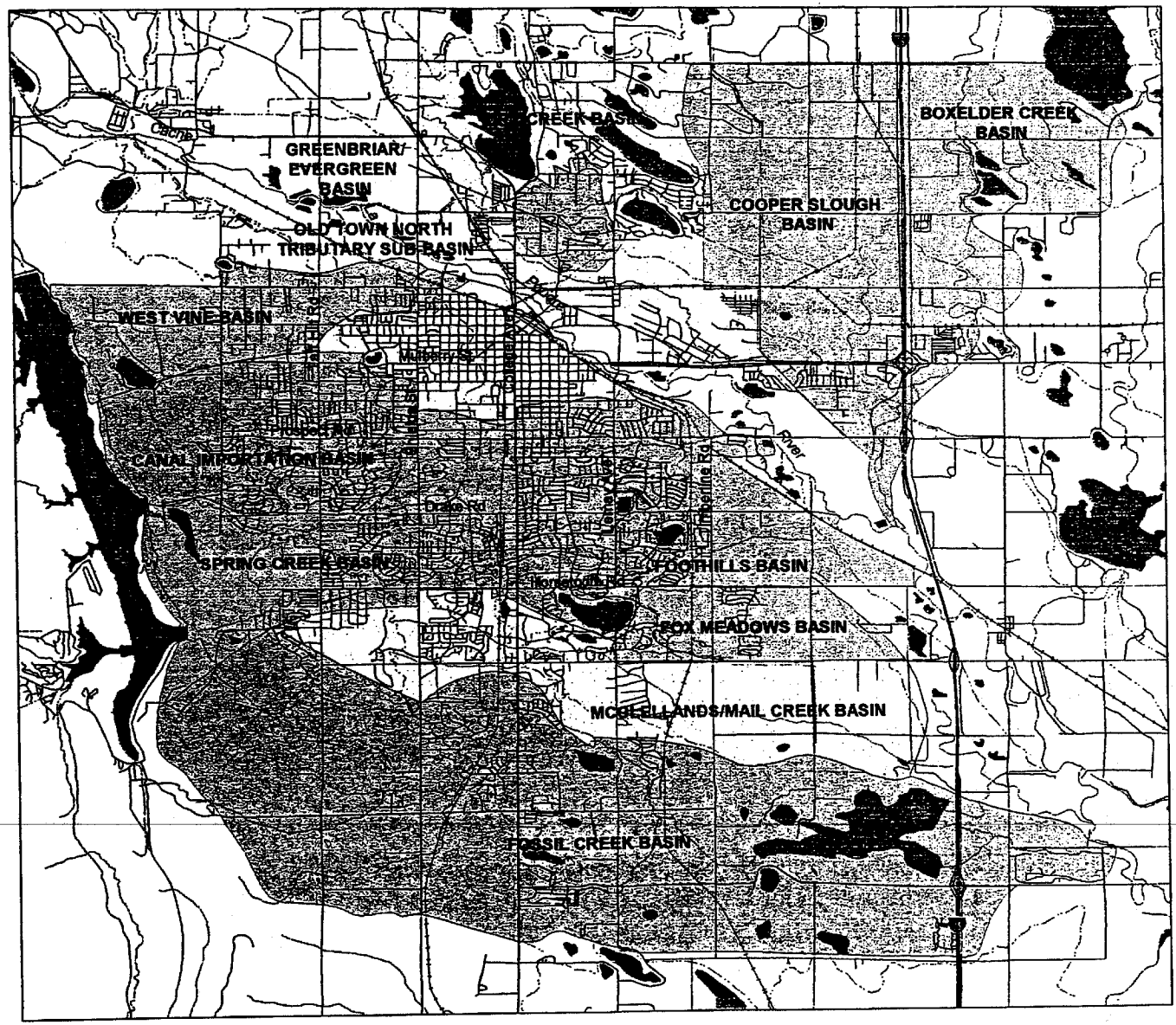

Figure 4.6-2

Larimer County

Fort Collins Stormwater Basins

- Rivers and Streams
- Canals and Ditches
- Primary Roads
- Secondary Roads and City Streets
- Railroads
- Lakes and Reservoirs

N

1 0 1 2 3

Miles

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drainage in the Dry Creek basin are unable to handle the larger peak flows caused by new developments in this area (City of Fort Collins 1998a).

Flooding problems within urban settings also are prevalent. The primary source of flooding within these urban areas is typically intense rain storms. Flash floods that occur from these storms cause ponding in several low-lying areas. Basements and ground floors of structures lying in these floodplains typically incur damage, as well as potential loss of utilities, such as the power and telephone service outages during the 1951 flood (City of Fort Collins 1998b). In other cases, urbanization and poor planning have resulted in residential structures that block the historical path of flood waters (Larimer County 1998a).

4.6.4 Storm Characteristics

Intense thunderstorms produced significant rainfall amounts and flooding in eastern portions of Larimer County during June, July, and August of 1997. A summary of the major precipitation events is presented in ***Table 4.6-1***.

Table 4.6-1
Dates of Significant Precipitation in Larimer County During 1997

Date	Maximum Precipitation	Comments
June 2	1.9 inches	Heavy rain and hail causing flooding and flash flooding problems in Fort Collins and eastern Larimer County
July 27-28	14.5 inches	Series of intense thunderstorms in Laporte and western Fort Collins producing record rainfall
August 5-6	3.69 inches	Additional flooding caused by saturated soils

Of these major events, the July 27 through 28 storms yielded the largest amount of rainfall and resulted in the most damage. A monsoonal moisture pattern developed over eastern Larimer County on July 27 as a cold front, pushing southward and met humid surface air originating from the plains of Colorado and Kansas. According to rain gage data, rainfall began east of the foothills at approximately 4 p.m. (Colorado State University, Department of Atmospheric Science 1998). This atmospheric condition eventually produced a 31-hour storm.

The Fort Collins weather station, located on the Colorado State University campus, collected atmospheric data for each of the events identified in ***Table 4.6-1***. A summary of these data is presented in ***Table 4.6-2***.

Table 4.6-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from north)
CSU[2]	6/2	57	73	24.99	82	56	4.4	144
CSU[2]	7/27	63	82	25.17	66	57	3.1	187
CSU[2]	7/28	61	69	25.26	95	63	4.6	122
CSU[2]	8/5	62	69	25.30	75	62	4.2	141
CSU[2]	8/6	57	73	25.34	58	55	3.4	274

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C) (Linsley et al. 1992)
[2]Colorado State University, Fort Collins, CO
Source: National Climatic Data Center 1998a

During the height of the July storms in Fort Collins on the 28th, the cloud depth where precipitation growth occurred was approximately 4 kilometers, or 13,000 feet (Kelsch 1998a). Consequently, the cloud top elevation was approximately 15,000 feet from the ground surface, or 20,000 feet above mean sea level. The cloud characteristics during this storm included warmer cloud top temperatures and less lightning strikes than is typical for Colorado; these are conditions more commonly found in tropical storms.

4.6.4.1 Storm Duration and Rainfall Quantities

The June 2 and early August storm events were localized and produced a wide range of rainfall amounts within the City of Fort Collins according to the spotter reports collected by Mountain States Weather Services (1997). The rainfall on June 2 ranged from 0.17 inch in the northwest portions of Fort Collins to just under 2 inches in southwest Fort Collins. The August 5 through 6 event produced a wider range of rainfall; no rain was reported at the Fort Collins Country Club (northeast of Fort Collins) while 3.69 inches were reported on the south side of the city.

The July 27 through 28 storms (a 31-hour event) produced the greatest rainfall amounts on the western side of Fort Collins. During this 31-hour period, four pulses of significant rainfall fell over the Fort Collins and surrounding eastern Larimer County areas (Colorado State University, Department of Atmospheric Science 1998). The heaviest rainfall quantities fell just east of the foothills and Horsetooth Reservoir.

Between 4 p.m. and 9 p.m. on July 27, the first set of storms hit eastern Larimer County, producing a peak of over 2 inches of rain just southwest of Horsetooth Reservoir. The next two rainfall pulses occurred between 10 p.m. and 1 p.m. on July 27 and 28, with a brief lull around 7 a.m. on the 28th.

Combined with the initial storm, the total rainfall amount that fell on this region by 1:00 p.m. on the 28th surpassed 10 inches northwest of Laporte. After 4 hours of little or no rain, the final storm pulse began at 5 p.m. and ended around 11 p.m. on July 28. During this 6 hours, a maximum of 10+ inches of rain fell over southwest Fort Collins just east of Horsetooth Reservoir.

A summary of the point precipitation readings during the July 27 and 28 storm events was compiled by Nolan Doesken and Thomas McKee (Colorado State University, Department of Atmospheric Science 1998) and is reproduced in ***Table 4.6-3***.

During this 31 hours of rainfall activity, a maximum of 14.5 inches of rain fell in portions of Larimer County, which is approximately the average amount of precipitation that falls annually near Fort Collins. ***Figure 4.6-3*** provides a spatial distribution of rainfall in eastern Larimer County, including the cities of Fort Collins and Laporte.

4.6.4.2 Estimated Point Precipitation Return Periods

The magnitude of the July 27 through 28 storms presents difficulties when estimating their actual rainfall frequencies. However, the estimated precipitation frequencies in the affected region of Larimer County (Fort Collins) are presented in ***Table 4.6-4***. Doesken and McKee (Colorado State University, Department of Atmospheric Science 1998) reported the 6-hour and 24-hour storm durations for the 100-year return period, while the 12-hour estimate was interpolated using the nomogram provided in the NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado (1973). The 10-year return period estimates also were taken from this NOAA atlas.

Not surprisingly, the July 27 through 28 storms produced rainfall amounts that far exceeded any of the 100-year precipitation frequency estimates. ***Table 4.6-5*** shows rainfall amounts for the July 27 through 28 and August 5 through 6 events.

Although the rainfall totals prior to 5 p.m. on July 28 were just under the 100-year frequency estimates, this rainfall completely saturated the soils in eastern Larimer County. These conditions caused the 5 p.m. to 11 p.m. storm to be more devastating.

Larimer County reported 4 to 4.5 inches of rain in a 2-hour period over the West Vine Drainage basin during the evening of July 28—an amount greater than the 500-year, 2-hour rainfall for this area (3.6 inches) (Larimer County 1998a). The August 5 through 6 event also caused more wide-spread flooding than typically would have occurred because of the saturated soils from the July storms.

Table 4.6-3
Hourly Rainfall Totals (inches) in Eastern Larimer County on July 27 and 28, 1997

July 1997	Hour Ending	Station Identification													
		A[1]	B[1]	C[1]	D[1]	E[1]	F[1]	G[1]	H[1]	I[1]	J[1]	K[1]	L[1]	M[1]	N[1]
Sunday 7/27/97	4 p.m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5 p.m.	0	0.02	0	0	0	0	0	0	0	T	0	0	0	0
	6 p.m.	0.20	0.11	0.22	0.19	0.14	0.28	0	0.04	0.08	T	0	0	0	0
	7 p.m.	0.02	0	0.08	0.02	0.04	0.02	0.83	0.05	0.04	0.03	0.01	0.02	0	0.01
	8 p.m.	0	0	0	0	T	0	0.33	0.06	0.03	0.01	0.04	0.03	0.04	0.02
	9 p.m.	0	0	0	0	T	0.01	0.01	0.01	0.02	0	0.05	0	0	0
	10 p.m.	0	0	0	0	0	0	0	0	0	T	0	0	0	0
	11 p.m.	0	0.17	0.04	0.05	T	0.04	0	0.65	0.16	T	0.05	0.05	0.16	0
	Midnight	0.02	0	0	0.02	0	0	0	0.02	0.03	0.02	0.03	0.01	0	0
Monday 7/28/97	1 a.m.	0.01	0	0	0	0	0	0	0	0	0.03	0	0	0	0.11
	2 a.m.	0.01	0.15	0.04	0.09	0.03	0.08	0.01	0.02	0.14	0	0	0	0	0
	3 am.	0.04	0.31	0.38	0.35	0.35	0.39	0.03	0.08	0.31	0.27	0.24	0.27	0.24	0.34
	4 am.	0.06	0.62	0.64	0.75	0.30	0.25	0.01	0	0.14	0.22	0.26	0.55	0.20	0.15
	5 am.	0.38	0.22	0.20	0.18	0.02	0.06	0	0	0	0.07	0.05	0.09	0.16	0.13
	6 am.	0.14	0.54	0.62	0.56	0.02	0.02	0.01	0	0	0	0	0.01	0	0.01
	7 am.	0	0.09	0.16	0.06	0.01	0	0.01	0	0	T	0	0	0.04	0
	8 am.	0.01	0.01	0.04	0.03	0.01	0.21	0.06	0.03	0.01	0.01	0	0.01	0	0.01
	9 am.	0.21	0.86	1.00	0.91	0.12	0.38	0	0.04	0.02	0	0	0	0.03	0
	10 am.	0.09	0.52	0.48	0.46	0.02	0.19	0	0	0	0	0	0	0	0
	11 am.	0.28	0.50	0.16	0.06	T	0.02	0.01	0	0	0	0	0	0	0
	Noon	0.14	0.02	0.04	0.02	0	0	0	0	0	0	0	0	0	0
	1 p.m.	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
	2 p.m.	0.01	0	0	0	0	0	0	0.01	0	0	0	0	0	0
	3 p.m.	0	0	0	0	0	0	0	0	0	T	0	0	0	0
	4 p.m.	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0
	5 p.m.	0.02	0	0	0	0	0	0	0	0	T	0.01	0	0	0
	6 p.m.	0.15	0.03	0.04	0.05	T	0.11	0	0.01	0.01	T	0	0	0	0
	7 p.m.	0.03	0.58	0.54	0.79	0.37	0.71	0.39	0.24	0.12	0.06	0.02	0.03	0.11	0.09
	8 p.m.	0.12	0.27	1.12	0.90	0.51	1.63	0.17	0.89	0.64	0.31	0.32	0.17	0.12	0.09
	9 p.m.	0.48	0.92	1.58	1.31	1.47	1.37	0.06	0.23	0.31	0.22	0.12	0.20	0.27	0.27
	10 p.m.	0.08	1.08	2.54	2.17	2.31	3.16	0	0.01	0.01	0.01	0.01	0.03	0.16	0.08
	11 p.m.	0	0.14	0.78	0.54	0.64	0.72	0	0	0	T	0	0	0.24	0.18
	Midnight	0	0	0	0	T	0	0	0	0	0	0	0	0.04	0.09
Tuesday 7/29/97	1:00 a.m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sum	**2.51**	**7.16**	**10.72**	**9.51**	**6.36**	**9.65**	**1.93**	**2.39**	**2.07**	**1.26**	**1.21**	**1.47**	**1.81**	**1.58**

*= clock times approximate on some gages.

[1]

Code	Description
A	U.S. Forest Service, Redstone Canyon
B	West Fort Collins Water District, Laporte
C	Colorado State University, Atmospheric Science Department, Foothills Campus
D	Colorado State University, Agricultural Engineering Research Center
E	Colorado State University, Main Campus
F	Fort Collins Water Department, Wakefield Drive
G	Northern Colorado Water Conservancy District, Loveland
H	South Fort Collins
I	City of Fort Collins, Collindale Golf Course
J	Mountain States Weather Services
K	City of Fort Collins, Resource Recovery Farm
L	Colorado State University, Horticulture Farm
M	Colorado State University, Agricultural Research Development and Education Center
N	Forensic Meteorology Associates, Inc.

Source: Colorado State University, Department of Atmospheric Science 1998

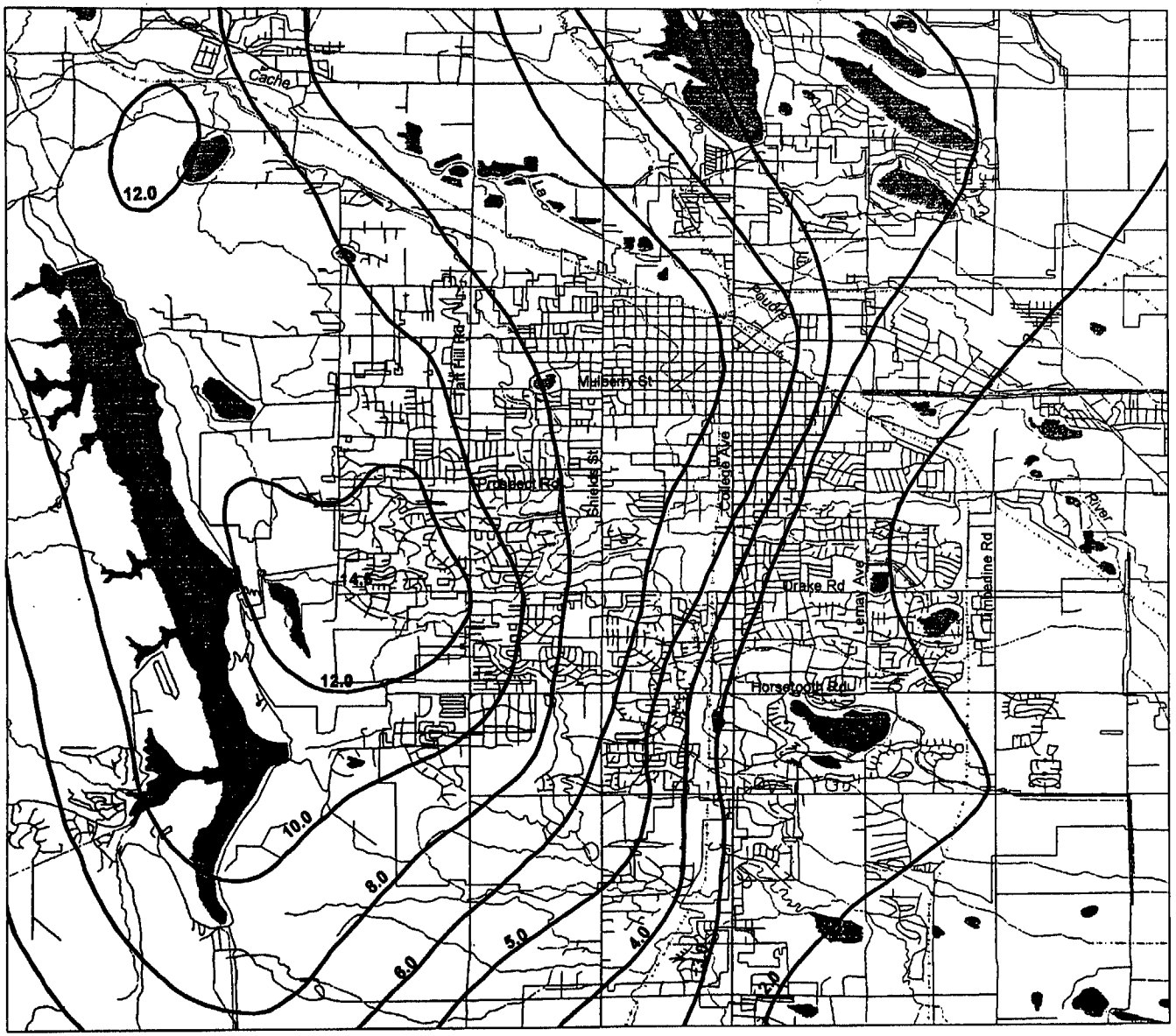

Figure 4.6-3

Larimer County

Fort Collins Precipitation

4:00 p.m. July 27 -
11:00 p.m. July 28, 1997

- 6.0 Isohyetal Line (Inches)
- Rivers and Streams
- Canals and Ditches
- Primary Roads
- Secondary Roads and City Streets
- Railroads
- Lakes and Reservoirs
- City of Fort Collins

N

1 0 1 2 3
Miles

Riverside Technology, inc.

Table 4.6-4
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-year Precipitation	100-Precipitation
6-hour	2.3 inches	3.5 inches
12-hour	2.8 inches	4.2 inches
24-hour	3.2 inches	4.8 inches

Table 4.6-5
Summary of Storm Return Period Precipitation, Duration, and Return Period for Larimer County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
Mountain States Weather Services (1997)	Fort Collins	June 2	1.9 inches	5 hours	< 100-year, 6-hour event
City of Fort Collins (1998a)	Fort Collins	July 27-4 p.m. July 28-5 p.m.	4.5 inches	25 hours	< 100-year, 24-hour event
City of Fort Collins (1998a)	Fort Collins	July 28 5 p.m. - 11 p.m.	10 inches	6 hours	> 100-year, 6-hour event
CSU, Dept. of Atmos. Sciences (1998)	Laporte	July 27 - July 28	4.1 inches	21 hours	< 100-year, 12-hour event
Mountain States Weather Services (1997)	Fort Collins	August 5 - August 6	3.7 inches	15 hours	< 100-year, 12-hour event

4.6.5. Hydrology and Hydraulic Findings

4.6.5.1 Locations/Reaches of Flooded Streams

A description of the locations and reaches of flooded streams within Larimer County is presented for the storm events of July 27 and 28 only. Little information regarding the hydrologic response of the watersheds as a result of the June 2 and August 5 through 6 events is available.

The City of Fort Collins sustained the greatest impact from the July 27 through 28 flood. Flood waters inundated streets and land near Fossil Creek, Old Town, and Colorado State University, and significant flood waters were reported in the Canal Importation and Spring Creek basins. Specifically, flooding along Spring Creek occurred from areas near County Road 38E (just east of Taft Hill Road) all the way through Fort Collins and to Spring Creek's confluence with the Cache la Poudre River. Several irrigation channels, including Clearview, Fairbrooke, and Plum, overtopped their banks between

Mulberry Street and Prospect Road within the Canal Importation basin. In addition, flooding was reported in the Fossil Creek drainage just east of the Shields Street bridge in south Fort Collins. ***Figures 4.6-4*** and ***4.6-5*** show flooding that occurred during the evening of July 28 along Spring Creek at a mobile home park and at Colorado State University, respectively. ***Figure 4.6-6*** shows inundated areas east of Shields Street along Spring Creek.

Flooding also occurred near the northwest boundary of Fort Collins and Larimer County lands within the West Vine Street drainage basin (Larimer County 1998a). Specifically, flooded areas in this region were bounded by North Overland Trail to the west, Laporte Avenue to the south, Cherry Street to the north, and New Mercer Ditch to the east. Flooding was greatest along Hollywood Street and Sunset Street in this area. Irrigation ditches in this area, including the Pleasant Valley/Lake Irrigation Canal (PVLC), overflowed in several locations causing additional flooding on county lands (Woodward-Clyde 1997). Most observed bank overflows along the PVLC were recorded between West Vine Drive to the north and Prospect Avenue to the south. ***Figures 4.6-7*** and ***4.6-8*** show flooded areas on Sunset Street and the intersections of Hollywood Drive and Cherry Lane, respectively.

4.6.5.2 Channel Characteristics

The primary channel affected by flooding in Larimer County was Spring Creek. Most of Spring Creeks' reaches wind through Fort Collins' developed areas, except for the reach downstream of Horsetooth Reservoir and near its confluence with the Cache la Poudre River. The slopes are relatively mild, and several channel and floodplain projects have stabilized the creek's banks under normal flows. Just upstream of the Timberline Road bridge, Spring Creek has a typical depth of less than a foot and a width of approximately 10 feet.

Except for a few irrigation ditches, the Canal Importation, Old Town, and West Vine basins (***Figure 4.6-2***) do not have defined channels. Instead, flooding in these basins results from uncaptured runoff that occurs in developed areas.

4.6.5.3 Peak Flows and Estimated Flood Return Periods

Peak discharges were estimated at several locations around Fort Collins. ***Table 4.6-6*** summarizes these estimates and contains the 100-year and 500-year flood frequency magnitudes for comparisons.

All Spring Creek and Clearview locations in ***Table 4.6-6*** experienced flow rates that far exceeded the estimated 500-year flood frequency. Other locations along the Fairbrooke and Plum canals also reported significant flooding. Discharge estimates for Fossil Creek were low because of the relatively small amount of rain that fell on this basin (see ***Figure 4.6-1***).

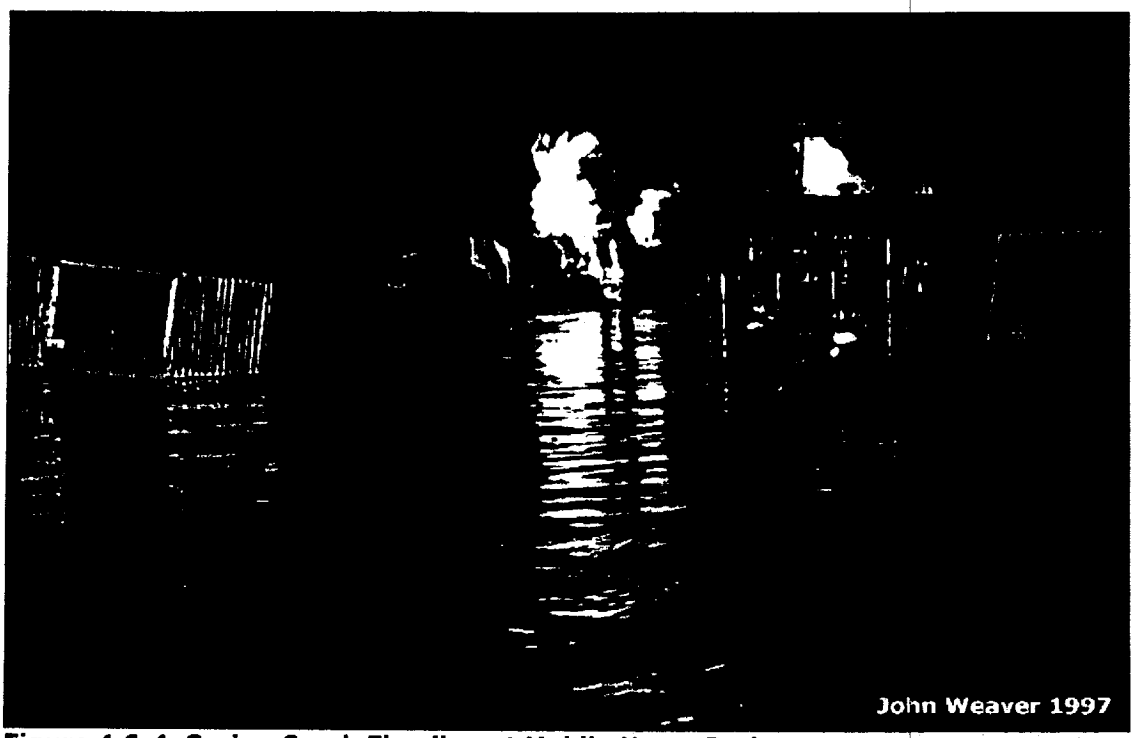

Figure 4.6-4 Spring Creek Flooding at Mobile Home Park

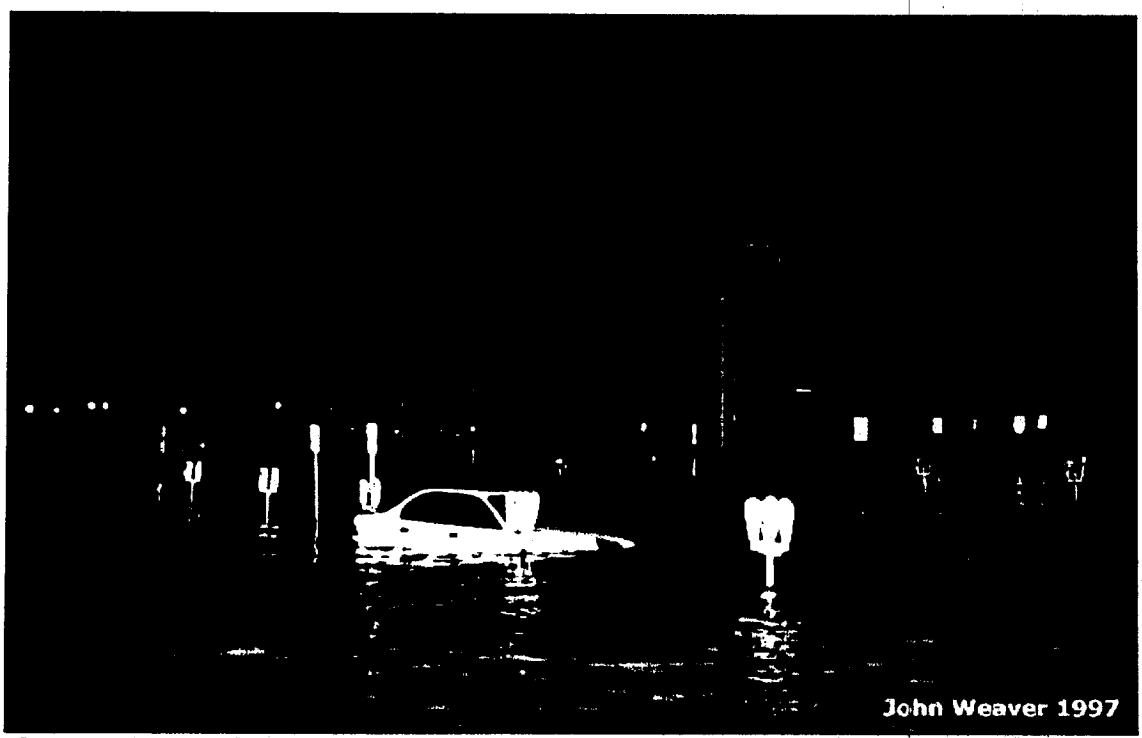

Figure 4.6-5 Spring Creek Flooding at Colorado State University

Figure 4.6-6 Shields Street Bridge Along Spring Creek

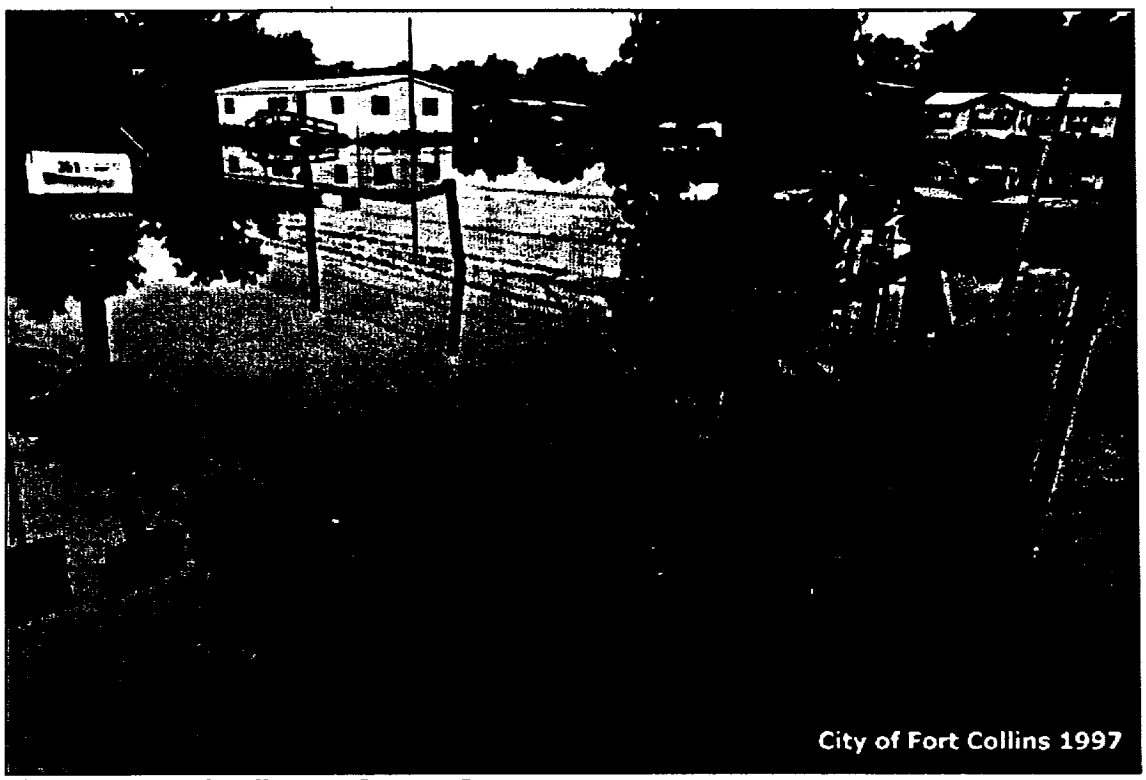

Figure 4.6-7 Flooding on Sunset Street

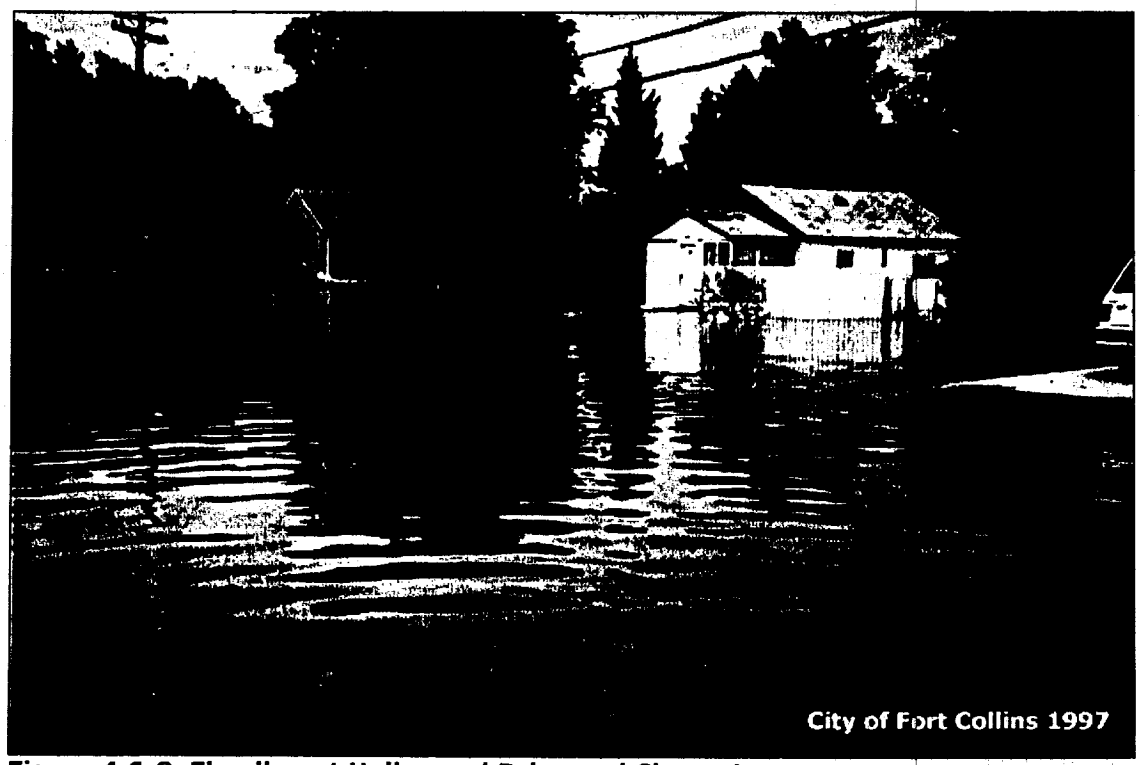

Figure 4.6-8 Flooding at Hollywood Drive and Cherry Lane

Larimer County and CWCB personnel estimated flood discharges along several locations within the West Vine Drainage basin. The peak discharge just east of Overland Trail Road was computed to be approximately 690 cfs (Larimer County 1998a). The estimated 500-year peak discharge for this location is 288 cfs. Clearly, the July 1997 flood was significantly greater than the best estimate of the 500-year flood event in this river basin.

Severe channel bank erosion occurred along most of the Spring Creek channel. Although many of the irrigation and drainage canals were overtopped, very little structural damage was incurred by these water conveyance structures.

4.6.5.4 Flood Hydrograph

Discharge data at the City of Fort Collins' Spring Creek gage, located just upstream of the Timberline Road bridge on the east side of the city, recorded data until the gage house was inundated at approximately 9 p.m. on July 28 (City of Fort Collins 1997). The USGS estimated the flood peak downstream from Riverside Avenue (located approximately 0.25 mile upstream of the Spring Creek gage) at 5,860 cfs (USGS 1998a). In addition, a photograph taken by Riverside Technology, inc. approximately 0.25 mile downstream of the city's Spring Creek gage (***Figure 4.6-9***) at 10 a.m. on July 29 depicts the water level approximately 2 feet below the debris line (i.e., the peak

discharge). Assuming the debris line occurred at 5,680 cfs, a rough estimate of the discharge at 10 a.m. was computed to be 3,223 cfs. No additional information was available to estimate discharges after 10 a.m. on July 29 for Spring Creek.

Table 4.6-6
Computed Peak Discharge for the Storm Event of July 28, 1997

Location	July 28, 1997 Peak Flow (cfs)	Estimated 100-year Peak Flow[1] (cfs)	Estimated 500-year Peak Flow (cfs)
Spring Creek			
Taft Hill Road	3,900	1,492[2]	2,347[1]
Downstream of Taft Hill Road	3,300	1,492[2]	2,347[1]
Drake Road	4,200	1,635[2]	2,575[1]
Downstream of Drake Road	3,700	1,635[2]	2,575[1]
Downstream of Shields above Canal Importation	5,200	1,955[2]	3,090[1]
Combined flow below Canal Importation	8,250	2,135[1]	3,325[1]
drop structure - main channel	6,100		
overflow to south	850		
Wallenberg	1,300		
Indian Meadows Condos	5,000	1,528[2]	1,846[1]
Mathews	5,500	1,528[2]	1,846[1]
Edora Park	6,000	2,187[2]	2,920[1]
Railroad trestle	5,860	2,187[2]	2,920[1]
Fairbrooke[3]			
Willow Lane Townhomes	425	260	420
Fairbrooke/Dorset Drive combined	1,750	326	
Fairbrooke Channel	530		
Dorset Drive	1,220		
Clearview[3]			
Clearview Channel at Taft Hill Rd	2,400	532	670
Clearview Channel at Avery Park	2,400	532	670
Plum[3]			
Culvert by Jefferson Commons	370	356 (developed)	[4]
Fossil Creek			
LeMay Ave. at Southridge Gold Course	1,800	2,520	[4]
West Vine			
Downstream of Overland Trail	690	204	288

[1]Source: CWCB 1997b
[2]FEMA regulatory discharge.
[3]These areas are included in the Canal Importation basin.
[4]No information is available for these locations.
Source: City of Fort Collins 1998a (except where noted)

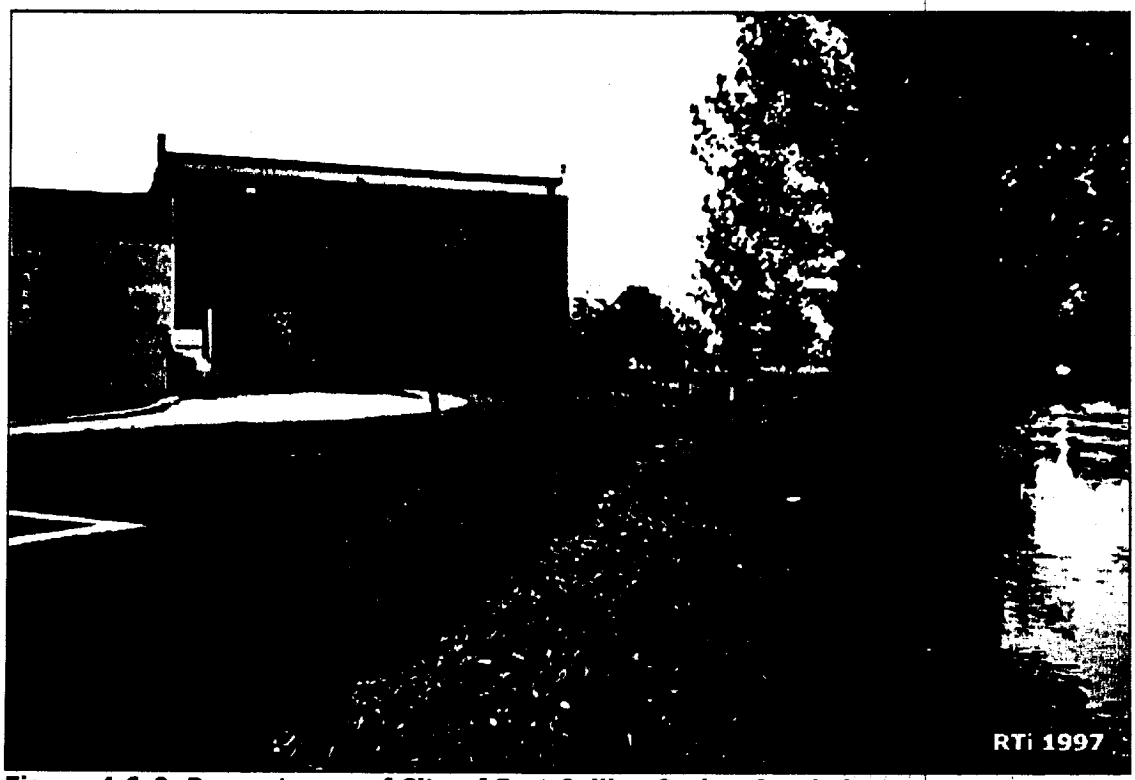

Figure 4.6-9 Downstream of City of Fort Collins Spring Creek Gage

Using this information and assuming the peak occurred at midnight on July 28, a flood hydrograph for the July 27 and 28 event was developed. *Figure 4.6-10* depicts the streamflow on Spring Creek near the Timberline Road bridge during this time period.

Typically, the streamflow in this urban drainage at this location is approximately 10 cfs. No other information was available from which to develop flood hydrographs in other basins resulting from the July 27 through 28 storms, nor from the June 2 or August 5 through 6 events.

4.6.6 Specific Flooded or Inundated Areas

Several areas of Fort Collins and Larimer County were affected by the July 1997 flooding, including the West Vine Drainage basin, the Canal Importation basin, Colorado State University, Old Town, and the Spring Creek basin. *Figure 4.6-11* displays the extent of the flooding within Fort Collins and surrounding Larimer County areas. The 100-year and 500-year floodplains are included to put this flood in perspective with typical design storms for flood control structures.

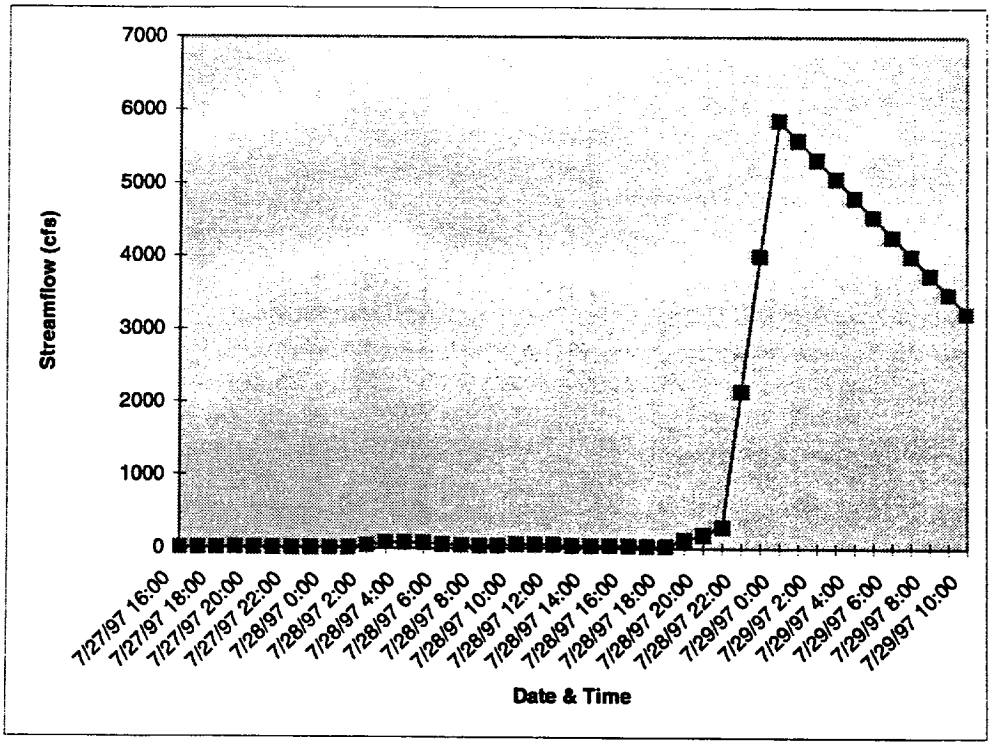

Figure 4.6-10 Spring Creek Streamflow on July 27-28, 1997

Inundated areas were common along the west side of Fort Collins from West Vine Drive to the north and West Harmony Road to the south. The West Vine Drainage experienced flooding beginning near North Overland Trail and encompassing both county and city lands to the east until it reached the New Mercer Ditch. In the Canal Importation basin, flood water inundated neighborhoods east of Overland Trail and between Mulberry Street and Prospect Road. Flooding continued east down Elizabeth Street and into the Colorado State University campus. Residential areas directly east of Colorado State University and scattered areas in Old Town experienced building damage as a result of the floods. While significant financial damage occurred on the Colorado State University campus and surrounding residential areas, the most serious region affected by the July 1997 floods was in the Spring Creek basin.

Inundated areas in the Spring Creek basin began forming just east of Horsetooth Reservoir, which compounded the existing flooding problems east of Taft Hill Road and north of West Horsetooth Road. Flood waters crossed South Shields Street and began pooling behind a railroad embankment. Once the embankment was overtopped, severe flooding occurred within a few blocks to the right and left of the Spring Creek channel from College Avenue east to the creek's confluence with the Cache la Poudre River. Flooding did occur between Timberline Road and the confluence point, but most areas in this vicinity were undeveloped.

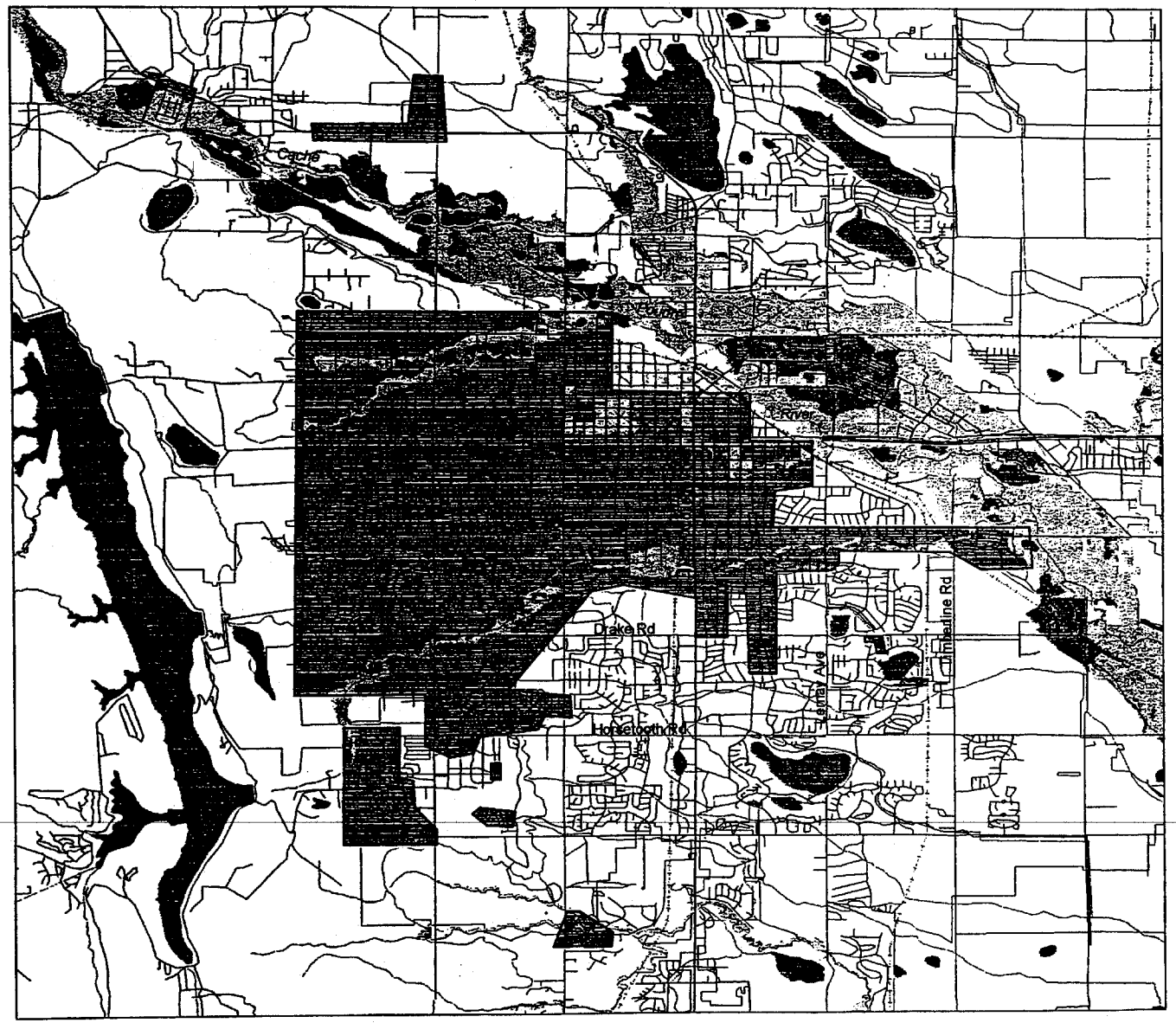

Figure 4.6-11

Larimer County

Fort Collins Damage Areas and FEMA Floodplains

- Rivers and Streams
- Canals and Ditches
- Primary Roads
- Secondary Roads and City Streets
- Railroads
- Lakes and Reservoirs
- City of Fort Collins
- FEMA 100-year Floodplain
- FEMA 500-year Floodplain
- Damage Extent

N

1 0 1 2 3

Miles

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4.6.7 Emergency Response Effort

On the morning of July 28, irrigation ditches were closed and sandbags were prepared in response to weather forecasts for that day (Hayes and Miner 1997-98). At 9:06 that night, the National Weather Service issued a flash flood watch until 11 p.m. for eastern Larimer County and a flash flood warning at 10:06 p.m. in the same area.

Firefighters were called to the Johnson Center and South College Mobile Home Parks just after 9 p.m. on July 28 to help rescue people from their mobile homes and from nearby trees (Eddy 1997). Rescuers used safety lines and boats to pull people from the inundated areas.

At 9:34 p.m., the Larimer County Dive Rescue Team was called out to help rescue people in deep water (Hayes and Miner 1997-98). At 10:11 p.m., all of the city's off-duty resources were called in to help with the emergency efforts. At 10:14 p.m., a city dispatcher called the Burlington Northern and Union Pacific Railroads to advise against sending trains through town. At 10:59, a natural gas leak caused an explosion at a liquor store, creating an additional hazard for rescuers at the mobile home parks nearby. One minute later, a Burlington Northern train derailed (see ***Figure 4.6-12***) and four rail cars slid down into the mobile home parks. During this time, along West Elizabeth (west of the Colorado State University campus), business owners were sandbagging their stores.

The Union Colony Fire/Rescue Authority in Greeley sent a dive team at 1 a.m. on July 29 to search for victims along Spring Creek. These rescue personnel and 11 other Greeley firefighters also helped search through the mobile home parks. In addition, 12 Greeley police officers helped Fort Collins officers control traffic and security around the flood areas on July 29 (Peters 1997).

In the aftermath of the flooding, the American Red Cross set up an assistance center at Christ United Methodist Church, as well as a shelter at Rocky Mountain High School for individuals who were displaced by the flood (Booth and Eddy 1997).

4.6.8 1997 Flood Damage

Damages caused by the July 1997 floods ranged widely (City of Fort Collins 1998a). The most significant consequences were the 5 deaths and 54 injuries associated with the flooding. The most serious structural and vehicular damage occurred in the mobile home parks located just downstream of the railroad embankment near College Avenue and Prospect Road (see ***Figure 4.6-13***). The Johnson Center Mobile Home Park and the South College Trailer Park were completely destroyed. Other residential areas throughout

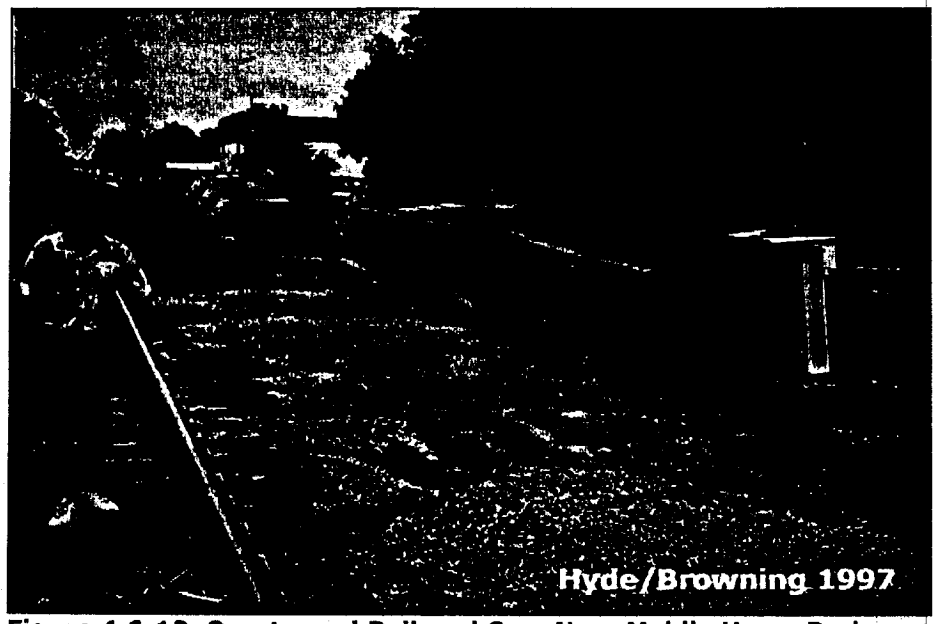


Figure 4.6-12 Overturned Railroad Cars Near Mobile Home Park

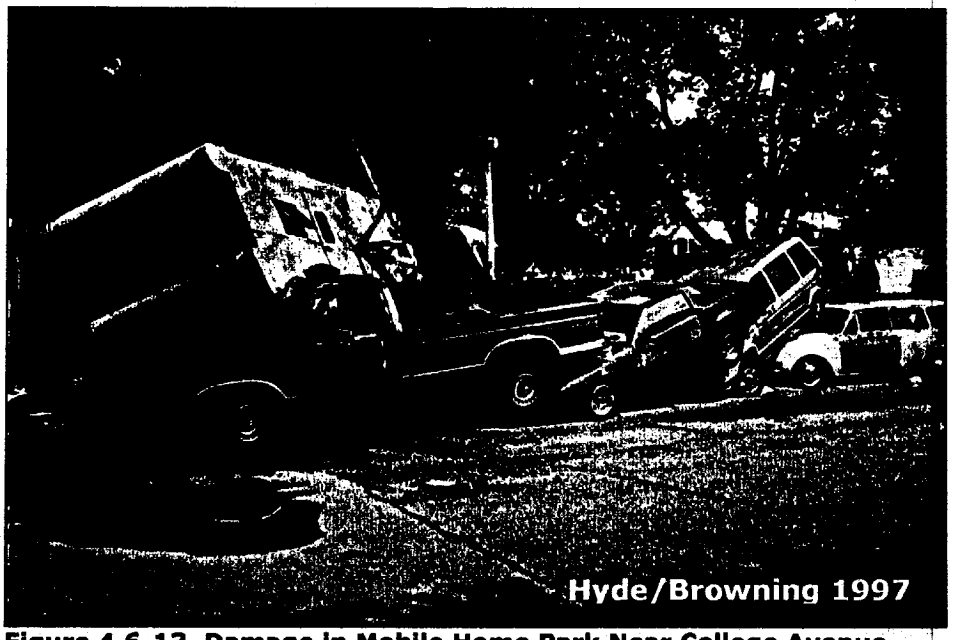


Figure 4.6-13 Damage in Mobile Home Park Near College Avenue

the city experienced widespread damage as well. FEMA identified a total of 1,988 housing units that were damaged (City of Fort Collins 1998a).

Several businesses in the Spring Creek basin and other inundated areas incurred damages from flood waters and debris. The City of Fort Collins reported that more than 100 businesses either were damaged or completely destroyed in this flood (City of Fort Collins 1998a).

Colorado State University sustained significant damage to its student union, library, and 15 other campus buildings (Colorado State University 1997). Approximately 10 percent of Colorado State University's library collection was destroyed, and nearly 230,000 water-damaged items were removed from the shelves for restoration (Colorado State University, Library Assistance Center 1997).

A summary of the damage estimates from the July 27 through 28 storm events to the City of Fort Collins, Larimer County, and other entities within the county are provided in ***Table 4.6-7***. Values in the table below may differ based on varied criteria used by each agency to estimate damages.

Table 4.6-7
Damage Estimates From the July 27-28, 1997, Storm Events

Description	Damage Estimate	Source
Fort Collins area, including Colorado State University	$200 million +[1,2]	City of Fort Collins (1998a)
Colorado State University	$100 million[1,2]	Colorado State University (1998)
Agriculture	No cost estimated	USDA- Farm Services Agency
FEMA - countywide	$2,837,409[3]	FEMA Damage Survey Reports (1998)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include some overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

The USDA-Farm Services Agency in Larimer County did not compute specific costs for damages resulting from the July floods. However, the agency estimated that 500+ tons of bailed hay were lost, as well as ranchers' time and materials to remove debris that washed up on their pasture land.

4.6.9 Flood Hazard Mitigation

4.6.9.1 Previous Efforts

The City of Fort Collins has developed and adopted some of the most progressive stormwater management programs in the state over the past 20 years (City of Fort Collins 1998b). In the Spring Creek basin, over $5 million has been spent on stormwater improvements since 1990. Flood mitigation efforts include acquiring various structures (mobile homes, residential houses, a retirement home, and a business) and open space within the

floodplains. Other structural mitigation measures include channelization to remove properties from floodplains, bridge improvements, and reinforcement of railroad embankments (which included plugging a box culvert at the base of the embankment (City of Fort Collins 1998b). Non-structural, community outreach mitigation efforts include flood information brochures, videos, training classes for realtors, school education programs, an automated city information line, and a flood resource collection in the public library [City of Fort Collins date unknown (a)].

The USDA Natural Resources Conservation Service also has been active in flood mitigation projects. In eastern Larimer County, the agency has constructed several dams on Boxelder Creek to reduce potential flood damage from this waterway (COE 1981).

4.6.9.2 Future Needs

Several projects are planned to further improve flood mitigation within the City of Fort Collins and surrounding Larimer County areas. Within the city limits, capital improvement projects are scheduled to improve the storm sewer and street conveyance capacity of stormwater runoff in the older sections of town (e.g., the Old Town basin) (City of Fort Collins 1998b). Structures in these areas pre-date contemporary floodplain and drainage regulations. Fort Collins also is planning to improve the conveyance capacity of historical drainage channels. This will require additional property acquisitions, easements, and various capital improvements to re-open the specified drainage corridors. Additional capital improvement projects are planned for controlling spills from irrigation canals that run throughout the city. To supplement these planned activities, Fort Collins recently proposed to develop an early warning system to improve flood mitigation.

The proposed early warning system includes improved data collection, communications, and computer software to manage the information. As part of this warning system, the existing streamflow and precipitation gage networks would be expanded and new gage hardware would be installed to report the current conditions on a real-time basis (as opposed to once an hour or day). Fort Collins leaders anticipate these improvements would provide increased warning time when flooding potential exists within or near the city boundaries.

Lands adjacent to Fort Collins in northwest Larimer County experience problems with structures obstructing the flowpath of the historical stormwater runoff. Recently, Larimer County proposed to develop a series of new conveyance facilities to help mitigate damages in the West Vine Drainage basin caused by the 100-year flood (Larimer County 1998a). These structural mitigation activities would include constructing a new stormwater outlet pipe to relieve ponding in portions of this basin, elevating two homes

to the level of the 100-year flood, and establishing a grass-lined drainage channel to convey stormwater to a new detention pond. In addition, other flood mitigation improvements have been proposed to further reduce inundation in the West Vine Drainage basin, including purchasing additional drainage easements and constructing larger detention ponds.

4.6.10 Special Circumstances

Several unanticipated events occurred during the 1997 flooding in Fort Collins, inhibiting rescue attempts and causing greater damage than was expected. At approximately 11:00 p.m. on July 28, the dirt plug that filled a 10 feet x 13 feet box culvert underneath the railroad embankment failed (NOAA 1997a). This failure was caused by pressure created by the large ponded flood waters stored upstream of the railroad embankment. Flood waters rushed into the rear of the mobile home parks, and their swift velocities hampered rescue efforts. Not until three mobile homes lifted off their foundations, floated downstream, and obstructed the flow path at the College Avenue bridge did the strong flow of water diminish and allow rescue attempts in the area.

In addition to the rushing waters created by the plug failure, the railroad embankment failure caused a train to derail near the mobile home parks. Four cars from a north-bound Burlington Northern freight train left the tracks and slid down the east side of the embankment. Approximately 1 minute before the derailment, another hazard developed during rescue attempts when a natural gas explosion occurred at Johnny's Liquor, located just north of the mobile home parks next to Spring Creek. The natural gas leak caused additional problems when a few of the mobile homes caught fire (City of Fort Collins 1998a).

Another problem was the bureaucratic nuance that exists between the City of Fort Collins and Colorado State University related to stormwater management and emergency response within the city. Each entity is responsible for stormwater management and flood mitigation measures on its own property, and Colorado State University has developed flood mitigation measures to minimize flood problems that occur as a result of heavy precipitation that falls on campus. However, in the July 1997 flood, flood waters from city-owned land near West Elizabeth Street flowed onto the Colorado State University campus and compounded the problems the university was already experiencing from the rain that fell locally.

4.7 Lincoln County

4.7.1 Study Area

Localized floods and damage to agricultural lands occurred in Lincoln County as a result of severe thunderstorms from early June through early August of 1997. The major structural damages occurred to roads, culverts and bridges in unincorporated areas of central and southern Lincoln County as a result of successive, intense precipitation events. These storms occurred both within Lincoln County itself and upstream in Elbert County to the west on July 27, 28, and 29, 1997. Additional significant storms occurred in central Lincoln County on June 9 and 10, and in southern Lincoln County on August 4 and 5, 1997.

The storms of early June occurred primarily at Genoa, Hugo, and to the southeast along Big Sandy Creek and its tributaries in east-central Lincoln County. Major storms followed in late July. These were centered over the Big Sandy watershed immediately northwest of Limon and in the headwaters of the Middle and South Forks of Rush Creek in extreme southeastern Elbert County and south central Lincoln County. Additional storms occurred approximately a week later in the Horse Creek region near Karval on August 4 and 5.

Lincoln County is in east-central Colorado (see ***Figure 1.1-1***). Located approximately 90 miles southeast of Denver, the Town of Hugo is the county seat. The county is located on the high plains and consists dominantly of steep to nearly level grasslands. Elevations range from approximately 5,700 feet along the western edge of the county to approximately 4,600 feet along on the southeastern boundary. The mean annual precipitation is approximately 12 inches.

The towns of Limon, Hugo, and Arriba have populations of 1,830, 660, and 220 people, respectively. Other community centers in Lincoln County consist of Shaw in the extreme north, Genoa in the central part of the county, and Karval in the southern portion. The major land use in the county is agriculture–ranching and wheat farming occur extensively. ***Figure 4.7-1*** is a general map of the county.

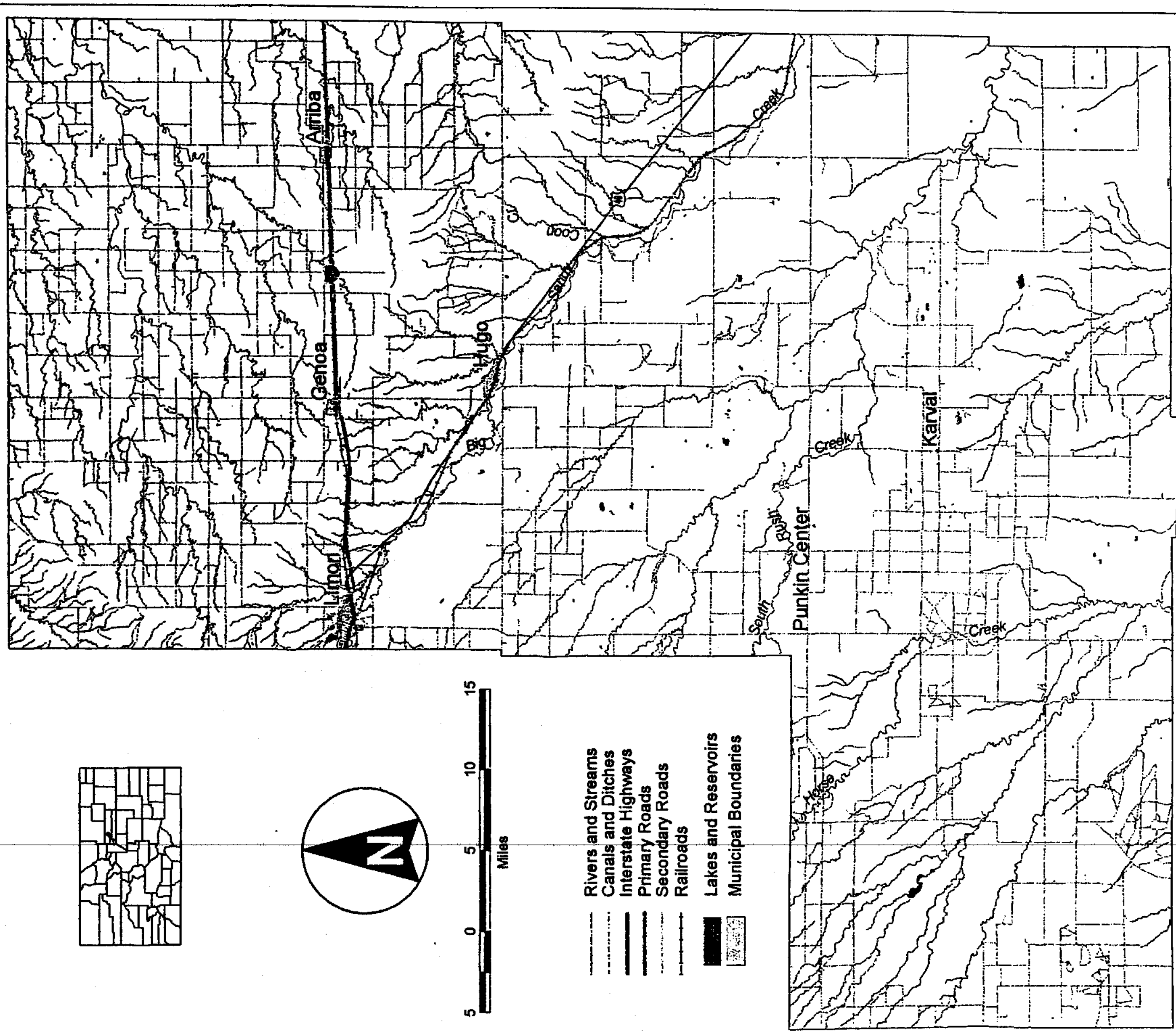
4.7.2 Watershed Description

The major drainages in Lincoln County include the Big Sandy watershed draining to the east and south through the central part of the county, the Arikaree River drainage in the north, and the Horse Creek and Rush Creek watersheds in the south. Horse Creek flows generally southward to join the Arkansas River near Las Animas, Colorado. Rush Creek joins Big Sandy Creek approximately 35 miles to the southeast, just north of where Big Sandy

Figure 4.7-1

Lincoln County

Vicinity Map



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Creek itself joins the Arkansas River near Lamar, Colorado. All of these streams have well-defined channels.

A USGS streamgage is located on Big Sandy Creek just upstream of the Arkansas River approximately 65 miles from the Lincoln County line. No gages occur on the streams within Lincoln County. Although all of these drainages extend through Lincoln County, their headwaters and additional contributing watersheds occur in southern Elbert County or northeastern El Paso County to the west. Intensive thunderstorm activity in the Big Sandy and Rush Creek headwaters during the last few days of July contributed to high streamflows in Lincoln County.

4.7.3 Local Flooding Problems

The primary stream in Lincoln County that historically has experienced flooding problems is Big Sandy Creek. Major damages from flooding typically are to county roads, related road drainage structures, and agricultural lands.

Floods on Big Sandy Creek tributaries at Limon are attenuated by three dams immediately north of town.

4.7.4 Storm Characteristics

Thunderstorms are common occurrences in east-central Colorado during the summer months. In 1997, major thunderstorms occurred in the Lincoln County area in early June, the last week of July, and the first week of August. During these periods, portions of Lincoln County experienced significant amounts of precipitation, as shown in ***Table 4.7-1***. The storms of late July were particularly severe, in part because they occurred so closely together in time between July 25 and 29. Wet watershed conditions contributed to runoff from the most severe storm on July 29.

A storm system moved into central Lincoln County during early June. The nearest comprehensive meteorological data for the storms in the Lincoln County region are taken from a station at Limon, Colorado, along the west-central county line.

Table 4.7-2 summarizes available meteorological data for the major storm events in Lincoln County (National Climatic Data Center 1998a).

4.7.4.1 Storm Duration and Rainfall Quantities

In June, intense rain fell near Coon Creek and the Big Sandy 10 to 12 miles southeast of Hugo. No rainfall measurements are known from the area, but 4 inches are believed to have fallen in a localized event (Lincoln County Commissioners 1998). As shown in ***Table 4.7-3***, observer records indicate

that much lighter rains fell in Genoa and Hugo to the northwest (Dreier 1997, Thaller 1997).

Table 4.7-1
Dates of Significant Precipitation in Lincoln County During the Summer of 1997

Date	Maximum Precipitation	Comments
June 9	1.5-2 inches	Hugo/Genoa area and southeast
June 10	1.5-2 inches	Hugo/Genoa area and southeast
July 27	3.5-8 inches	Near River Bend - reports vary
July 27	1-1.5 inches	In Hugo and Limon
July 28	2-3.5 inches; 2 inches	In Rush Creek area, and approximately 15 miles south of Limon
July 29	4.5-6 inches	In Rush Creek area
July 29	4.4 inches	Immediately south of Limon
August 4-5	1-2 inches	Hugo and southeast of Hugo
August 5	2 inches	Karval area

Table 4.7-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from north)
Limon, CO	6/8	54	69	24.38	56	53	14.5	14
Limon, CO	6/9	50	61	24.51	52	51	13.5	12
Limon, CO	6/10	49	68	24.51	54	52	13.7	15
Limon, CO	7/27	60	90	24.54	54	57	8.6	340
Limon, CO	7/28	58	77	24.66	78	61	9.3	100
Limon, CO	7/29	59	79	24.64	76	61	14.4	150
Limon, CO	7/30	60	83	24.62	68	61	13.9	160
Limon, CO	8/4	60	82	24.76	64	58	9.8	100
Limon, CO	8/5	--	--	24.68	--	--	--	--
Limon, CO	8/6	55	69	24.68	78	55	8.8	40

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C) (Linsley et al. 1992)

Source: National Climatic Data Center 1998a

Intense localized storms formed over Lincoln County on July 25, 27, 28, and 29, 1997 (see ***Table 4.7-4***). The events on the 25th through the 28th produced significant rainfall amounts by themselves, but more importantly, they created high moisture conditions over several watershed areas prior to events on July 29. Areas notably affected were along Big Sandy Creek and Middle and South Rush Creek.

Table 4.7-3
Point Rainfall Amounts Recorded in
Central Lincoln County for June 9 - 10, 1997

Source	Location	Amount	Recording Period
NOAA/NWS (1997c)	Genoa	1.71 inches	6/9, times unknown
NOAA/NWS (1997c)	Genoa	1.13 inches	6/10, times unknown
NOAA/NWS (1997c)	Hugo	1.73 inches	6/10/97 @ midnight to 4:00 a.m.

Table 4.7-4
Point Rainfall Amounts Recorded in
Lincoln County for July 29 - 30, 1997

Source	Location	Amount	Recording Period
NOAA/NWS (1997c)	Just south of Limon	4.79 inches	7/29 @ 9:00 p.m. to 7/30 @ 6:30 a.m.
Ashcraft (1997)	Northwest of Punkin Center	6 inches	7/29 @ 7:30 p.m. to 11:00 p.m. (approx.)
Atwater (1998)	Northwest of Punkin Center	4.5 inches	7/29 @ 7:30 p.m. to 11:00 p.m. (approx.)
Dennis Stone (1997)	North of Punkin Center	4.0 inches	7/29 @ 7:30 p.m. to 11:00 p.m. (approx.)
Rain (1997)	North of Punkin Center	5+ inches	7/29 @ 7:30 p.m. to 11:00 p.m. (approx.)
NOAA/NWS (1997c)	Karval	1.89 inches	7/29 @-7:00 p.m. to 7/30 @ 2:30 a.m.
NOAA/NWS (1997c)	Rush (22 miles west of Punkin Center)	2.63 inches	7/30, times unknown

CWCB rainfall bucket surveys in the area indicate that approximately 3.5 inches fell in the River Bend area of extreme eastern Elbert County on July 27. Rainfall reports in Limon varied from 1.5 to 3 inches for July 27, as reported by the *Eastern Colorado Plainsman* (1997). This particular storm was short, lasting an hour or so, but it produced high flows in Big Sandy Creek and its tributaries near River Bend, as well as immediately downstream in Lincoln County. In addition, strong winds damaged trees, windows, and power lines in the Limon area, and Interstate 70 was closed because of approximately 4 feet of water flowing over the highway.

On the night of July 28 - 29, radar imagery indicated that approximately 2 inches of rain fell in the Middle and South Rush Creek watersheds in the southeastern part of the county. Relatively minor flood damages were reported for the storms of July 27 - 28 in Lincoln County.

Late in the evening of July 29, extremely heavy rains fell again in the Big Sandy Creek headwaters in Elbert and northern El Paso counties. At the same time, intense rainfall occurred again in the Big Sandy watershed at Limon and on the Middle and South Rush Creek drainages along the county line. The maximum reported rainfall total in the latter area was 6 inches, with 3.5 to 5 inches more commonly reported from individual rain gages in the area (Ashcraft 1997, Atwater 1997, Hendrix 1997, Rain 1997, Stone 1997). Approximately 4.8 inches fell in the Limon area late on July 29 and during the early morning of July 30 (Hass 1997). Using NWS radar data (see Technical Addendum for radar images), a rainfall bucket survey conducted by CWCB, and reports from other observers, an isohyetal map was generated for storms along the Big Sandy and for the Rush Creek storm for the night of July 29, 1997 (see ***Figure 4.7-2***). Extensive flood damages occurred from these storms, particularly to roads and agricultural lands throughout the county.

Further discussion of storm events upstream in Elbert County on the night of July 29 is presented in Section 5.4, Elbert County Flood Documentation. These events contributed to high flows and flood damages in downstream areas of Lincoln County.

Storms in the Horse Creek area near Karval generally occurred on August 5, with additional rain falling in some locales a day or so before or later on August 6 (see ***Table 4.7-5***). Precipitation amounts of 1 to 2 inches fell across southern Lincoln County, generally in a narrow east-west band during August 5. Flooding in the Horse Creek area resulted from several closely-spaced days of rain. Observer reports along Horse Creek indicate that 0.75 inch of rain fell approximately 13 miles southwest of Karval on July 28, and 1.1 inches fell on July 29, with heavier rains in the same drainage several miles to the north also on the 29th. Horse Creek ran bankfull on July 29. An additional 1.4 inches of rain fell in a localized event lasting approximately 1 hour on August 2, and 2.5 inches fell between the night of August 4 and mid-day August 5 (Stogsdill 1997). Horse Creek reached flood stage west of Karval on that day (Taylor 1998).

4.7.4.2 Estimated Point Precipitation Return Periods

As summarized from NOAA information, the 10-year and 100-year point precipitation totals for storm durations of 6 hours, 12 hours, and 24 hours are shown below in ***Table 4.7-6*** for the Limon/Hugo area, for the Middle and South Rush Creek area, and the Karval area (NOAA 1973).

A summary of the point precipitation values for the major Lincoln County storm events of June, July, and August, 1997 is shown in ***Table 4.7-7***. The estimated recurrence interval for the Rush Creek event northwest of Punkin Center is over 100 years; over the long-term there is less than a 1 percent chance of such an event occurring in any particular year. Storms similar to

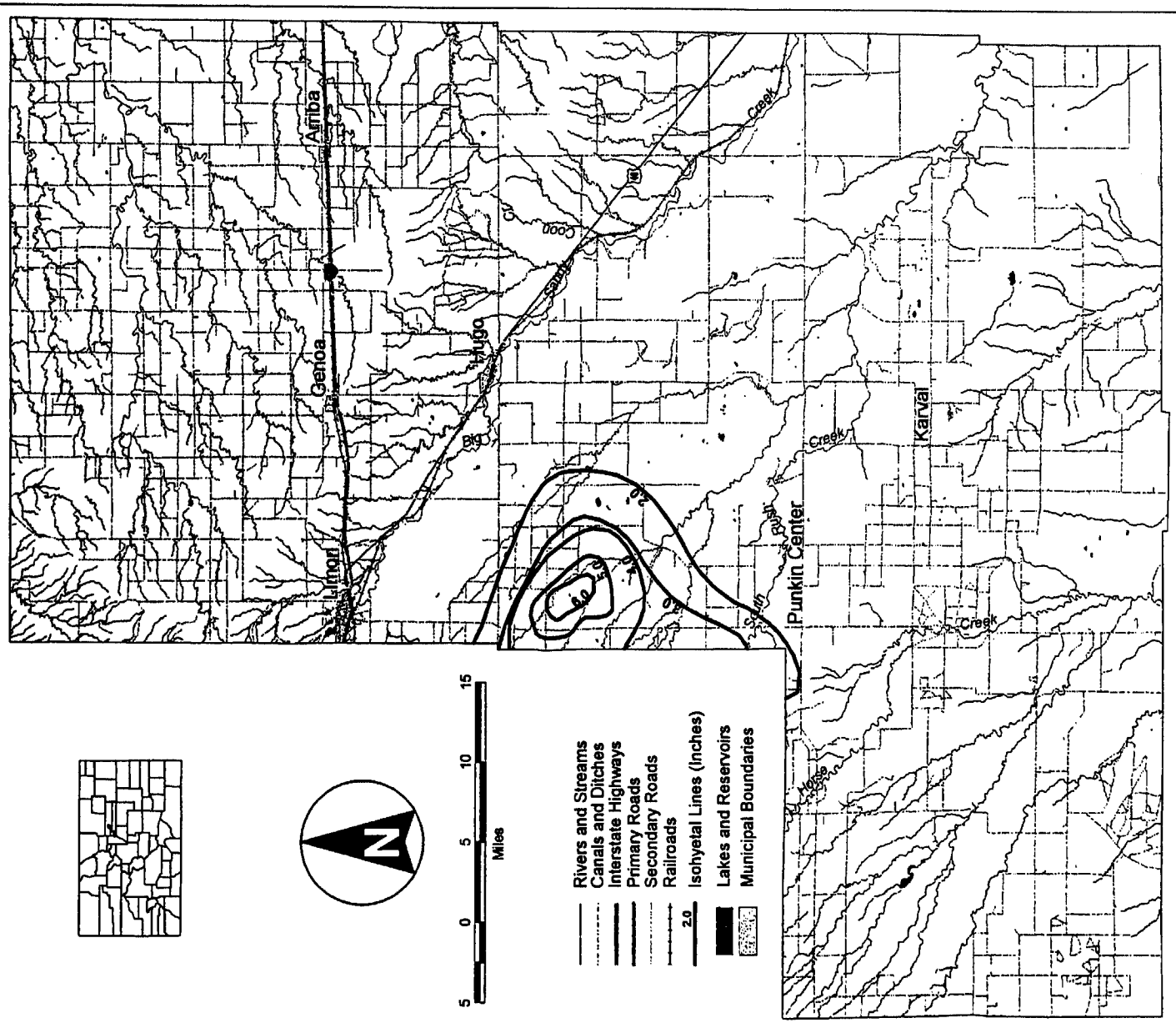

Figure 4.7-2

Lincoln County

Precipitation Map

7:18 a.m. July 29 -
6:21a.m. July 30, 1997

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the June and August events occur much more frequently in the area. The June and August events were substantially less severe than those of late July.

Table 4.7-5
Point Rainfall Amounts Recorded in Southern Lincoln County for August 4 - 5, 1997

Source	Location	Amount	Recording Period
Stogsdill (1997)	13 miles southwest of Karval	2.5 inches	8/4 @ 7:00 p.m. to 8/5 at 12:00 p.m. (approx.)
Maskus (1997)	Karval	1.8 inches	8/5 - 6, times unknown
NOAA/NWS (1997c)	Karval	1.23 inches	8/6, intermittent between 12:00 a.m and 12:00 a.m., 8/7

Table 4.7-6
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation		100-yr Precipitation	
	Limon	Karval	Limon	Karval
6 hours	2.4 inches	2.5 inches	3.6 inches	3.8 inches
12 hours	2.7 inches	2.8 inches	4.1 inches	4.2 inches
24 hours	3.0 inches	3.1 inches	4.5 inches	4.8 inches

4.7.5 Hydrology and Hydraulic Findings

4.7.5.1 Locations/Reaches of Flooded Streams

Major flooding occurred on July 28, 29, and 30 along Middle and South Rush creeks, along Big Sandy Creek, and along Horse Creek. Additional flooding occurred along North Rush Creek, Long Branch, Adobe Creek, and the East Fork of Adobe Creek (Devers 1998). North Rush Creek and Long Branch flow through the south-central part of the county, and the Adobe Creek watershed is tributary to Horse Creek in the southwestern part of the county. Particularly high flows occurred in July along South Rush Creek between Simla in Elbert County and Punkin Center (***Figure 4.7-3***). The overall watershed for the South Rush Creek site in Lincoln County extends a considerable distance into Elbert County upstream (see Section 5.4, Elbert County Flood Documentation, for additional discussion of the area). Stream levels in the channel rose and subsided swiftly according to local witnesses (Atwater 1998, Dennis Stone 1998). Flows in Big Sandy Creek were higher than normal for several days after the July 27-30 events. The storms caused the creek and its tributaries to flow during the summer season for the first time in years. The high flows temporarily caused Interstate 70 to be closed

(*Eastern Colorado Plainsman* 1997). Throughout the county, numerous other channels contained high flow rates relative to normal conditions in late July.

Table 4.7-7
Summary of Storm Precipitation, Duration, and Return Period for Lincoln County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
NOAA/NWS (1997c)	Genoa	June 9	1.71 inches	unknown	unknown
NOAA/NWS (1997c)	Genoa	June 10	1.13 inches	unknown	unknown
NOAA/NWS (1997c)	Hugo	June 10	1.73 inches	4 hours	5- to 10-year
NOAA/NWS (1997c)	just south of Limon	July 29	4.40 inches	10 hours	>100-year
Ashcraft (1997)	Northwest of Punkin Center	July 29	6 inches	3.5 hours (approx.)	>100-year
Atwater (1997)	Northwest of Punkin Center	July 29	4.5 inches	3.5 hours (approx.)	>100-year
Dennis Stone (1998)	North of Punkin Center	July 29	4.0 inches	3.5 hours (approx.)	>100-year
Rain (1997)	North of Punkin Center	July 29	5+ inches	3.5 hours (approx.)	>100-year
NOAA/NWS (1997c)	Karval	July 29-30	1.89 inches	8 hours	2-year (approx.)
NOAA/NWS (1997c)	Rush (22 miles west of Punkin Center)	July 29-30	2.63 inches	unknown	unknown
Stogsdill (1997)	13 miles southwest of Karval	August 4,5	2.5 inches	16 hours (approx.)	<2-year
Maskus (1997)	Karval	August 5,6	1.8 inches	unknown	unknown
NOAA/NWS (1997c)	Karval	August 6	1.23 inches	24 hours	<2-year

Flooding also occurred southeast of Hugo at Coon Creek during early June. Road drainage structures were washed out along Highway 40 in the area. In early August, additional flooding occurred along Horse Creek and its Adobe Creek tributaries west of Karval because of sequential storms there. Damage to roads, culverts, and pastures occurred as a result.

4.7.5.2 Channel Characteristics

Natural channels in Lincoln County drain undeveloped rangelands and croplands planted to grains (generally wheat). Because of the storm and flooding characteristics, an RTi flood documentation team visited South

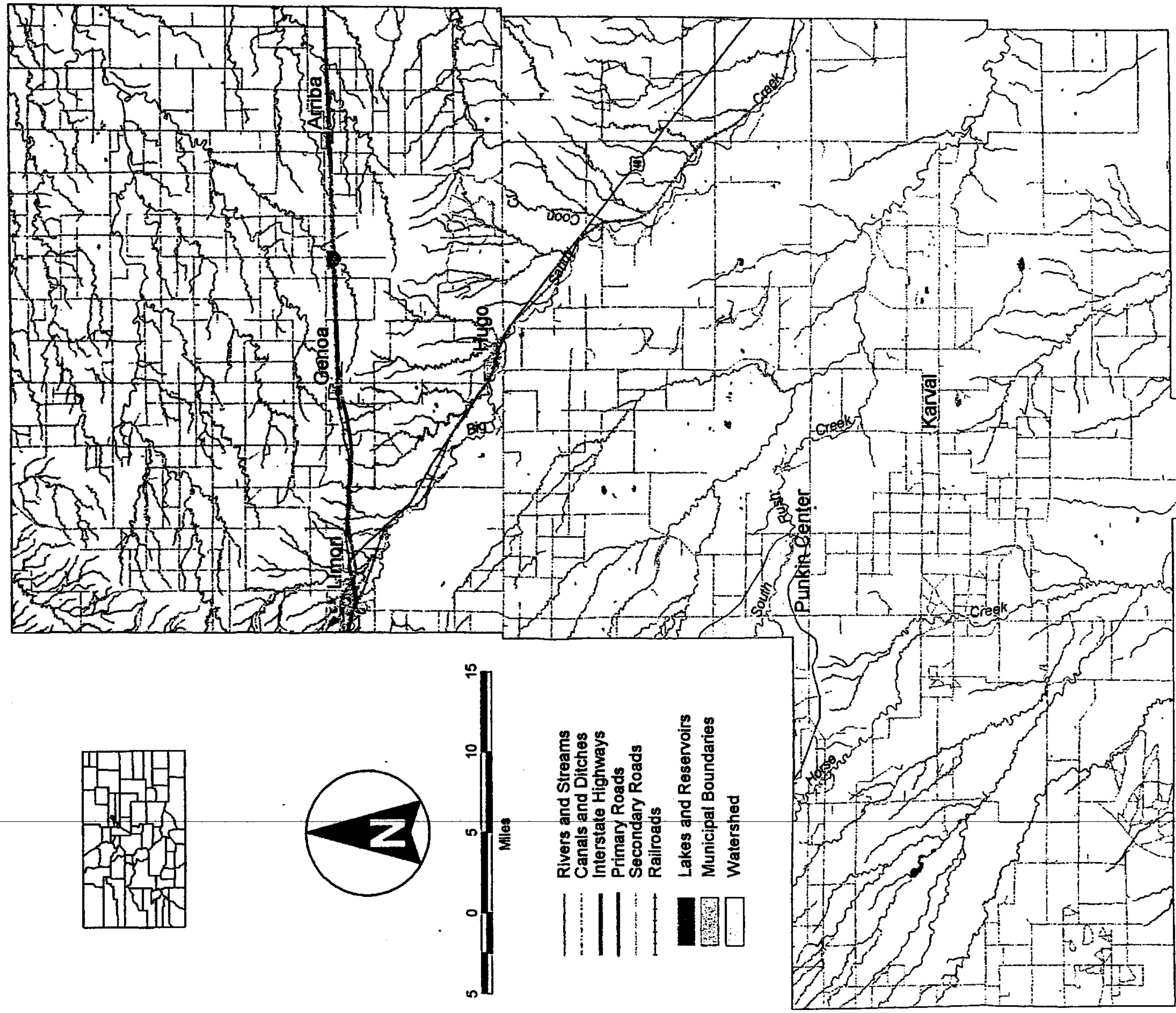

Figure 4.7-3

Lincoln County

Affected Watershed

Riverside Technology, inc

Rush Creek in order to investigate conditions in that particular flood-damaged area. The stream generally has a sandy to silty bed, and flows in a broadly meandering channel within a wide floodplain. Shortgrass prairie vegetation dominates the site, with a few small cottonwoods scattered along the streamcourse. The stream flows generally eastward and is crossed by a north-south county road bridge. The roadfill is elevated above the floodplain, particularly along the approach to the bridge from the south.

4.7.5.3 Peak Flows and Estimated Return Periods

Runoff from the July 29 storm caused South Rush Creek to overflow its banks in the southwestern part of the county. Four miles east of Punkin Center, the rising flood and the accompanying debris extended approximately 1,000 feet across the floodplain as flows broke out of the channel at a bend. A large amount of flood debris, mostly cottonwood logs and branches, was carried in the flow and left at the outer margins of the flood. At its maximum height, the stage in South Rush Creek rose approximately 10 feet above its normal level. Rangelands along the creek were flooded, and fences and the county road were washed out as the floodplain flow passed downstream through a low spot across the road south of the bridge.

Substantial scour and erosion occurred at the county road bridge. The bridge approach from the south (***Figure 4.7-4***) was washed out, with the most substantial damage to the road embankment occurring where overbank flows returned to the channel at the bridge. This water flowed along the upstream side of the road fill on the south approach and created a deep cut along the road fill and at the abutment. The guardrails were left suspended in the air. The flow depth was higher than the low steel on the bridge deck to the south, but was below the low steel on the north where the bridge deck is somewhat higher on the approach through a road cut in the hillside (***Figure 4.7-5***) (Monks 1998). Scour also occurred at the bridge piers, but the total depth of scour could not be identified. An RTi flood documentation team visited this area after the road and bridge approach had been reconstructed and reinforced. Pier footings were generally buried at the time of the survey.

The team surveyed the channel, noted high water marks, and measured channel slope. Flood debris lines were well evident at the location at the time of the site visit. The peak discharge was then estimated using Manning's equation under the assumption of steady to gradually varied flow. The computed peak discharge for the site is presented in ***Table 4.7-8***. A range of flow is presented because of the uncertainties in estimating peak discharge. The watershed area for the affected stream is shown in ***Figure 4.7-3***.

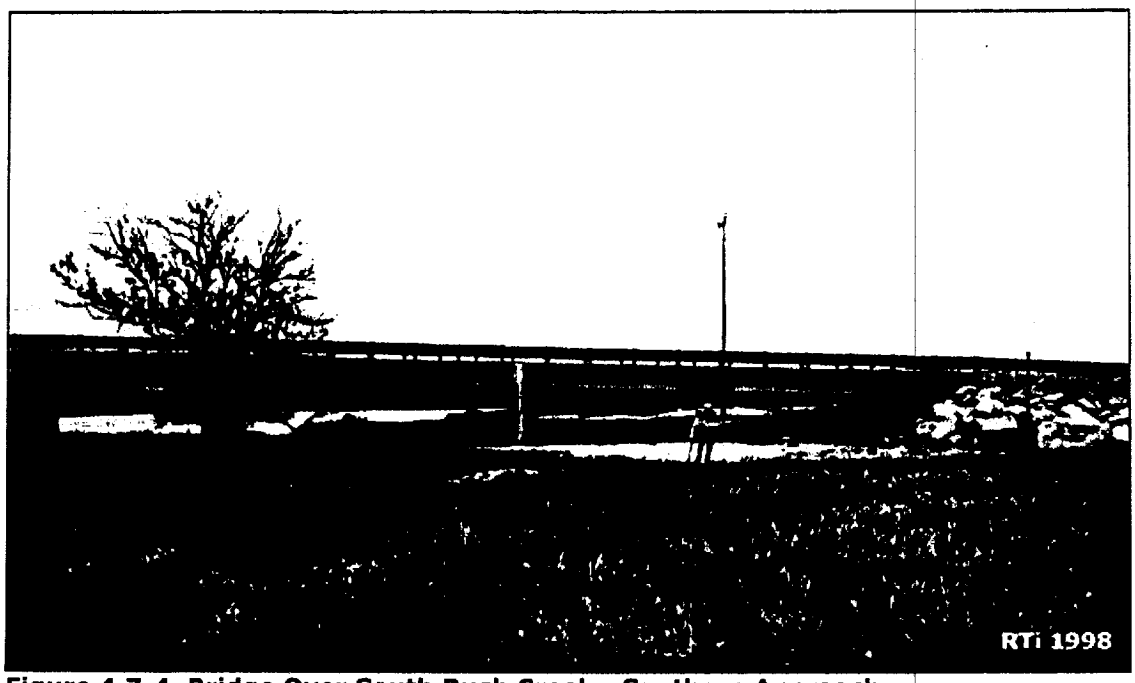

Figure 4.7-4 Bridge Over South Rush Creek - Southern Approach

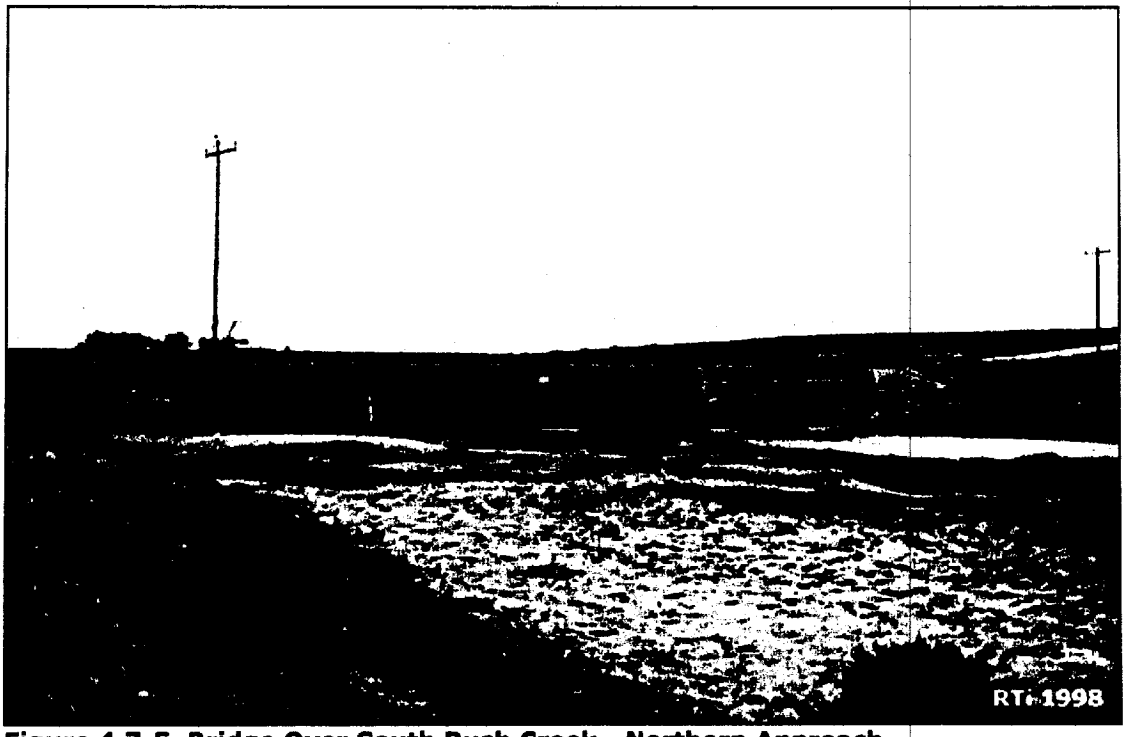

Figure 4.7-5 Bridge Over South Rush Creek - Northern Approach

Table 4.7-8
Computed Peak Discharge for the South Rush Creek
Storm of July 29, 1997

Location	Drainage Area (square miles)	Estimated Peak Flow (cfs)	Estimated 100-year Peak Flow[1] (cfs)
South Rush Creek four miles east of Punkin Center	181	13,000 to 15,000	27,000

[1]Source: CWCB 1997b

4.7.5.4 Flood Hydrograph

Individuals living along South Rush Creek in Elbert County approximately 8.5 miles upstream were able to describe the events of July 29 in sufficient detail to allow a streamflow hydrograph to be estimated and related to the storm event at that site (Atwater 1998, Dennis Stone 1998). Additional data describing the events in Elbert County are presented in Section 5.4. From this information, the site inspection, and subsequent calculations, a generalized flood hydrograph is presented for the bridge location in Lincoln County (*Figure 4.7-6*). It is known that South Rush Creek rose in Lincoln County during the night of July 29 - 30, and occupied the entire width of the floodplain there at daybreak on July 30 (Williams 1998).

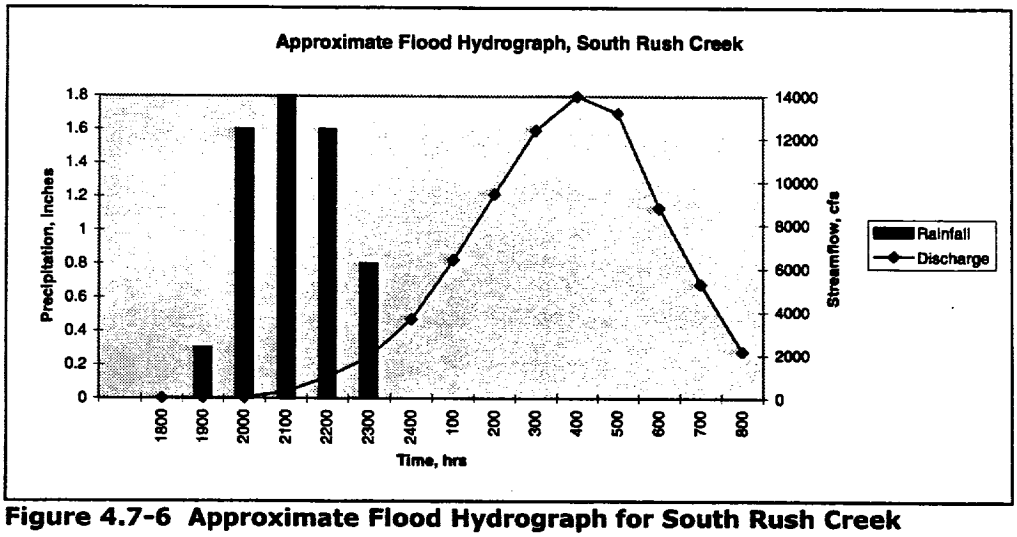

Figure 4.7-6 Approximate Flood Hydrograph for South Rush Creek

The storm itself was relatively short when compared to the 6- to 24-hour events for which data are published. Rains were fairly steady throughout the storm's approximately 3.5-hour duration, which began at approximately 7:30 p.m. The storm cell was concentrated heavily in the watersheds of Middle and South Rush creeks, but lighter rains fell over a wider area to the south and west along Mustang Creek and Antelope Creek. Runoff from these areas contributed to the flooding in Lincoln County, but most of the flow originated in the Rush Creek tributaries to the north.

Upstream in Elbert County, South Rush Creek had risen significantly (the flow width was approximately one-third of its peak width) within 3 hours from the onset of precipitation. The flood peaked in Elbert County approximately 5.5 hours after the start of precipitation (approximately 1:00 a.m.), and the height of flow had returned to near-normal levels within approximately 12 hours after the start of precipitation.

No observed flood or storm chronology is available for the site. It is likely that the flood peaked in Lincoln County 2 to 4 hours after it did in Elbert County. This would place the time of peak at 3:00 to 5:00 a.m., with waters still receding at daybreak when they were observed to extend across the floodplain (Williams 1998).

4.7.6 Specific Flooded or Inundated Areas

No areas of long-term flooding or inundation are documented for Lincoln County. Most of the flooding that did occur was limited to the immediate proximity of stream channels that rose up out their banks on the nights of July 28, 29, and 30. High waters in these areas typically receded rapidly. Flatter pastures or areas of obstructed drainage were inundated for a longer time, but detailed descriptions of these occurrences were not available for the county in general. Short-term flooding did occur in pastures along Big Sandy Creek near Hugo and at South Rush Creek immediately after the storm events of late July, and along Horse Creek in early August. *Figure 4.7-7* shows the flooding along Horse Creek west of Karval.

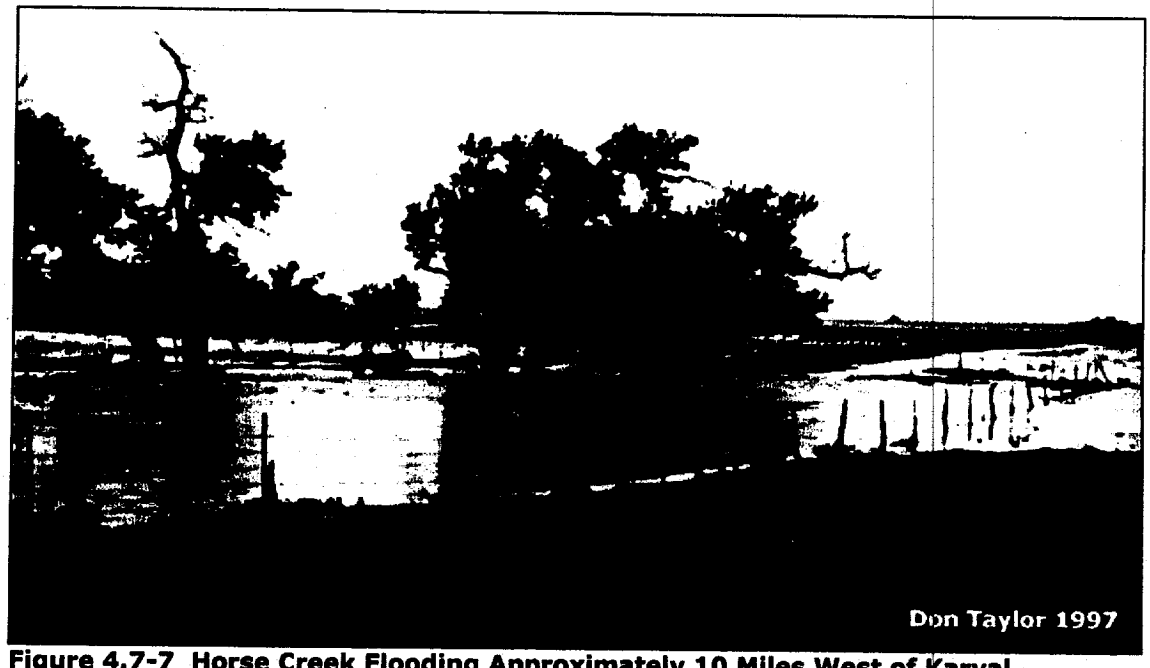

Figure 4.7-7 Horse Creek Flooding Approximately 10 Miles West of Karval

4.7.7 Emergency Response Effort

Emergency responses were carried out by the Lincoln County Sheriff's Office, the county road department, and by numerous individuals under their own initiatives. Since most of the structural damage occurred to county roads, typical emergency responses consisted of barricading, monitoring, or otherwise marking road washouts to the extent that materials and personnel for these activities were available. Repairs of these sites continued for months after the damages occurred.

4.7.8 1997 Flood Damage

Within Lincoln County itself, the major storm damages to structures occurred in the Big Sandy watershed in June and July, and along South Rush Creek on July 29 and 30, 1997. Additional damages occurred throughout the county, mostly to roads. Flooding caused road washouts and damaged or destroyed road drainage structures (dominantly culverts). Some basements were flooded in the Limon area, and a water main was washed out approximately 6 miles west of Limon. Areas of major flood damages are shown in ***Figure 4.7-8***.

Damage costs to road surfaces and related road structures are shown in ***Table 4.7-9***. No dollar estimates of agricultural losses are available.

Table 4.7-9
Damage Estimates From the July 29, 1997, Storm Event

Description	Damage Estimate	Source
Culverts, bridges, and road surfaces	$112,510[1]	Lincoln County Commissioners' Office (1998)
Dwellings and private structures	No figures available	
Agricultural crops and features	No dollar cost estimated	USDA - Farm Services Agency (Fritzler 1998)
FEMA	$69,522[2]	FEMA Damage Survey Reports (1998)

[1]Value is unofficial; it is a best estimate at the time of the study.
[2]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

Preliminary agricultural damages were estimated for Lincoln County for the crop-damaging storms of June and July, 1997, as shown in ***Table 4.7-10***. Several of these events were hailstorms not related to major flooding.

Figure 4.7-8

Lincoln County

Damage Areas

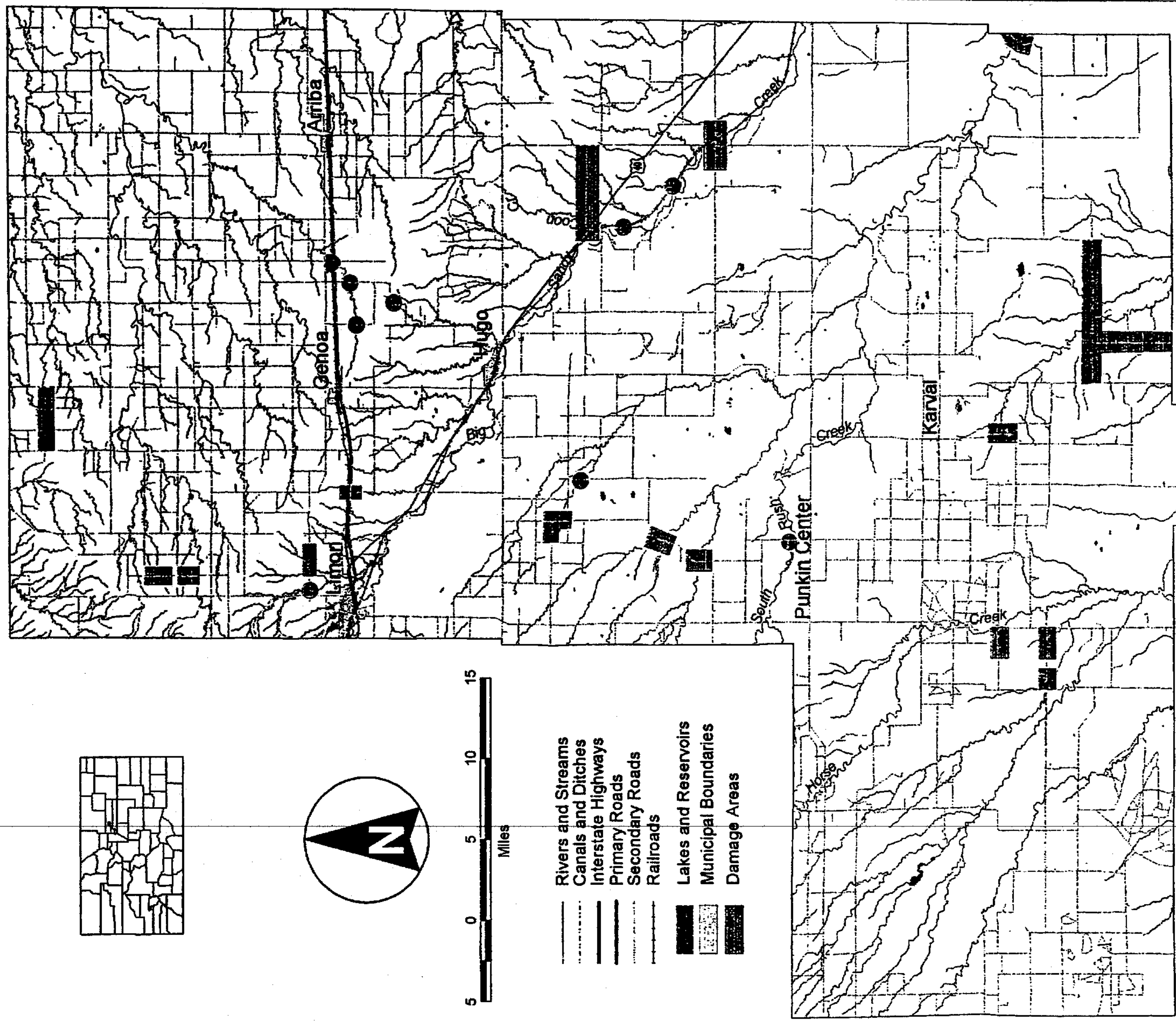

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Table 4.7-10
Unofficial Crop Damages Associated With the 1997 Storm Events

Date	Crop	Affected Acres	Percent Loss
June 13, 1997	Wheat	2,668	85
June 24, 1997	Wheat	4,000	60
	Millet	500	75
July 26-29, 1997	Millet	400	50
	Proso	400	50
	Sunflowers	160	80
	Native pasture	1,000	60
	Hay	100	40

Source: Fritzler 1998

4.7.9 Flood Hazard Mitigation

No specific future flood mitigation projects have been identified in Lincoln County as a result of the 1997 summer storms. Maintenance schedules for road structures and flood control dams in the county are ongoing, as they were previous to these events. Scour at bridge piers and abutments was not investigated for this document, but may be of concern for some locations in the county. Regular inspections and a program of reviewing historical designs for adequacy could be of benefit if bridge scour concerns exist.

4.7.10 Special Circumstances

In general, all of the streams in Lincoln County can experience flooding where they are crossed by county or state roads. The bridge at South Rush Creek generally was sized well for the event on July 29. Other bridges in the county may be somewhat undersized. The design criteria for bridge and culvert crossings was not investigated for this document. Structurally, bridges generally performed well during the high flows of the 1997 flood season.

4.8 Logan County

4.8.1 Study Area

From May through June of 1997, Logan County was subject to a series of storms that produced significant rainfall causing substantial damage to homes, businesses, crops, and infrastructure in the county. Both incorporated and unincorporated areas were affected by flooding, including the communities of Sterling and Atwater.

Logan County is located in northeastern Colorado (see ***Figure 1.1-1***). The City of Sterling, the county seat, is approximately 125 miles northeast of Denver, 120 miles east of Fort Collins and 126 miles southeast of Cheyenne, Wyoming. ***Figure 4.8-1*** displays a map of the county. Sterling is the largest community in Logan County, with a population of approximately 11,000 (1995 estimate). The total population within Logan County is approximately 19,000 (1995 estimate) (Icon Engineering, Inc. and CWCB 1998).

The climate in the Sterling area primarily is affected by northwestern winds (FEMA 1989a). For this town, the average annual precipitation is 19 inches, while the average annual snowfall is 39.4 inches. The mean annual temperature is 48.6°F, and the average annual number of clear days is 299. The topography of Sterling consists of high rolling plains.

4.8.2 Watershed Description

The watershed of interest in Logan County is the Pawnee Creek basin, which is within the South Platte River basin (see ***Figure 4.8-2***). Pawnee Creek is a left bank tributary to the South Platte River and drains an approximately 700-square-mile area. The watershed is located in extreme northeast Colorado mainly within Logan and Weld counties. The mouth of Pawnee Creek is located approximately 5 miles southwest of Sterling and approximately 1 mile northeast of Atwood in Logan County. The watershed elevation ranges from approximately 3,980 feet to 5,400 feet. The Pawnee Buttes in the upper reaches of the basin are the predominant topographic features within the basin. The soils in the basin are mostly loams and clay loams, with sandstone, shale, and siltstone outcroppings. Land use consists of open range land with some winter wheat and a significant amount of irrigated cropland in the lower part of the basin. The mean annual precipitation for the basin ranges from 14 to 16 inches. The major tributary streams in the Pawnee Creek watershed are listed below:

- Raymer Creek
- South Pawnee Creek
- Wildhorse Creek
- North Pawnee Creek

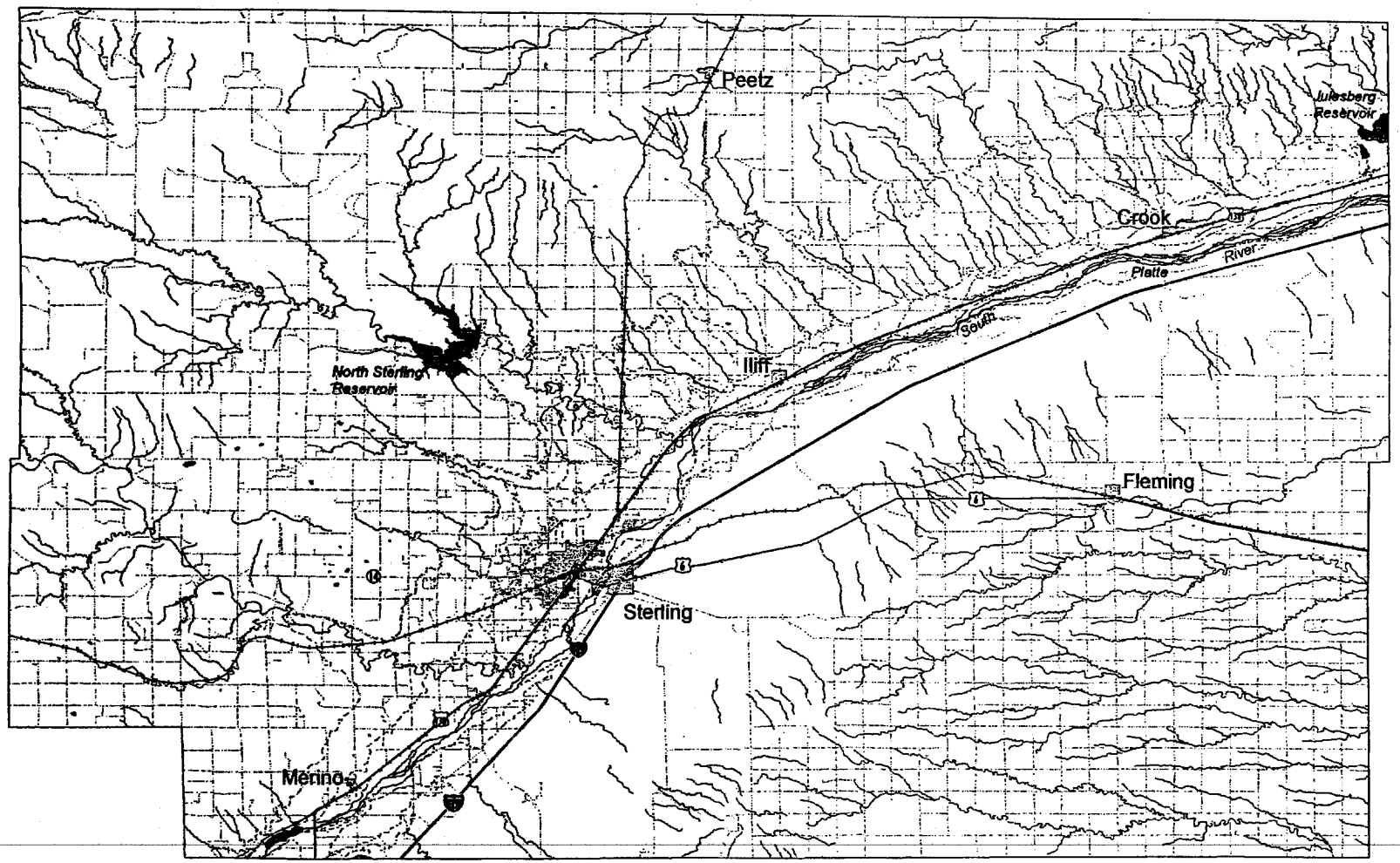
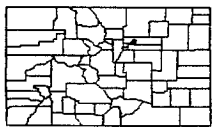


Figure 4.8-1

Logan County

Vicinity Map



Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries

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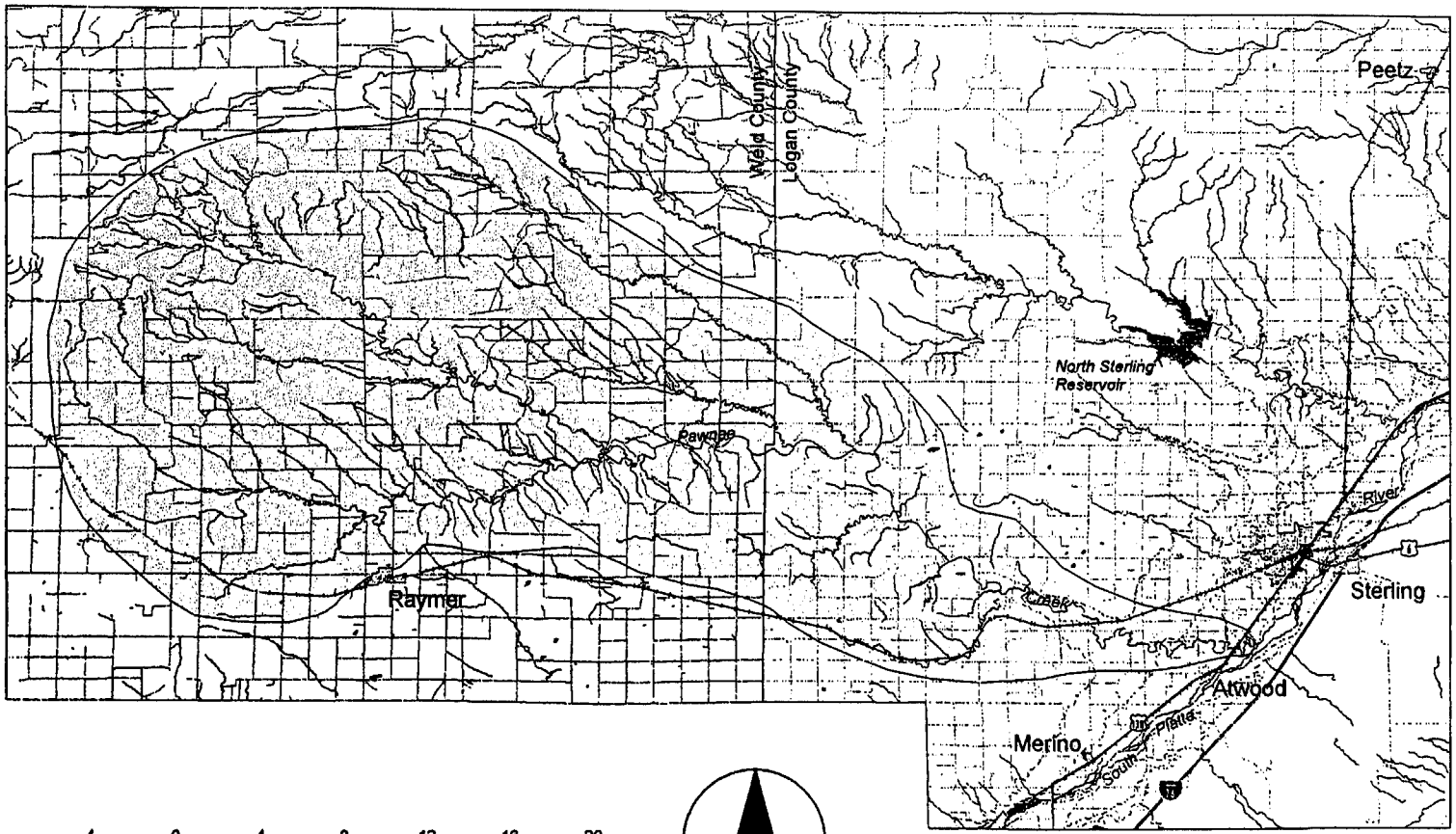
5 0 5 10 15 20
Miles

Figure 4.8-2

Logan County

Affected Watershed



Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries
Affected Watershed

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- Igo Creek
- Cottonwood Creek
- Horsetail Creek
- Spring Creek

4.8.3 Local Flooding Problems

Flooding on Pawnee Creek can occur as a result of general rains over large areas or from local thunderstorms over smaller areas. A significant flood event on Pawnee Creek occurred on June 14/15, 1965. As a result of this event, a peak flow estimate of 35,200 cfs was indirectly measured at the Colorado Highway 14 bridge approximately 10 miles upstream from Atwood. During the 1965 event, overflows from Pawnee Creek flooded areas on the west side of Sterling and did not affect the residential and business (downtown) areas on the east side of the city. The 1965 flood event was preceded by another large flood event in May of 1935. Discharge estimates for the 1935 event are not readily available. Pawnee overflows during several flood events, including those in 1935, 1965, and 1997, were diverted into Sterling via manmade features that transect the natural stream channel and floodplain areas. During high water events on the Pawnee, flood overflows are directed away from the natural drainage path toward Sterling by the existing Highway 6 and the railroad embankments.

Flooding problems in Sterling also are caused by overflows from Sand Creek and the Pioneer Drainage Ditch. Floodwaters from the South Platte River mainstem typically have not caused serious flooding problems for Sterling.

4.8.4 Storm Characteristics

Although a number of noteworthy storms occurred during June, July, and August in northeastern Colorado (***Table 4.8-1*** summarizes the precipitation events from May through August of 1997), the primary focus here is on the July 29 through 30 storm event. Heavy rains in northeast Colorado during the week of July 28, caused significant flooding in several areas, including Fort Collins, Weldona, Atwood, and Sterling. Rainfall over the Pawnee Creek watershed on the evening of July 29 saturated agricultural/range lands and caused major storm runoff in the tributaries and main channel. Thunderstorms producing heavy localized rainfall moved across Weld, Morgan, and Logan counties on July 29 and 30, 1997. The same system of storms that caused severe flooding in Weldona moved eastward and dropped extremely heavy rains on the Pawnee watershed in eastern Weld and western Logan counties. A summary of meteorological data is presented in ***Table 4.8-2.***

Table 4.8-1
Dates of Significant Precipitation in Logan County During 1997

Date	Maximum Precipitation	Comments
May 27	1.71 inches	Sterling
June 3	1.40 inches	Sterling
June 3	1.17 inches	New Raymer
June 26	2.40 inches	Sterling
July 29	2.38 inches	New Raymer
July 30	1.90 inches	Sterling
July 30	3.60 inches	New Raymer
August 6	1.55 inches	Sterling

Table 4.8-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches of Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
Akron, CO	6/2	55	76	25.20	73	57	15.4	100
Sidney, NE	6/2	56	73	25.54	70	55	10.6	130
Akron, CO	6/25	53	82	25.37	66	56	9.6	110
Sidney, NE	6/25	49	78	25.71	70	54	9.9	100
Akron, CO	7/29	61	79	25.47	79	63	16.6	110
Akron, CO	7/30	63	85	25.44	74	65	15.0	130
Sidney, NE	7/29	62	75	25.80	84	64	17.4	140
Sidney, NE	7/30	64	79	25.80	81	66	16.2	150

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T} \right)^8$ where T = average air temperature (°C), T_d = average dew point (°C)

(Linsley et al. 1992)
Source: National Climatic Data Center 1998a

4.8.4.1 Storm Duration and Rainfall Quantities

Point rainfall amounts of up to 15 inches in a 9-hour period were reported in the central watershed area of Pawnee Creek for the thunderstorm that traversed Weld and Logan counties on the evening of July 29 and into the early morning hours of July 30.

A rainfall bucket survey, which included areas within Logan County and eastern Weld County, was performed by a CWCB flood documentation team. Numerous ranchers, farmers, irrigators, and homeowners also were solicited via door-to-door and telephone contacts. Nearly 100 point rainfall amounts were collected and processed for this storm. A map showing the precipitation isohyets for the Pawnee Creek event, which is based on the

rainfall bucket survey, is shown in *Figure 4.8-3*. The NWS radar estimates of the precipitation for this storm confirmed its location, areal extent, and intensity. Cumulative rainfall information for the July 29 through 30 area of maximum rainfall is shown in *Table 4.8-3*.

Table 4.8.3
Cumulative Rainfall Recorded in Logan County for July 29-30, 1997

Date	Cumulative Rainfall	Recording Period
7/29/97	0.1 inch	6:08 p.m.
7/29/97	2.0 inches	7:08 p.m.
7/29/97	4.0 inches	8:07 p.m.
7/29/97	5.8 inches	9:00 p.m.
7/29/97	8.5 inches	10:00 p.m.
7/29/97	10.2 inches	10:58 p.m.
7/29/97	11.5 inches	11:58 p.m.
7/30/97	12.6 inches	12:57 a.m.
7/30/97	13.4 inches	1:59 a.m.
7/30/97	14.0 inches	2:58 a.m.
7/30/97	14.0 inches	4:00 a.m.

Source: NOAA/NWS 1997c

A rainfall verification study for the Pawnee Creek storm event, which is outside of the scope of this report, is being conducted by the Department of Atmospheric Science, Colorado Climate Center in Fort Collins, Colorado. Results from that study will be available in August of 1998.

4.8.4.2 Estimated Point Precipitation Return Periods

The point precipitation totals for Pawnee Creek for storm durations of 6 hours, 12 hours, and 24 hours for 10-year and 100-year return periods (as developed from the NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado [1973]) are shown in *Table 4.8-4.*

Table 4.8-4
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation	100-yr Precipitation
6 hours	2.3 inches	3.4 inches
12 hours	2.6 inches	3.8 inches
24 hours	2.8 inches	4.1 inches

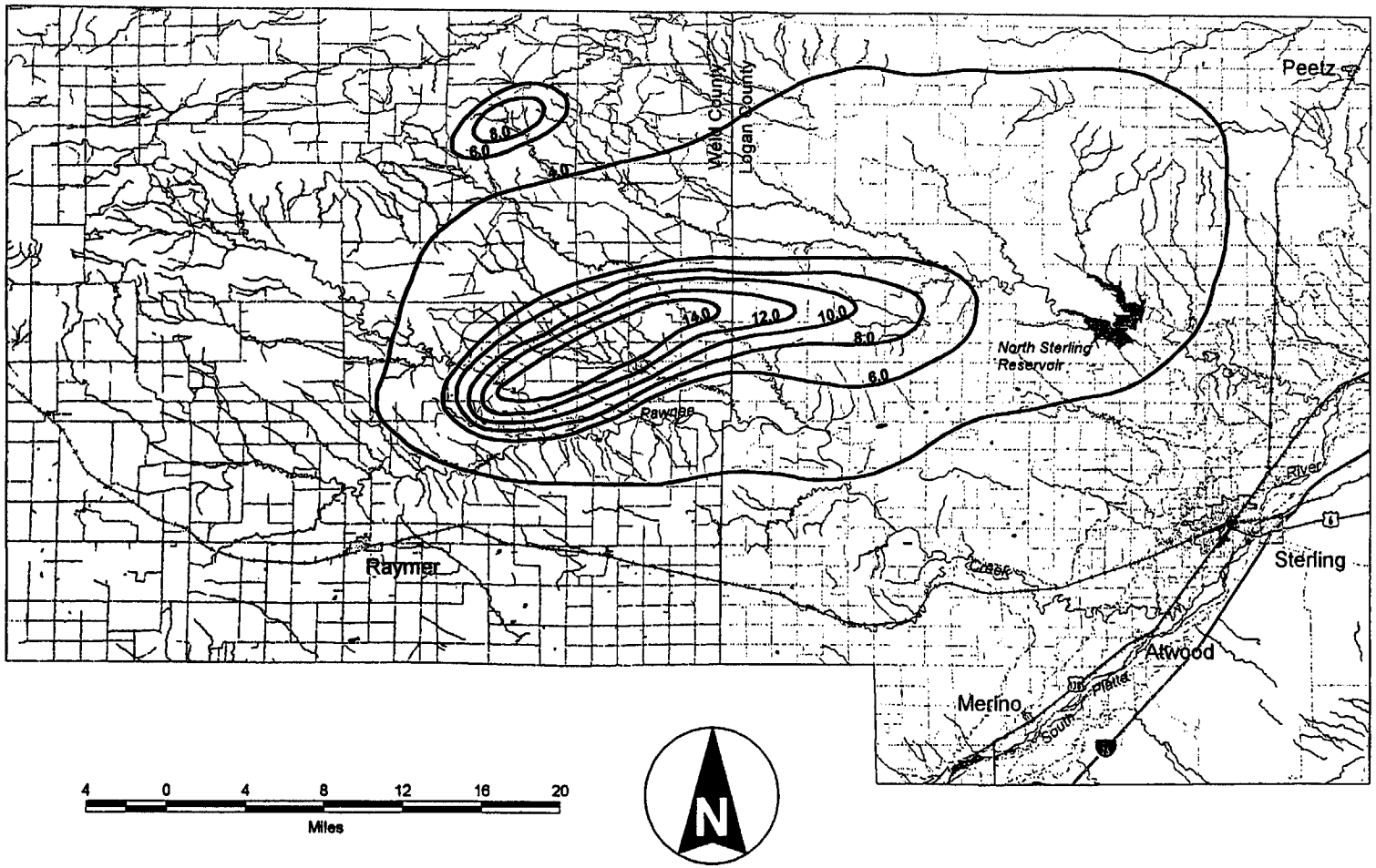
A summary of the point precipitation for the Logan County storm event of July 29 through 30, 1997, is shown in *Table 4.8-5*.

Figure 4.8-3

Logan County

Precipitation Map

6:00 p.m. July 29 -
3:00 a.m. July 30, 1997



- Rivers and Streams
- Canals and Ditches
- Interstate Highways
- Primary Roads
- Secondary Roads
- Railroads
- 4.0 Isohyetal Lines (Inches)
- Lakes and Reservoirs
- Municipal Boundaries

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Table 4.8-5
Summary of Storm Precipitation, Duration, and Return Period for Logan County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
Mountain States Weather Services (1997)	Sterling	July 29-30	2.1 inches	9 hours	< 100-year
CWCB (1997a)	Weld County 10 miles north of Stoneham	July 29-30	14+ inches	9 hours	> 500-year
NOAA/NWS (1997c)	Weld County 10 miles north of Stoneham	July 29-30	12+ inches	9 hours	> 500-year

4.8.5 Hydrology and Hydraulic Findings

4.8.5.1 Locations/Reaches of Flooded Streams

A description of the locations and reaches of the flooded streams within Logan County is presented for the storm of July 29 through 30, 1997. The centroid of the large rainstorm was located just east of the Logan-Weld county line approximately 10 miles north of Stoneham and several miles southeast of the Pawnee Buttes. Because of the size of the Pawnee Creek drainage basin, a large percentage of the rain fell in Weld County, but the runoff mainly affected downstream land areas within Logan County.

Several tributary watersheds experienced extremely rare rainfall amounts that caused record flow rates in their streams. For example, the Colorado Highway 71 bridge over Cottonwood Creek, which was just east of the storm centroid, was substantially damaged during the flood. That structure had to be replaced completely by CDOT (Colorado Department of Transportation) after the flood.

Upstream of Colorado Highway 14, floodwaters were mainly contained in the relatively narrow floodplain (approximately 1,000 feet wide) of the Pawnee mainstem. During the late evening of July 29 and the early morning of July 30, a tractor-trailer driver became stranded on the Highway 14 bridge over Pawnee Creek. Floodwaters from the creek inundated the overbank areas and overtopped the bridge by several feet. After an unsuccessful attempt at crossing the flooded highway and bridge, the truck driver spent the night in his vehicle as waters rose to the doors of the tractor. The driver was rescued on the morning of July 30.

Downstream of Highway 14, floodwaters spread out significantly in some areas with floodplain widths of more than a mile. A number of county roads and bridges were completely inundated by deep and swift moving floodwaters as the flood wave moved toward Atwood. Many acres of irrigated cropland were inundated by highwater, and an unspecified number of acres of crops were destroyed.

Once the floodwater reached the embankments and the undersized bridges at Highway 6 and the railroad, overflows had nowhere else to go except toward the City of Sterling. Floodwaters in Atwood resulted from overflows at the highway/bridge constriction and from out-of-bank flows that broke out of the Pawnee Creek main channel several miles north of that community.

4.8.5.2 Channel Characteristics

The natural low flow channel of lower Pawnee Creek is a meandering, intermittently flowing stream with a sand bed and vegetated side slopes. The width of the channel varies from a few feet to a few tens of feet, with average depths of less than 5 feet. Several locations along the main channel have experienced erosional forces that have created high, steep banks along the outsides of bends. The overbanks (floodplain areas) of the lower Pawnee Creek are shallow and extremely wide for the most part. Floodplain widths of up to 2 miles or more exist in the lower watershed.

The Pawnee Overflow is almost an entirely manmade feature because of the highway and railroad embankments that generally run parallel to the South Platte River. The manmade embankments cause overbank flows from the mainstem to pond up and flow toward the northeast into the City of Sterling. The Pawnee Overflow path occurs on the north side of the highway/railroad embankments through irrigated farmlands, pasture, and sparsely developed areas.

4.8.5.3 Peak Flows and Estimated Flood Return Periods

In order to estimate peak discharges at various stream and overflow locations, a flood documentation team identified cross section locations, flagged high water marks, and field surveyed channel and overflow cross sections for the Pawnee Creek flooded areas. A private surveying company, which was under contract with the City of Sterling, surveyed several cross sections that were located and marked by the flood documentation team. Data from the field surveys was transmitted to the CWCB and forwarded to the COE (Omaha District) for review and analysis.

The Pawnee Overflow into Sterling was based on survey data taken perpendicular to Highway 6 and the railroad embankment near the Riverside Cemetery. The flow estimates were made by using indirect flow

measurement techniques. The resulting discharge estimates are presented in *Table 4.8-6*.

Table 4.8-6
Computed Peak Discharge Estimates for Pawnee Creek and Pawnee Overflow for the Storm Events of July 30-31, 1997

Location	Estimated Peak Flow (cfs)	Estimated 100-yr Peak Flow (cfs)
Total Pawnee Overflow into Sterling just northeast of the Riverside Cemetery	3,800[1,2]	5,000[3]
Portion of Pawnee Overflow into Sterling between the Riverside Cemetery and the railroad embankment	2,500[1]	N/A
Pawnee Creek mainstem of Highway 14	65,000[1,3]	12,200[2]
Pawnee Creek mainstem at County Road 25	50,000[4]	11,400[2]

[1]Source: CWCB 1997b.
[2]Assumes that the Sterling No. 1 ditch was full prior to Pawnee Overflow peak discharge.
[3]Source: U.S. Department of Agriculture, Soil Conservation Service 1992.
[4]Value is less than the upstream value because of valley storage and flow attenuation.

In general, this was a very significant flood event. The peak flow estimate on the Pawnee Creek mainstem above Colorado Highway 14 is significantly higher than the 1965 peak flow estimate. An eyewitness account from one landowner (located along the left bank of the creek approximately 1,500 feet upstream of Highway 14) substantiated the 1997 high water mark at approximately 5 feet above the 1965 high water mark (Lindstrom 1997). Another landowner downstream of Highway 14 estimated that the 1997 peak flow rate was at least 50 percent higher than the 1965 peak flow rate (Amen 1997).

Flow widths for the surveyed cross sections across the Pawnee Creek floodplain ranged from approximately 1,600 feet at the upstream end to several thousand feet at the downstream end. The flow depth in the confined channel at the upstream cross section was just over 11 feet, while the flow depth closer to Atwood was much more wide and shallow, with depths on the order of 4 feet.

4.8.5.4 Flood Hydrograph

Flood waters in the Pawnee Creek floodplain crested in Atwood at approximately 3 p.m. on July 30. Flood waters from the Pawnee Overflow first reached the south side of Sterling at approximately 4 p.m., and then crested in the downtown area around midnight on July 30th.

A landowner who witnessed the entire flood flow on the Pawnee Creek mainstem several miles upstream of Atwood (and downstream of Colorado Highway 14), was able to assist with re-creating an approximate flood hydrograph (Amen 1997). The hydrograph is shown in ***Figure 4.8-4***. The flood hydrograph for downtown Sterling was significantly different from the mainstem hydrograph because of the characteristics of the Pawnee Overflow versus the Pawnee mainstem flow, respectively. Compared to the mainstem hdyrograph, the downtown Sterling hydrograph had a much lower peak discharge, occurred nearly 12 hours later, lasted longer, and was much more flat.

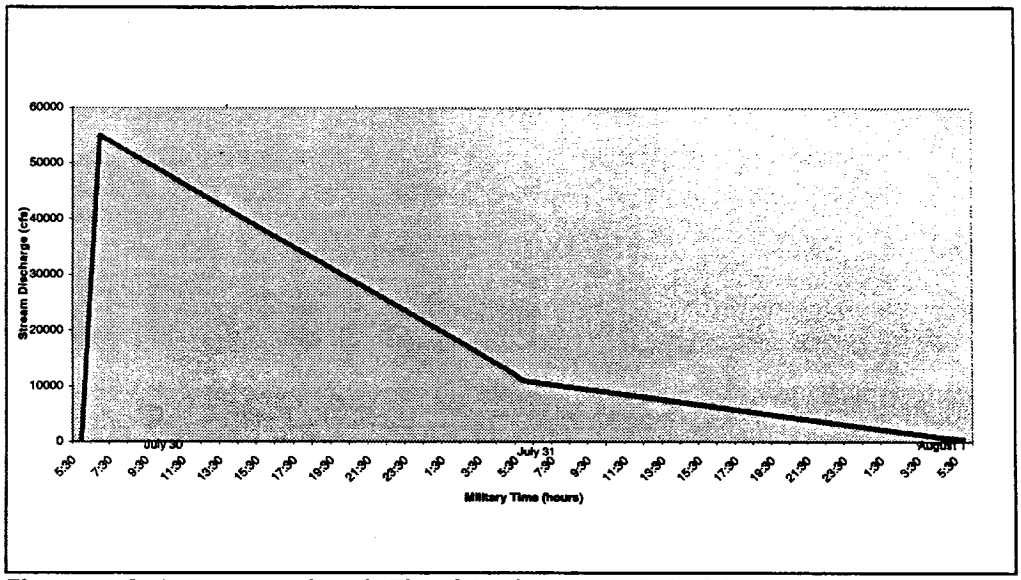


Figure 4.8-4 Pawnee Creek Flood Hydrograph July 30 - August 1, 1997, Logan County

4.8.6 Specific Flooded or Inundated Areas

A detailed description of specific flooded or inundated areas is presented only for the communities of Atwood and Sterling as a result of the July 29 through 30 flood event. Limited information is available regarding flooded areas during other storms or for other portions of Logan County.

Most of the homes and other buildings in Atwood were inundated by floodwaters when Pawnee Creek overflowed its banks and backed up behind Highway 6 and the railroad embankments (see ***Figures 4.8-5*** and ***4.8-6***). Although Atwood is approximately 2 miles away from the Pawnee

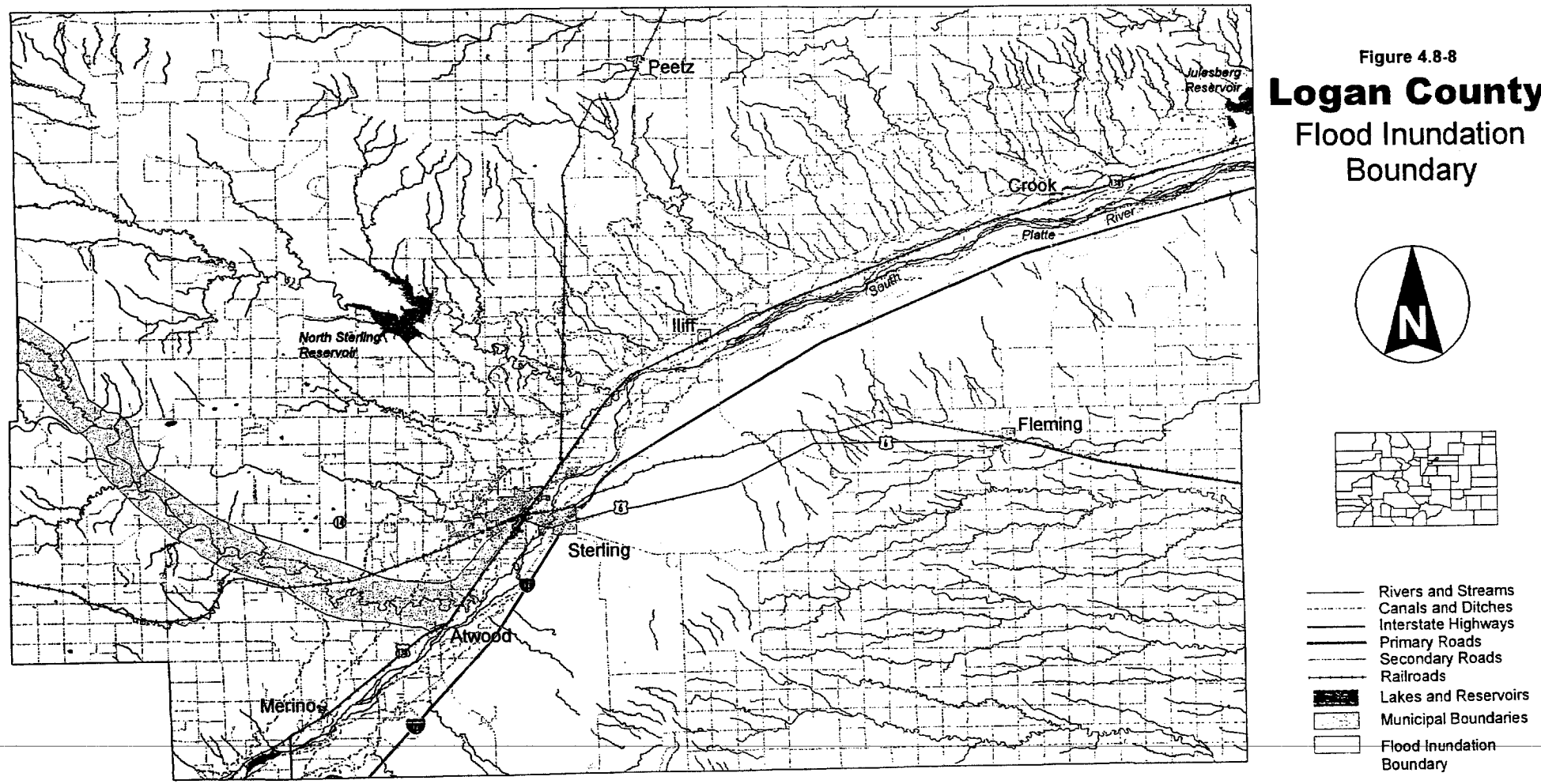


Figure 4.8-8

Logan County

Flood Inundation Boundary

Riverside Technology, inc.

CWCB staff documented the flooding in cooperation with the U.S. Army Corps of Engineers (Omaha District) and the CSU Extension Office in Logan County. The majority of the field work for the flood documentation occurred on August 5 through 7, 1997, with additional field work during several site visits thereafter.

4.8.8 1997 Flood Damage

Floodwaters from Pawnee Creek and the Pawnee Overflow damaged or destroyed homes, businesses, utilities, bridges, highway and railroad embankments, county roads, crops and farmland, irrigation facilities, streambanks, vegetation, and vehicles. Northeastern Junior College, located near the north end of the city, experienced significant flood damage estimated at $2,000,000. Preliminary damage figures for the Sterling area were estimated to be in the range of $10,000,000. ***Table 4.8-7*** summarizes the 1997 damage costs.

Table 4.8-7
Damage Estimates From the June 15, 1997, Storm Event

Description	Damage Estimate	Source
Total damage to private and public structures and facilities in Sterling (not including crop damage)	$10,000,000[1,2]	CWCB (1997d) Kiolbasa (1997)
Damage to railroad tracks, ballast, and embankments	$100,000[1,2]	Heanan (1998)
FEMA - countywide	$812,307[3]	FEMA Damage Survey Reports (1998a)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance vary among counties.

4.8.9 Flood Hazard Mitigation

The CWCB, Logan County, and a private consulting firm submitted a Hazard Mitigation 404 Grant Program Application to FEMA as a result of the 1997 Presidential Disaster Declaration for the County. This grant application included a feasibility study with a recommended structural plan for mitigating future flood losses in Sterling, Atwood, and unincorporated portions of the county.

A summary of components for the recommended structural mitigation plan is provided below. A detailed description of the plan is available in the application (CWCB et al., [Logan County] 1998).

Sterling/Logan County Recommended Mitigation Components for the lower Pawnee Creek and Pawnee Overflow into Sterling.

- Construction of diversion berms near the Riverside Cemetery (south side of Sterling)
- Construction of new box culverts under the railroad near the Riverside Cemetery
- Construction of a new channel from the railroad culverts downstream to the South Platte River
- Widening of the Highway 6 bridges over the Pawnee Creek mainstem
- Construction of new box culverts under the railroad embankment at the community of Atwood
- Channel cleaning and debris removal on the mainstem upstream of the Highway 6 bridges

Prior to the publication of this report, FEMA granted preliminary approval of the proposed mitigation project. Local, state, and federal officials will continue their efforts to move forward with a mitigation project for Sterling and Logan County.

4.8.10 Special Circumstances

The City of Sterling lies approximately 4 miles northeast of the confluence of Pawnee Creek and the South Platte River. The community of Atwood lies approximately 1.5 miles to the southwest of the confluence. The Atwood area is located near the natural floodplain of Pawnee Creek, but Sterling is not. Flood flows from Pawnee Creek into Sterling are mainly caused by manmade obstructions. The U.S. Highway 6 embankment and the railroad embankment run parallel to each other along the west side of the South Platte River. These two embankments act as diversion structures because flood flows on the Pawnee are not entirely able to pass directly to the South Platte River through the existing bridges or over the embankments. When flow in the Pawnee is high enough, a portion of the flow is diverted to Sterling along the northwest side of the highway and railroad embankments. This situation is known as the Pawnee Overflow. The Pawnee Overflow followed this course in 1935, 1965, and 1997. The estimated overflow in 1965 was 5,000 cfs, while the estimated overflow in 1997 was 3,800 cfs.

Existing FEMA floodplain mapping for Sterling indicates that overflow from Pawnee Creek will reach the south side of Sterling and then turn and flow generally in the direction of the Sterling No. 1 ditch (northwesterly direction). This floodplain alignment mainly affects the west side of Sterling. The assumptions used for the existing FEMA floodplain study are based on documentation and observations of the actual flood event of 1965.

During the 1997 flood event, however, the Pawnee Overflow continued along the highway and railroad embankments in a northeasterly direction. The flow did not turn and follow the alignment of the Sterling No. 1 ditch as it did in 1965. During the 1997 event, most of the residential and commercial areas in the eastern part of Sterling were affected by floodwaters. The impacted area included downtown and the central business district. As a general observation, the flooded portion of Sterling in 1997 was generally mapped in the FEMA 500-year floodplain, while the unflooded portion of Sterling was generally mapped in the FEMA 100-year floodplain. There are some qualitative explanations as to why the 1965 flooded areas (and the FEMA floodplain areas) are different from the flooded areas of July 1997. The possible explanations are summarized below.

- Since 1965, development has occurred on the south side of Sterling that has changed the topography and the local drainage patterns.

- The 1965 flood occurred in mid-June when the row crops were not mature. The 1997 flood occurred at the end of July when crops (i.e., corn stalks) were mature and quite tall. Hundreds of acres of mature corn fields south and west of Sterling acted as flow barriers. Debris, hay, and other materials were caught in the corn fields, thus attenuating the Pawnee Overflow as it approached Sterling. The 1997 Pawnee Overflow into Sterling may have involved a higher discharge had the flood happened earlier in the growing season.

- The spoil berm and ground elevations along the right bank (north bank) of the Sterling No. 1 ditch may have been different in 1997 versus 1965. Specifically, the reach of the ditch that is just west of Highway 6 and north of the Riverside Cemetery was significantly overtopped in the 1997 flood event. This allowed the Pawnee Overflow to continue in a northeasterly direction.

- Individual irrigation dikes and other manmade irrigation features on private farmlands may have diverted the Pawnee Overflow in directions that were different from the 1965 flow path.

- The Pawnee Creek flood hydrograph in 1965 contained a high volume of water over a long duration. The 1997 flood hydrograph involved a lower volume of water with a higher peak discharge over a shorter duration.

The differences in the Pawnee Creek flood hydrographs may have caused the Pawnee Overflow to behave differently in 1965 than in 1997.

The quantitative effects of the above factors have not been analyzed. More detailed analyses would need to be performed in order to determine the quantitative effects of each of the factors. Another factor that influenced the location of flooded areas in Sterling was an emergency berm that was constructed along the right bank of the Sterling No. 1 ditch just north of Iris Drive. This berm was constructed to protect certain homes located to the north of Iris Drive. Flow in the ditch was diverted in a northerly direction toward the Pioneer drainage ditch. The Pioneer drainage ditch had sufficient capacity to handle the increased/diverted flow; however, undersized culverts at a roadway crossing (or abandoned railroad crossing) caused the ditch to spill over its banks. This spilling caused shallow sheet flooding in the adjacent neighborhood.

4.9 Morgan County

4.9.1 Study Area

From June through August of 1997, Morgan County received heavy precipitation, and parts of the county sustained considerable flood damage. The county is located in northeastern Colorado (see ***Figure 1.1-1***). Both unincorporated areas and incorporated communities were affected by the flooding, especially the communities of Weldona, Fort Morgan, and Hillrose.

Weldona is approximately 80 miles northeast of Denver and 12 miles northwest of Ft. Morgan (see ***Figure 4.9-1***). Weldona's population is approximately 150, while the population of Fort Morgan is approximately 15,000 (CWCB 1998a). On July 30, 1997, homes and businesses in Weldona were seriously damaged as a result of the runoff generated in Schaefer Draw, an unnamed tributary adjacent to Schaefer Draw, and from a breach of two irrigation ditches that transect the watershed. The flooding experienced in Weldona on July 30 was the most significant event in Morgan County during the 1997 flood season (CWCB 1998a). The majority of the flood documentation for Morgan County summarizes this event. Other significant events in Morgan County for the 1997 flood season are discussed in the storm characteristics section.

Land use consists of agricultural, ranching, and open range land. The mean annual precipitation for the area ranges from 13 to 14 inches (CWCB 1998a).

4.9.2 Watershed Description

The watersheds of primary interest includes Schaefer Draw and an unnamed watershed adjacent to Schaefer Draw. These watersheds are left bank tributaries to the South Platte River and drain approximately 14 square miles. The community of Weldona is located approximately 0.5 mile north of the main channel of the South Platte River. The topography near Weldona is relatively flat with watershed elevations ranging from 4,350 feet at Weldona to approximately 4,500 feet in the upper portions of Schaefer Draw (CWCB 1998a). ***Figure 4.9-2*** shows the watersheds and surrounding study area.

Three small irrigation reservoirs are located in Schaefer Draw. The largest reservoir has a storage capacity of approximately 70 acre-feet, while the other two reservoirs have less capacity. The dams were built by private individuals primarily for irrigation supply and, to a lesser extent, for flood control (CWCB 1998a).

Two irrigation canals, the Riverside Canal and the Weldon Valley Ditch, run parallel to the South Platte River and transect the Schaefer Draw watershed causing a man-made obstruction to the natural flow path. The Riverside Canal is located approximately 1.5 miles north of Weldona and is the first

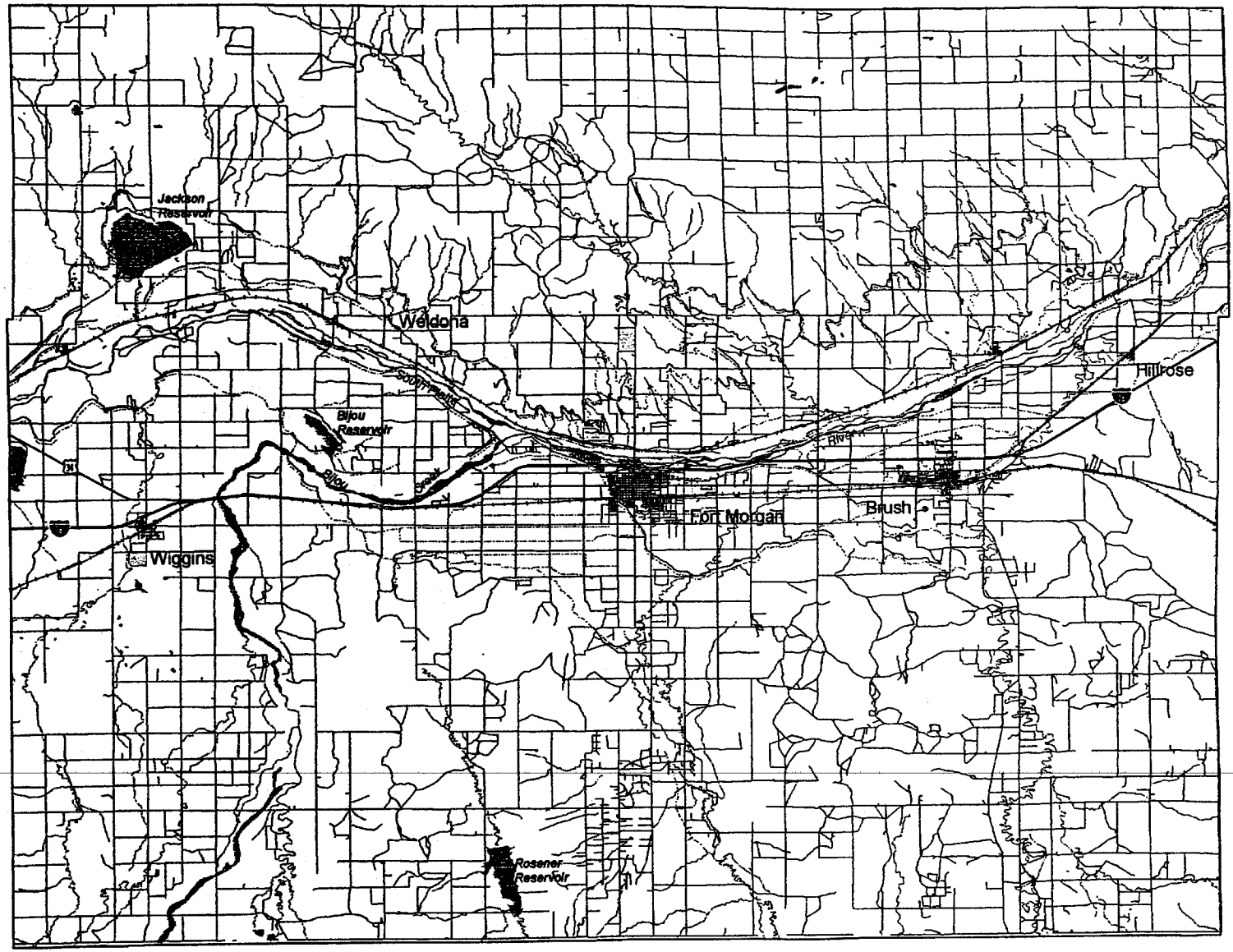
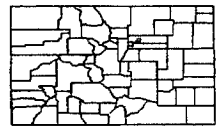


Figure 4.9-1

Morgan County

Vicinity Map



Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries

2 0 2 4 6 8 10

Miles

Riverside Technology, inc.

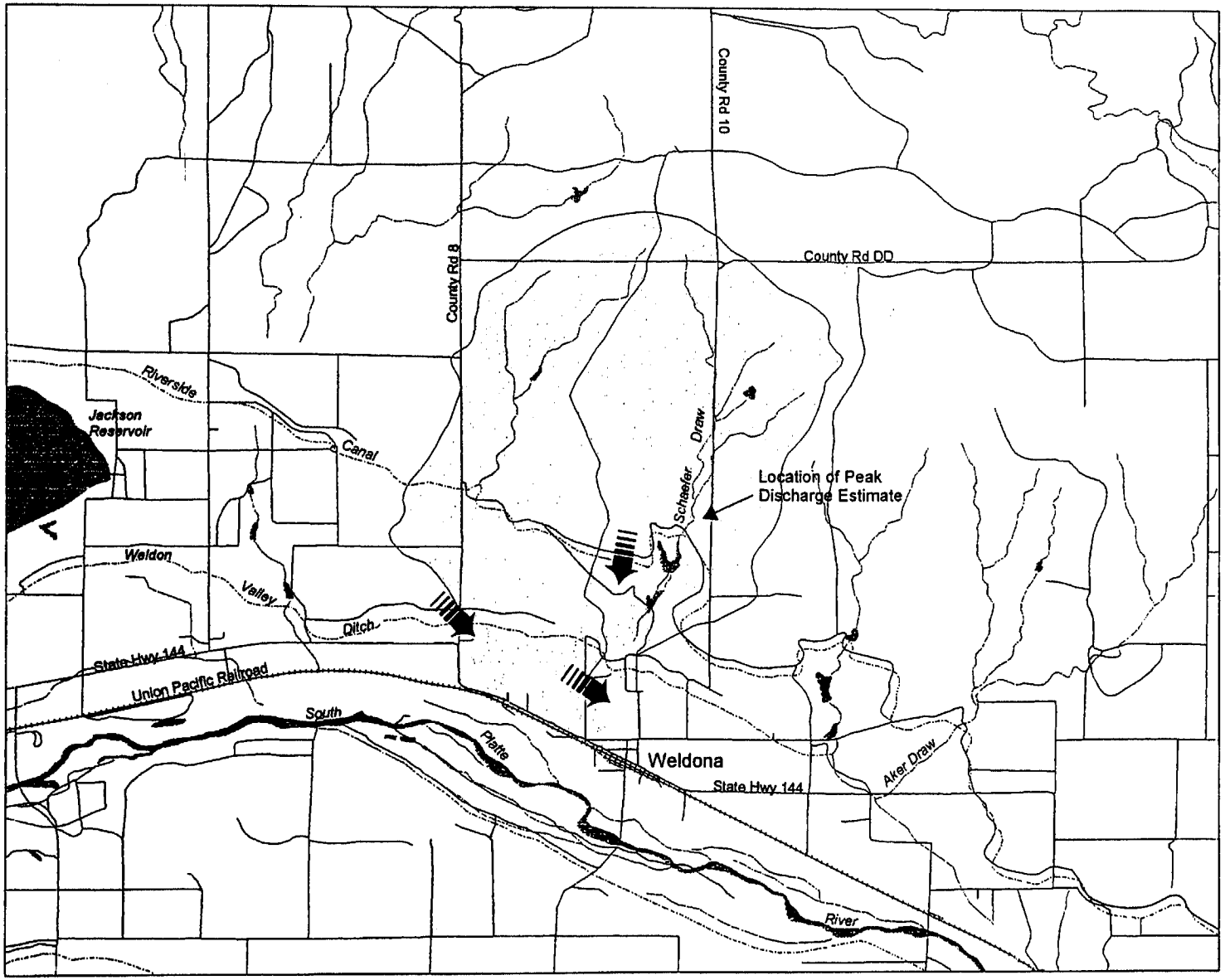


Figure 4.9-2

Morgan County

Affected Watershed

Schaefer Draw Watershed near Weldona

- Rivers and Streams
- Canals and Ditches
- Primary Roads
- Secondary Roads
- Railroads
- Lakes and Reservoirs
- Municipal Boundaries
- Schaefer Draw Watershed
- Direction of Flood Flow

N

1 0 1 2 3

Miles

Riverside Technology, inc.

man-made structure encountered by water traveling from the upper reaches of Schaefer Draw (CWCB 1998a) (see ***Figure 4.9-2***). There are no overpass flumes or culverts that allow Schaefer flows to get past the ditches. Colorado State Highway 144 and a railroad embankment also run parallel to the South Platte River and form the southern boundary of the watershed. This study focuses on Schaefer Draw (including the adjacent watershed and irrigation ditches) down to its confluence with the South Platte River.

A second watershed of interest is Wildcat Creek. This watershed also is a left bank tributary to the South Platte River and drains approximately 136 square miles. The community of Fort Morgan is located south of the watershed, and its confluence with the South Platte River is approximately 7 miles east of Fort Morgan (CWCB 1998a).

Two irrigation canals running parallel to the South Platte River transect the Wildcat drainage. These canals are the Riverside Canal and the Deuel and Snyder Canal.

4.9.3 Local Flooding Problems

Tributaries in Morgan County, including Schaefer Draw, Wildcat Creek, and Bijou Creek, typically experience nuisance flooding during the summer months.

4.9.4 Storm Characteristics

Heavy rains in northeastern Colorado, including several days of very heavy localized precipitation in June, July, and August of 1997, caused significant flooding in several areas within Morgan County. The dates of these events are enumerated in ***Table 4.9-1***.

Table 4.9-1
Dates of Significant Precipitation in Morgan County During 1997

Date	Maximum Precipitation	Comments
June 1-2	2.0 inches	Weldona
July 19	2.7 inches	North of Fort Morgan
July 29-30	10 inches	Storm centered 6.5 miles southeast of Weldona
July 31	3.0 inches	Up to 3 inches of rain between Fort Morgan and Snyder
August 3-4	3.5 inches	Hillrose

The community of Weldona experienced its first nuisance flooding of the 1997 summer on June 2, 1997, when 18 inches of water flooded parts of town.

Heavy rainfall and hail in the Weldona area resulted in flooding problems for the community.

The second significant flooding during the 1997 flood season occurred about 15 miles north of Fort Morgan as a result of runoff generated from a severe thunderstorm on July 19, 1997. Heavy rainfall in the Weldona area resulted in flooding and flash flooding problems for the community. Reports of up to 4 feet of water covering County Roads 14 and KK were received by the NWS (NOAA 1997b).

The precipitation events for July 29 through July 31, 1997, were the most significant in terms of total precipitation and damage caused by the subsequent flooding. Thunderstorms producing heavy localized rainfall moved across Weld, Elbert, Logan, and Morgan counties on July 29 and July 30. Heavy precipitation beginning the night of July 29 produced major storm runoff from Schaefer Draw and the surrounding tributaries. Severe thunderstorms developed again on the evening of July 31, causing heavy localized precipitation in Morgan County in the area between Fort Morgan and Snyder.

Thunderstorms producing heavy localized rainfall moved across northeastern Morgan County on August 3 and 4, 1997. Heavy precipitation of up to 4 inches was reported near the community of Stoneham. Several homes in Hillrose were flooded, as well as Highway 6 east of Hillrose (NOAA 1997b).

Table 4.9-2 summarizes some of the general storm characteristics for Morgan County for several dates of interest.

Table 4.9-2
Summary of Morgan County Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches of Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
Akron, CO	07/19	60	88	25.33	64	61	10.9	140
Akron, CO	07/29	61	79	25.47	79	63	16.6	110
Akron, CO	07/30	63	85	25.44	74	65	15.0	130
Akron, CO	07/31	64	85	25.42	69	64	8.0	200
Akron, CO	08/04	61	82	25.58	71	62	9.5	80
Akron, CO	08/05	57	66	25.54	93	60	11.4	90

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C) (Linsley et al. 1992)
Source: National Climatic Data Center 1998a

4.9.4.1 Storm Duration and Rainfall Quantities

The severe thunderstorm of June 1 through 2, 1997, that produced localized heavy precipitation and hail in Morgan County near the community of Weldona produced rainfall totals of approximately 2 inches for the 24-hour period extending from 7:00 a.m. on June 2 through 7:00 a.m. on June 3. The CWCB did not conduct a bucket survey for this event, but several weather observers in Morgan County collected rainfall information that is summarized in ***Table 4.9-3***.

Table 4.9-3
Point Rainfall Amounts Recorded in Morgan County
for June 2, 1997

Source	Location	Amount	Recording Period
Mountain States Weather Services (1997)	2.5 miles southwest of Fort Morgan	1.30 inches	June 2, 6:00 p.m.- June 2, 11:00 p.m.
Mountain States Weather Services (1997)	Fort Morgan	0.03 inch	June 2
Mountain States Weather Services (1997)	6 miles south of New Raymer	1.44 inches	June 2, 2:00 p.m. - June 2, 10;00 p.m.
Mountain States Weather Services (1997)	3 miles northeast of Wiggins	0.71 inch	June 2, 8:00 p.m. - June 2, 11:00 p.m.

Neither a radar estimate of total storm precipitation nor an isohyetal map were obtained for the June 2 event.

The severe thunderstorm of July 19, 1997, that produced localized heavy precipitation in northern Morgan County produced rainfall totals of more than 2.5 inches for the 24-hour period extending from 7:00 a.m. on July 19 through 7:00 a.m. on July 20. The majority of rain fell within a 2-hour period on the afternoon of July 19 from approximately 1:45 p.m. to approximately 5:00 p.m. The CWCB did not conduct a rainfall bucket survey for this event, but several weather observers in Morgan County collected rainfall information that is summarized in ***Table 4.9-4***.

Neither a radar estimate of the total storm precipitation nor an isohyetal map were obtained for the July 19 event.

The severe thunderstorm of July 31, 1997, that produced localized heavy precipitation in central Morgan County produced rainfall totals of up to 3 inches in the region from Fort Morgan to Snyder. The CWCB did not conduct a rainfall bucket survey for this event, but one weather observer

in Morgan County collected rainfall information that is summarized in *Table 4.9-5*.

Table 4.9-4
Point Rainfall Amounts Recorded in Morgan County
for July 19, 1997

Source	Location	Amount	Recording Period
Mountain States Weather Services (1997)	2.5 miles southwest of Fort Morgan	0.71 inch	July 19, 2:00 p.m. - July 19, 5:30 p.m.
Mountain States Weather Services (1997)	Fort Morgan	0.30 inch	July 19
Mountain States Weather Services (1997)	6 miles south of Raymer	2.68 inches	July 19, 3:00 p.m. - July 19, 5:00 p.m.
Mountain States Weather Services (1997)	3 miles northeast of Wiggins	2.81 inches	July 19, 2:30 p.m.- July 19, 7:00 p.m.

Table 4.9-5
Point Rainfall Amounts Recorded in Morgan County
for July 31, 1997

Source	Location	Amount	Recording Period
Greeley Tribune (1997a)	Fort Morgan	3.0 inches	7/31/97 @ 4:30 p.m. to 7/31/97 @ 6:30 p.m.

Neither a radar estimate of the total storm precipitation nor an isohyetal map were obtained for the July 31 event.

Rainfall totals of up to 4 inches were reported in and around the community of Hillrose for the 24-hour period extending from 7:00 a.m. on August 3 through 7:00 a.m. on August 4. The majority of rain fell within a 2-hour period from approximately 11:00 p.m. on August 3 to 1:00 a.m. on August 4. In the community of Hillrose, 3.5 inches were reported for the 2-hour period extending from 11:00 p.m. to 1:00 a.m.. The *Greeley Tribune* reported that 4 inches had fallen in a "small pocket east of Stoneham" (1997b). The CWCB did not conduct a rainfall bucket survey for this event, but several weather observers in Morgan County collected rainfall information that is summarized in ***Table 4.9-6***. In addition, a total precipitation radar image (Technical Addendum) was obtained from the NWS for this event and is summarized in ***Table 4.9-6***.

Table 4.9-6
Point Rainfall Amounts Recorded in Morgan County for August 3-4, 1997

Source	Location	Amount	Recording Period
National Climatic Data Center (1998)	Hillrose	3.7 inches	8/3/97 @ 12:25 p.m. to 8/4/97 @ 1:11 a.m.
Mountain States Weather Services (1997)	East of Stoneham in Weld County	4.0 inches	8/3/97 @ 10:00 p.m. to 8/4/97 @ 1:52 a.m.
Mountain States Weather Services (1997)	Hillrose	3.5 inches	8/3/97 @ 11:00 p.m. to 8/4/97 @ 1:00 a.m.

An isohyetal map was not developed for the August 3 through 4 event.

A severe thunderstorm produced extremely heavy precipitation over the Schaefer Draw watershed and neighboring tributaries near Weldona beginning approximately 5:00 p.m. on July 29 and extending sporadically to approximately 3:00 a.m. on July 30, 1997. Point rainfall amounts of up to 10.5 inches in a 15-hour period were reported by the NWS. The *Denver Post* and *Rocky Mountain News* reported the heaviest precipitation (5 to 7 inches) occurring from approximately 7:00 p.m. on July 29 through approximately 1:00 a.m. on July 30.

A CWCB flood documentation team conducted a rainfall bucket survey during August of 1997. ***Table 4.9-7*** shows collected rainfall amounts from this survey.

Table 4.9-7
Rainfall Bucket Survey Point Rainfall Amounts for July 29-30, 1997

Amount	Section	T(N)	R(W)
4.5 inches	34	5	59
7.0 inches	12	5	60
3.5 inches	21	5	60
2.1 inches	6	5	60
4.0 inches	4	5	60
2.9 inches	15	6	60
2.8 inches	6	6	60
4.0 inches	10	6	59
2.5 inches	22	6	59
5.8 inches	26	5	59
3.2 inches	30	5	59

Source: Adams 1998

In addition to the rainfall bucket survey, the NWS (NOAA/NWS 1997c) computed the total storm precipitation using NWS radar data from July 29 at 12:00 p.m. through July 30 at 3:00 a.m. (the Technical Addendum contains a graphical image of the storm total precipitation). The radar data showed that the storm center of the July 29-30 storm was located approximately 6.5 miles east, southeast of the community of Weldona. The peak storm total computed by the NWS from the radar data is approximately 10.5 inches. The peak storm intensity computed using a storm duration of 7 hours is approximately 1.5 inch/hour.

Although the heaviest precipitation occurred just southwest of Schaefer Draw, the watershed did receive a maximum precipitation depth of approximately 4.2 inches near the basin centroid during a 4-hour period. More than 4.2 inches fell in Schaefer Draw to the north of the basin centroid. This rainfall depth was determined from the NWS radar data after the radar estimates of rainfall amounts were calibrated to ground-truth data from the Fort Collins and Pawnee Creek storms.

The NWS storm total precipitation map for July 29-30 was digitized and overlaid on a map containing the point rainfall totals collected by the CWCB rainfall bucket survey team for the period July 28-29. Using both the NWS radar data and the rainfall bucket survey amounts, an isohyetal map was generated for the period July 28 at midnight through July 30 at 3:00 a.m. and is shown in ***Figure 4.9-3***.

4.9.4.2 Estimated Point Precipitation Return Periods

The point precipitation totals for Schaefer Draw for storm durations of 6 hours, 12 hours, and 24 hours, for return periods of 10 and 100 years (as developed from NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado [1973]) are shown in ***Table 4.9-8.***

Table 4.9-8
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation	100-yr Precipitation
6 hours	2.2 inches	3.4 inches
12 hours	2.5 inches	3.7 inches
24 hours	2.7 inches	4.0 inches

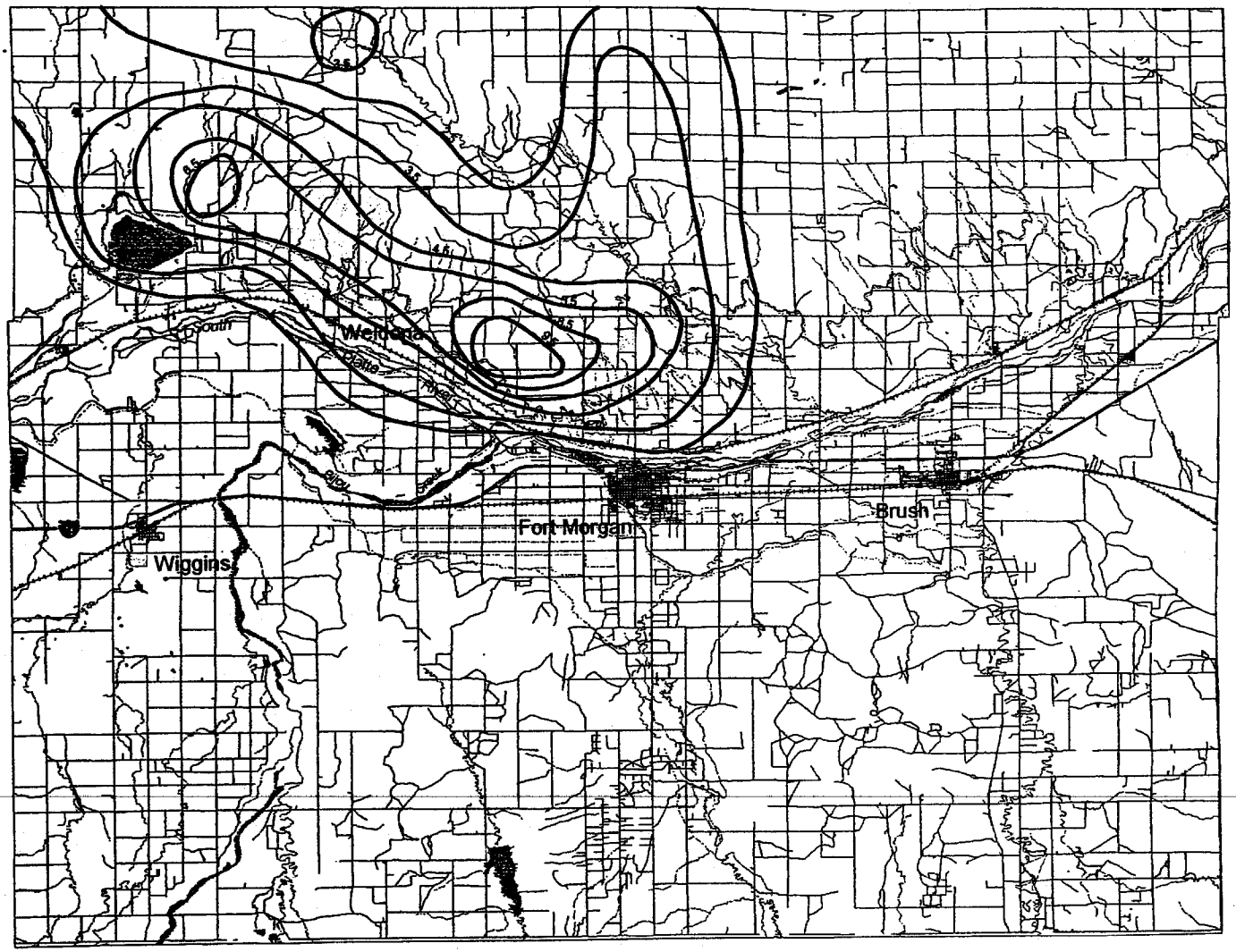
A summary of the point precipitation for the Morgan County storm events of July 29 through 30, July 31, and August 3 through 4, 1997, are shown in ***Table 4.9-9***.

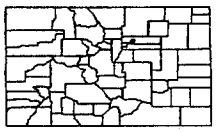
Figure 4.9-3

Morgan County

Precipitation Map

12:00 a.m. July 28 -
3:00 a.m. July 30, 1997





Isohyetal Line (Inches)
Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries
Schaefer Draw Watershed

2 0 2 4 6 8 10 12 14 16

Miles

Riverside Technology, inc.

Table 4.9-9
Summary of Storm Precipitation, Duration, and Return Period for Morgan County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
National Climatic Data Center (1998)	Southeast of Schaefer Draw	July 29-30	10.5 inches	15 hours	> 100-year
National Climatic Data Center (1998)	Near Schaefer Draw basin centroid	July 29-30	4.2 inches	4 hours	> 100-year
Miniclier (1997)	Weldona	July 29-30	5.0 inches	6 hours	> 100-year
National Climatic Data Center (1998)	Southeast of Schaefer Draw	July 29-30	1.5 inches	1 hour	5 - 10 year
Greeley Tribune (1997a)	Fort Morgan	July 31	3.0 inches	2 hours	> 100-year
National Climatic Data Center (1998)	East of Stoneham	Aug 3-4	3.7 inches	12 hours	100-year
Mountain States Weather Services (1997)	Hillrose	Aug 3-4	3.5 inches	2 hours	> 100-year

4.9.5 Hydrology and Hydraulic Findings

4.9.5.1 Locations/Reaches of Flooded Streams

A detailed description of the locations and reaches of flooded streams within Morgan County is presented for the storm event of July 29 through 30, 1997. The storm events of June 1 through 2 and July 19, 1997, occurred in the same general vicinity. Runoff from these events was generated by the drainages surrounding the community of Weldona, which experienced flooding from both events. The runoff from the June 1 through 2 and July 19 events, however, did not cause a breach in the irrigation canals upstream of Weldona in the Schaefer Draw watershed.

The storm event of July 31 was concentrated in northern Morgan County between the communities of Fort Morgan and Snyder. In general, the tributaries between Fort Morgan and Snyder, including Wildcat Creek, experienced flooding conditions along several reaches. The flooding situation was complicated by the presence of highway and railroad embankments that transect these drainages. Flooding on several county roads between Highway 52 and Highway 71 was reported.

The storm event of August 3 through 4 was concentrated in northeastern Morgan County between the communities of Stoneham (in Weld County)

and Hillrose. In general, the tributaries surrounding these two communities, including Beaver Creek, experienced flooding conditions along several reaches. Again, the flooding situation was complicated by the presence of highway and railroad embankments that transect these drainages. Flooding on Highway 6 near Hillrose was reported.

The flooding situation experienced by the community of Weldona on July 30, 1997, was complicated by the presence of two irrigation canals that cross the natural drainage course of Schaefer Draw (***Figure 4.3-2***). Excess runoff from the natural drainage upstream of the Riverside Canal caused a breach at numerous locations along the canal. Water from the Schaefer Draw watershed, along with residual water being carried in the Riverside Canal, began its progression toward the community of Weldona. The Riverside Canal had been shut off on July 28 because of the previous rains. The water then breached a second irrigation canal, the Weldon Valley Ditch located just north of Weldona. A landowner estimated that the flow below the Weldon Valley Ditch was double the amount flowing in Schaefer Draw upstream of the Riverside Canal.

Flow from County Road 8, including runoff from a large watershed to the west of Schaefer Draw, emptied into the Weldon Valley Ditch where the ditch crosses the road. The Weldon Valley Ditch was overtopped by as much as 2 feet between County Road 8 and County Road 9. These flood waters migrated in a southeasterly direction toward Weldona and eventually flooded a 6-block area with as much as 4 to 6 feet of water (see ***Figures 4.9-4*** and ***4.9-5***).

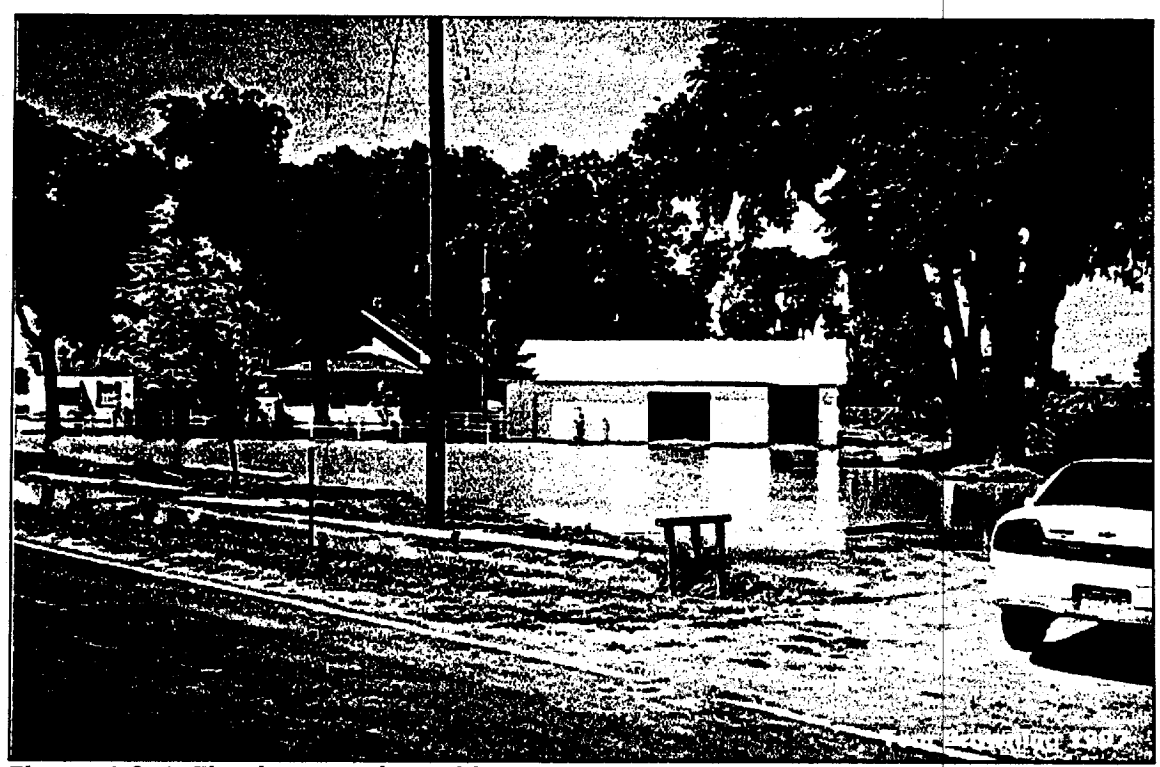


Figure 4.9-4 Flood Waters in Weldona North of Highway 144

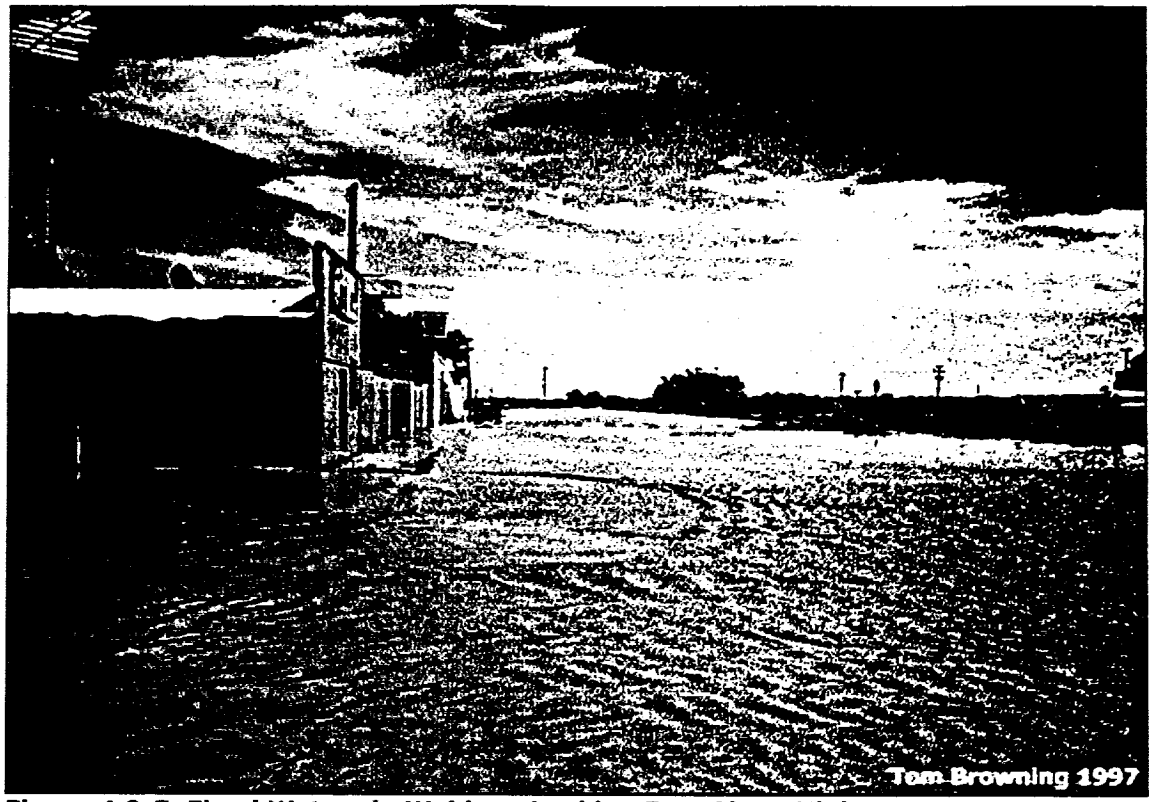


Figure 4.9-5 Flood Waters in Weldona Looking East Along Highway 144

4.9.5.2 Channel Characteristics

The natural channel upstream of the Riverside Canal drains undeveloped rangeland, is irregular in nature, and has a relatively mild slope. The natural channel has an average depth of approximately 3 feet, an average width of approximately 100 feet, and an average slope of approximately 0.75 percent. The channel consists of a primary stream cross section with overbank flood plains. However, the flows (based on the high water marks) were contained in the primary stream cross section. The natural channels are generally well defined.

4.9.5.3 Peak Flows and Estimated Flood Return Periods

A hydrologic/hydraulic assessment was prepared for the flooding that occurred as a result of the storm event on July 29 through 30, 1997. Little to no hydrologic/hydraulic information is available for the flooding associated with the other events. A CWCB flood documentation team computed peak discharge estimates for the Weldona study area using indirect methods for a location in the natural drainage just upstream of the Riverside Canal. No attempt was made to estimate discharges below the Riverside Canal because of the complicated water courses formed once the canal was breached. Peak discharges were also estimated on Wildcat Creek just upstream of Colorado State Highway 52.

In order to estimate peak discharges, CWCB and RTi flood documentation teams identified and surveyed cross section locations, flagged high water marks, and measured channel slopes. The teams estimated peak discharges by employing Manning's equation under the assumption of normal flow. Several indirect flow estimates were determined and averaged at locations on Schaefer Draw above the Riverside Canal and on Wildcat Creek upstream of the bridge on Colorado State Highway 52. The drainage area above each observed location is essentially natural, unregulated, and undeveloped rangeland. The drainage area tributary to the location where the indirect flow estimate was determined in Schaefer Draw is approximately 5 square miles. The drainage area tributary to the location where the indirect flow estimate was determined on Wildcat Creek is approximately 100 square miles. The computed peak discharges for Schaefer Draw and Wildcat Creek are presented in ***Table 4.9-10***.

Table 4.9-10
Computed Peak Discharges for the Storm Events of July 29 -30, 1997

Location	Drainage Area (square miles)	Estimated Peak Flow (cfs)	Estimated 100-year Peak Flow (cfs)	Estimated 100-year Peak Flow Using Soil Conservation Service TR-55 (cfs)
Schaefer Draw upstream of Riverside Canal	5	1,300[1]	2,030[1]	1,310[1]
Wildcat Creek 100 feet upstream of Bridge on Highway 52	100	2,500-3,300[2]	14,000[2]	Not computed[2]

[1]Source: CWCB 1997b
[2]Source: RTi 1998

4.9.5.4 Flood Hydrograph

On the basis of information gathered from community residents and county officials, the approximate chronology of flooding within the community of Weldona is shown in ***Table 4.9-11***.

Table 4.9-11
Chronology of Flooding in Weldona

Date/Time	Description of Event
July 29, 7:00 p.m. - July 30, 1:00 a.m.	Period of heaviest rainfall
July 29, 11:00 p.m. - July 30, 1:00 a.m.	Breach of Riverside Canal
July 29, 12:00 p.m.	First report of running water in Weldona
July 30, 5:00 a.m. - 6:00 a.m.	Peak flood stage in Weldona, 4-5 feet
July 30, 1:20 p.m.	Evacuation of Weldona ordered
July 30, 2:00 p.m.	2-3 feet of standing water in Weldona
July 31, 10:00 a.m.	Residents return to Weldona

Source: Fong and Wallace 1997

Based on the chronological information contained in ***Table 4.9-11,*** an approximate hydrograph can be established for both the location upstream of the Riverside Canal (location of peak discharge estimate) and for the community of Weldona. These two hydrographs are shown in ***Figure 4.9-6.***

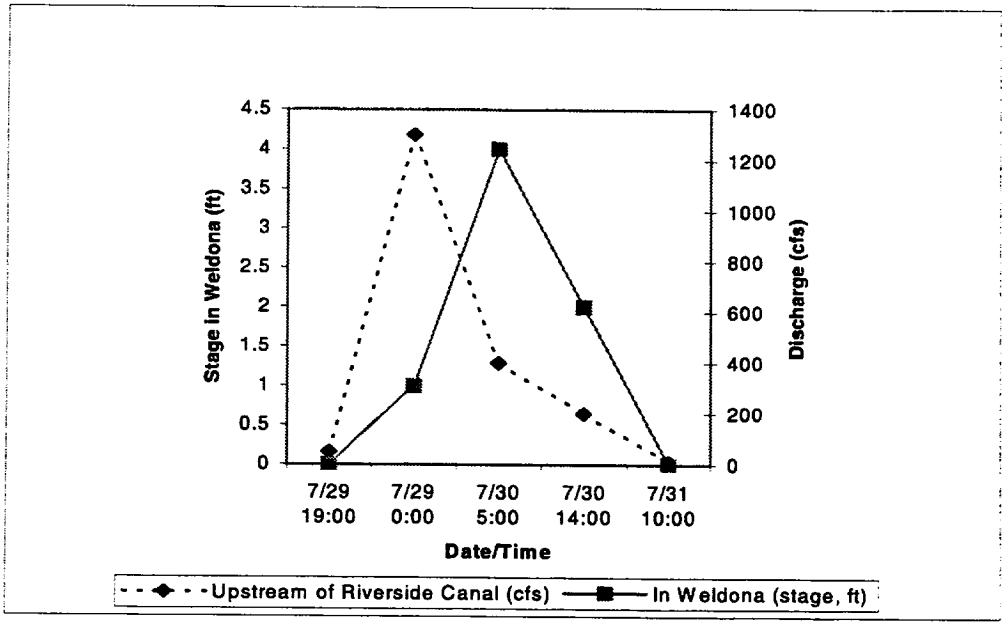


Figure 4.9-6 Approximate Flood Hydrograph for Schaefer Draw and Weldona

4.9.6 Specific Flooded or Inundated Areas

A detailed description of specific flooded or inundated areas is presented only for the community of Weldona for the storm event of July 29 through 30, 1997. Little information regarding specific flooded or inundated areas is available for the other storm events, although some basement flooding was reported in the community of Hillrose as a result of the August 3 through 4 storm event.

A 6-block area, or approximately 80 percent of the community of Weldona was inundated by flood water soon after the breach of the Riverside Canal on July 30, 1997. ***Figure 4.9-7*** shows the approximate level of high water in the community of Weldona. The water receded slowly during July 30; however, by 2:00 p.m. in the afternoon, as much as 2 to 3 feet of standing water was still present.

In addition to the community of Weldona, a large amount of irrigated land downstream of the Riverside Canal and upstream of Weldona also was inundated with water.

Figure 4.9-7 Approximate High Water Level in Weldona - Flood of July 29-30, 1997

4.9.7 Emergency Response Effort

Emergency response efforts are described only for the Weldona area for the flooding experienced on July 30, 1997. In the early morning hours of July 30, 1997, Morgan County officials and volunteer firefighters evacuated nine Weldona residents from their flooded homes. National Guardsmen based in Greeley and Fort Collins were called in to assess the damage and help with rescue efforts at 4:00 a.m. of this same day.

The Colorado State Patrol initiated a mandatory evacuation at 1:20 p.m. on July 30, 1997. National Guard troops, volunteer firefighters, and Wiggins police helped with the evacuation. All 120 residents left Weldona by 2:00 p.m. on July 30. Although flood waters had begun to recede at this time, health issues, along with the possibility of additional rains for the evening of July 30, prompted the evacuation.

The Morgan County Red Cross established a shelter at the Wiggins School the morning of July 30 to provide shelter, clothes, and food for those needing assistance.

4.9.8 1997 Flood Damage

Flood waters from Schaefer Draw damaged homes, businesses, utilities, bridges, highway and railroad embankments, county roads, agricultural land, and vehicles. ***Figure 4.9-8*** shows the extent of flood damaged areas.

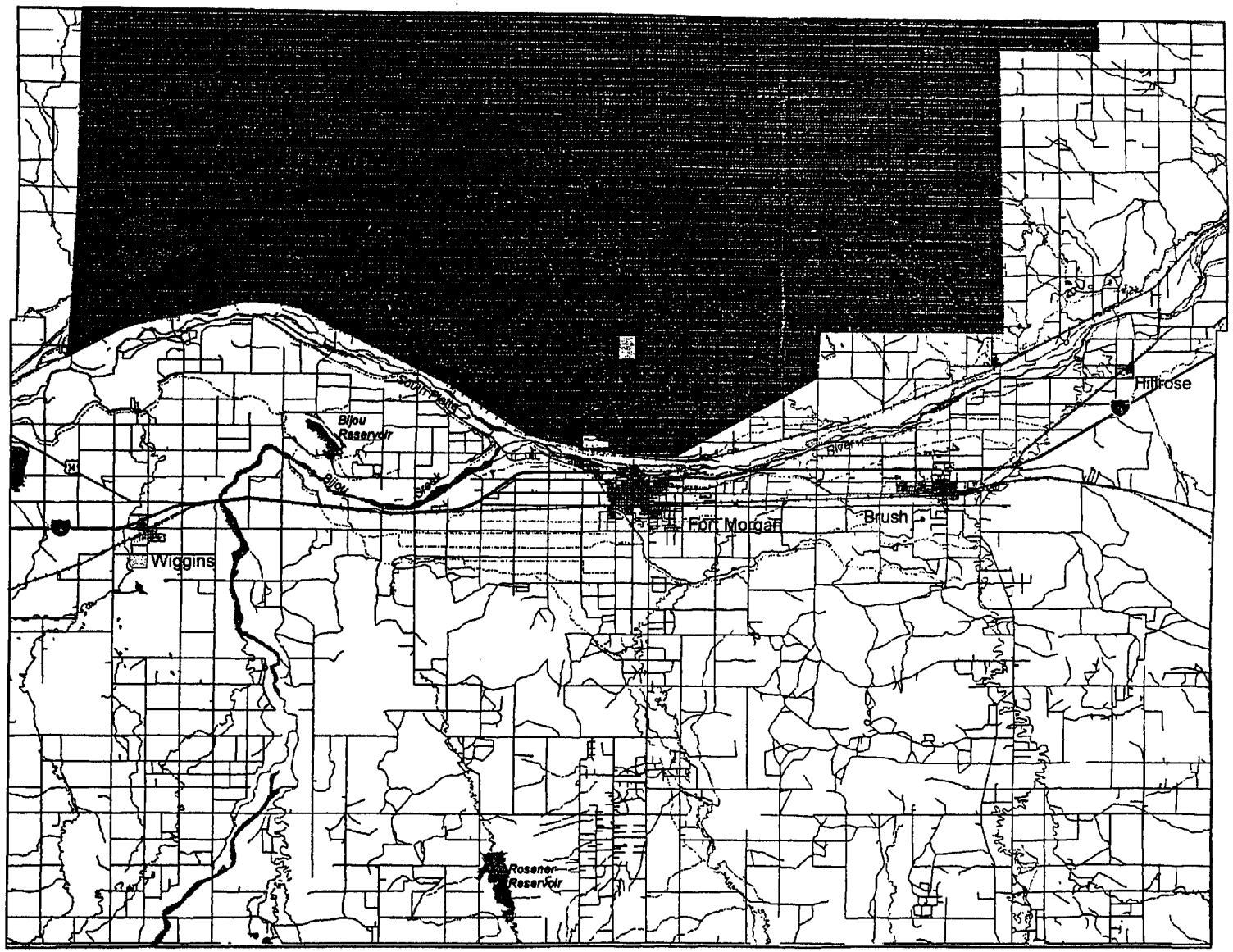


Figure 4.9-8

Morgan County

Damage Areas

Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries
Flood Damage Extent

(Damage to Roads, Railroads, Ditches, Buildings, and Agricultural Land)

N

2 0 2 4 6 8 10

Miles

Riverside Technology, inc.

Eighty percent of the homes in Weldona were flooded, in addition to the U.S. Post office, the Weldon Valley High School, businesses, and nearby feedlots (see ***Figures 4.9-9*** and ***4.9-10***).

Heavy precipitation on June 2 and July 19, 1997, produced storm runoff from Schaefer Draw, Wildcat Creek, and neighboring unnamed tributaries. Damage to county roads, bridges, and residential and commercial properties was not estimated for these events.

However, heavy precipitation on July 29 through 30, 1997, also produced major storm runoff from Schaefer Draw and neighboring unnamed tributaries. Damage to county roads and bridges, to residential and commercial properties in Weldona, and to agricultural lands were recorded for this event.

The following properties in and around Weldona were damaged by flood waters on July 30, 1997:

- Twenty-seven single family homes
- Eleven mobile homes
- Six commercial properties
- Weldon Valley High School and annex
- Catholic Church and annex
- U.S. Post Office
- County Roads, road embankments, and bridges
- Culverts and low-water crossings
- Riverside Canal and the Weldon Valley Ditch
- Agricultural lands

Total damage costs were estimated to be approximately $1,106,348. ***Table 4.9-12*** summarizes these costs.

Although no dollar figures were determined for the damage sustained by agricultural crops, the USDA-Farm Service Agency did estimate the acreage and extent of damage (Hottle 1998) (see ***Table 4.9-13***).

Heavy precipitation on August 3 through 4, 1997, produced storm runoff from Beaver Creek and neighboring unnamed tributaries near Hillrose. Damage to county roads, bridges, and residential and commercial properties was not estimated for this event.

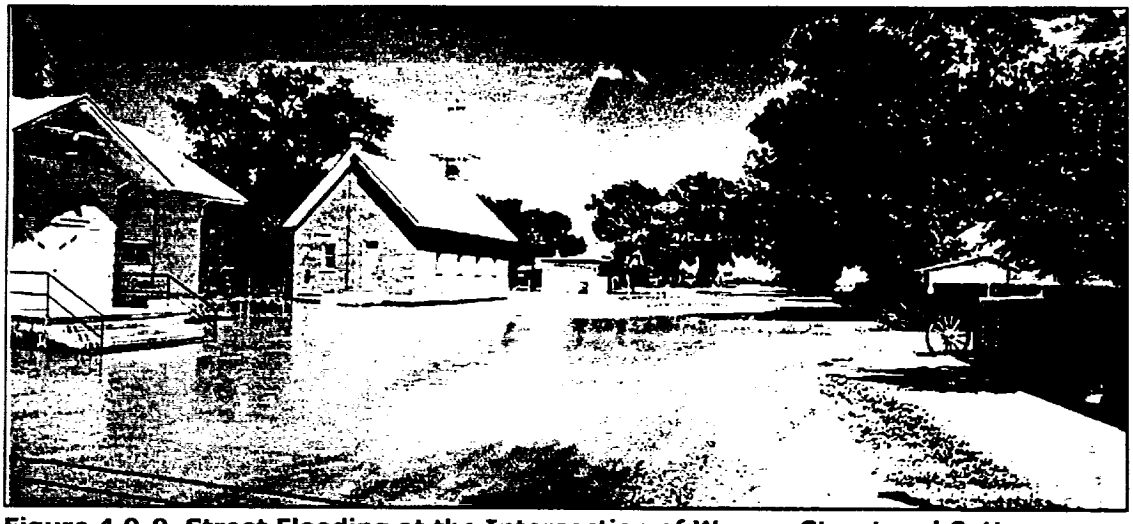


Figure 4.9-9 Street Flooding at the Intersection of Warren Street and Cottage Street, Weldona

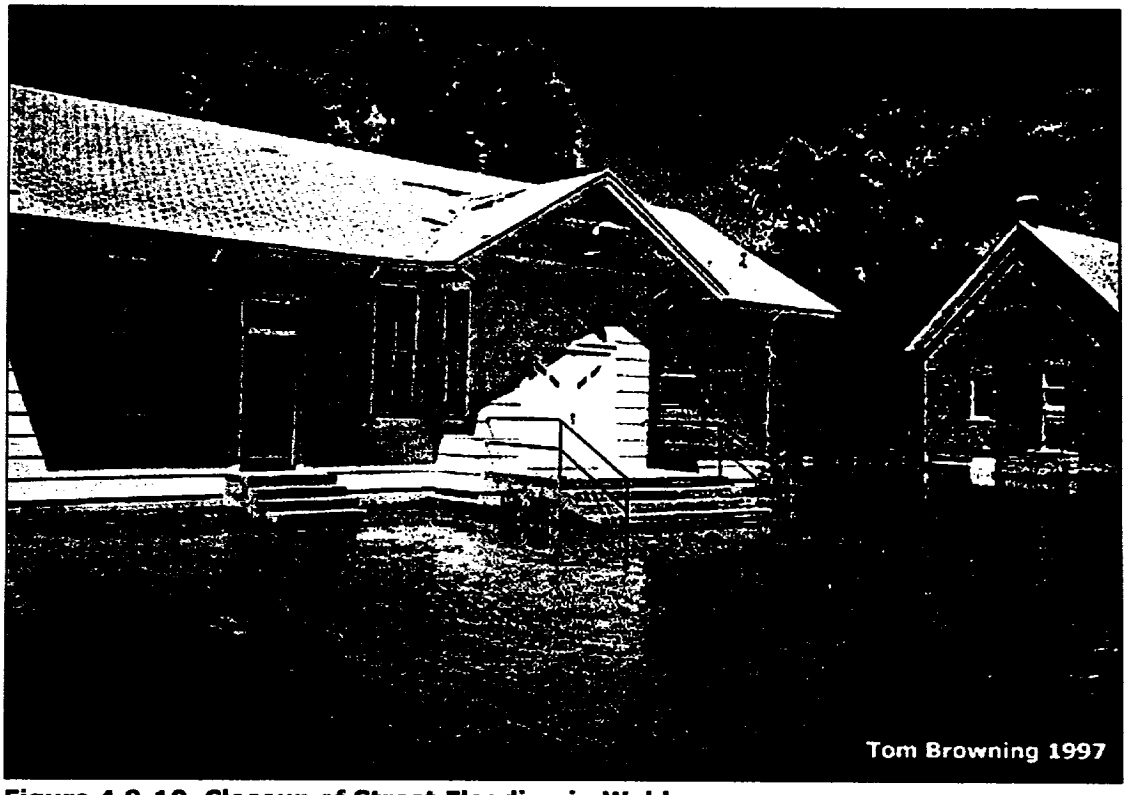


Figure 4.9-10 Closeup of Street Flooding in Weldona

Table 4.9-12
Damage Estimates From the July 30, 1997, Storm Events

Description	Damage Estimate	Source
County Roads	$122,341[1,2]	Baltazar (1998)
County Bridges	$20,000[1,2]	Baltazar (1998)
Residential Properties	$327,080[1,2]	CWCB et al. (Morgan County 1998)
Commercial Properties	$333,427[1,2]	CWCB et al. (Morgan County 1998)
High School	$144,000[1,2]	CWCB et al. (Morgan County 1998)
Catholic Church	$97,500[1,2]	CWCB et al. (Morgan County 1998)
Railroad	$0	None
Agriculture	No dollar cost estimated	USDA - Form Service Agency (Hottle 1998)
Weldon Valley Ditch	No dollar cost estimated	None
Riverside Canal	$62,000[1,2]	Riverside Irrigation Company (CWCB 1998)
FEMA - countywide	$276,590[3]	FEMA Damage Survey Reports (1998)

[1]Estimates are unofficial; they are best estimates at the time of the study.
[2]These estimates were gathered from various sources and may include overlaps and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

Table 4.9-13
Crop Damage Associated With the July 30, 1997, Storm Events

Crop	Affected Acres	Percent Loss
Alfalfa	4,000	35
Corn	2,000	10
Grain sorgum	200	5
Pinto beans	700	7
Sugar beets	1,000	5
Pasture land	7,000	Unknown

Source: Hottle 1998

4.9.9 Flood Hazard Mitigation

4.9.9.1 Previous Efforts

Previous non-structural mitigation efforts undertaken by private and county personnel included maintaining the Riverside Canal and the Weldon Valley Ditch to prevent bank failure under high flow conditions. Other than maintenance activities, there have been no previous mitigation efforts, either structural or non-structural, on Schaefer Draw.

No previous mitigation efforts were identified for Morgan County.

4.9.9.2 Future Needs

As a result of the flooding sustained during the storm event of July 29 through 30, 1997, Morgan County and the CWCB prepared a Hazard Mitigation 404 Grant Application to the Federal Emergency Management Agency (Region 8) for the Community of Weldona (CWCB et al. [Morgan County] 1998). This grant application presented a feasibility study and the resulting preferred structural mitigation alternative.

A summary of the preferred structural mitigation alternative components is provided here. A detailed description is included in the Technical Addendum.

- Constructing a dike/channel system to the north of Weldona to protect the community from a 100-year flood event
- Constructing box culverts or a bridge under Highway 144 near County Road 9
- Constructing a 100-year-capacity channel downstream of the Highway 144 crossing
- Increasing the capacity of the existing ditch located between (and parallel to) the railroad and Highway 144
- Placing riprap on the downstream banks of the Riverside Canal and the Weldon Valley Ditch to prevent future bank failures
- Widening the existing drainage ditch that flows from north to south from the intersection of County Road Y and County Road 10 to Highway 144

No future mitigation projects were identified by Morgan County.

4.9.10 Special Circumstances

The flooding situation in the community of Weldona was complicated by the presence of two irrigation canals that cross the natural drainage course of Schaefer Draw (these structures are discussed in Section 5.10-5). Excess runoff from the natural drainage upstream of the Riverside Canal caused a breach at four locations along the canal. Water from the Schaefer Draw watershed, along with water being carried by the Riverside Canal, began to flow southward toward Weldona. This water then breached a second irrigation canal, the Weldon Valley Ditch located just north of Weldona, before inundating the community.

The presence of Colorado State Highway 144 and a railroad embankment south of Weldona contributed to the flooding experienced by the community. These embankments helped retain portions of the flow as it progressed toward the South Platte River. The embankments generally create a ponding condition that exacerbates flooding problems in the community.

4.10 Otero County

4.10.1 Study Area

During the first two weeks of August in 1997, localized thunderstorms produced several inches of rainfall, and runoff from upstream counties spread over rural areas of Otero County. Otero County, composed primarily of agricultural land, is located on the eastern plains of Colorado just east of Pueblo County and south of Crowley County (see ***Figure 1.1-1***). Both northeastern and southern portions of the county were significantly affected by the flooding, but most of the communities located along Highway 50 escaped serious damage. Only the Town of Rocky Ford experienced some minor flooding. While damages were wide-spread in unincorporated parts of the county, some of the heaviest rain was observed just south of Rocky Ford and the Town of Swink.

In Otero County, county roads and bridges were subject to the most serious damage as a result of the runoff generated in the Horse Creek drainage and some unnamed arroyos. The City of La Junta, the county seat (population approximately 7,700), is located along the Arkansas River approximately 65 miles southeast of Pueblo, Colorado. Although the Arkansas River is the primary drainage that traverses the county, flows from storm events in 1997 did not affect this city enough to cause damages.

Land use in Otero County is predominantly agricultural and includes grazing livestock and cultivating corn, alfalfa, and several types of vegetables (e.g., cantaloupe, watermelon, peppers, and squash). The topography of Otero County is relatively flat with low hills dividing watersheds. The mean annual precipitation for Otero County is approximately 11 inches. ***Figure 4.10-1*** is a general map of the county.

4.10.2 Watershed Description

The watersheds of interest in Otero County include Horse Creek and Timpas Creek. Water in Horse Creek flows southeast through Otero County and eventually drains into the Arkansas River a few miles west of the Town of Las Animas, located in Bent County. Timpas Creek enters Otero County near its southwest corner and flows northeast until it reaches the Arkansas River between Rocky Ford and La Junta. The Apishapa River skirts the western edge of the County line and feeds the Arkansas River downstream of Fowler.

The headwaters of Horse Creek are located within El Paso County, near the Town of Calhan (see ***Figure 4.3-2***). The USGS gage for Horse Creek near Sugar City, located approximately 8 miles upstream of the Otero County line, records flows from a drainage area of 1,026 square miles (USGS ID #07123500), while the Colorado Department of Natural Resources' gage,

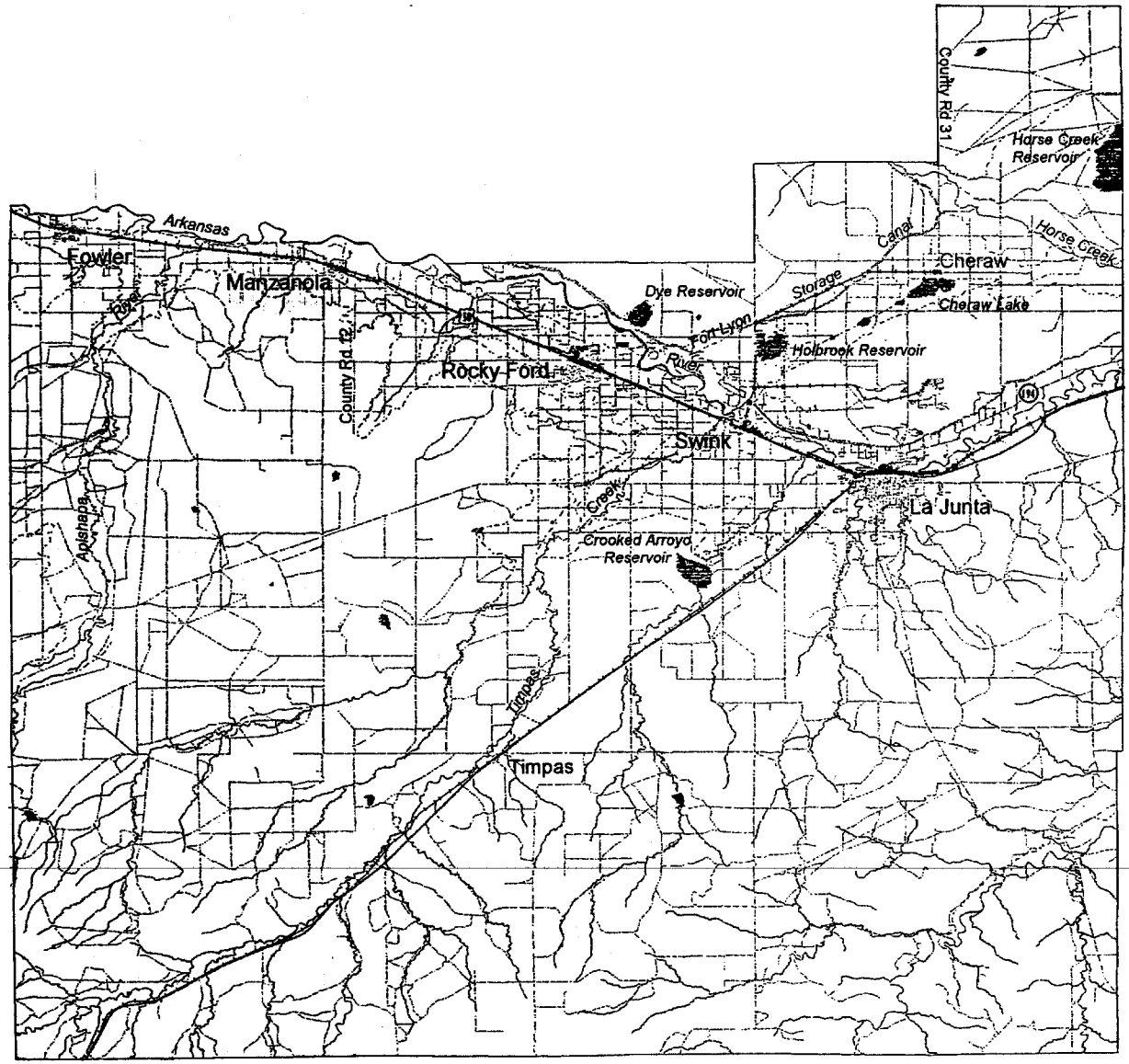


Figure 4.10-1

Otero County

Vicinity Map

Horse Creek at Highway 194 (ID # HRC194CO), has a drainage area of 1,403 square miles. Thus, the approximate local drainage area of the Horse Creek basin in Otero County is 377 square miles. The elevation of the Horse Creek watershed ranges from 6,600 to 4,200 feet.

Nearly the entire basin of Timpas Creek is contained in Otero County, though its headwaters originate in Las Animas County approximately 10 miles southwest of the Otero-Las Animas county line. According to the records for the USGS gage at Timpas Creek at its mouth near Swink, Colorado (ID # 07121500), its drainage area is 496 square miles. Watershed elevations extend from approximately 5,400 at the headwaters to 4,120 feet at the gage.

4.10.3 Local Flooding Problems

Drainages in Otero County damaged by the 1997 storm events historically have not experienced frequent flash flooding during the summer months (Parker 1998). Because of the rare occurrence of flooding in these rural areas of the county, little information is available about local flooding problems. However, flooding problems are more common along the Arkansas River, where 100-year flood boundaries are clearly delineated.

4.10.4 Storm Characteristics

While other counties described in this report experienced damaging storm events throughout the summer, heavy rainfall in Otero County was concentrated during early August of 1997. ***Table 4.10-1*** summarizes the intense storms that produced over 1 inch of rain recorded at NWS cooperative stations during a 24-hour period from June through August of 1997.

Although the NWS cooperative stations indicated several storms produced moderate amounts of rainfall at these locations, no additional information is available for these storms. Therefore, the primary focus of this discussion is on the storms that produced rainfall over the first few days of August, particularly the evening of August 4 and the morning of the August 5. While the entire county witnessed some rainfall, the strongest precipitation intensity on the evening of August 4 occurred south of Highway 50 near Rocky Ford and Swink.

The nearest weather station that records multiple types of atmospheric data is located in La Junta. Daily data was collected at this station for each of the events identified in ***Table 4.10-1***. A summary of this data is presented in ***Table 4.10-2***.

Table 4.10-1
Dates of Significant Precipitation in Otero County During 1997

Date	Maximum Precipitation	Comments
June 5	1.97 inches	Precipitation within a 6-hour period around the La Junta area
July 29	1.42 inches	Short downburst producing heavy rain within a 6-hour period
August 4-5	2.5+ inches	Heavy rains over the northern half of the county
August 10	1.34 inches	Widespread thunderstorms producing heaviest rains south of La Junta
August 11	1.83 inches	Intense thunderstorms producing rain in Rocky Ford and south of La Junta

Table 4.10-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches of Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
La Junta, CO	6/6	58	85	25.58	59	57	12.6	80
La Junta, CO	7/29	64	89	25.87	64	64	13.7	300
La Junta, CO	8/4	64	91	25.97	60	63	9.4	40
La Junta, CO	8/5	64	73	25.91	84	64	13.0	120
La Junta, CO	8/10	60	73	25.77	81	61	12.2	120
La Junta, CO	8/11	59	76	25.77	53	50	6.4	80

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C) T_d = average dew point (°C)
(Linsley et al. 1992)
Source: National Climatic Data Center 1998a

Despite being the closest, most well-equipped gage near Otero County, the data presented in ***Table 4.10-2*** may not completely represent the local meteorological conditions in the areas described earlier. This is primarily because of the convective nature of thunderstorms on the eastern plains of Colorado, which produces significant spatial variability within a region.

4.10.4.1 Storm Duration and Rainfall Quantities

The storm precipitation estimates for the evening of August 4 are based on NWS radar data from the Pueblo Weather Service Office (see Technical Addendum for radar images). The radar data of precipitation totals and the NWS cooperative ground-level 24-hour observer data (***Table 4.10-3***) were converted to isohyets and are displayed in ***Figure 4.10-2.*** As observed from

this map, the largest pocket of rainfall, 3.0+ inches, fell over western and extreme northeastern regions of Otero County.

A summary of the point precipitation data collected for all storm events greater than 1 inch is presented in ***Table 4.10-3***.

Table 4.10-3
Point Rainfall Amounts Recorded in Otero County
From June - August 1997

Source	Location	Amount	Recording Period
Colorado Climate Center (1998)	1 mile south of La Junta	1.97 inches	6/6/97 @8 p.m. to 6/7/97 @ 12 a.m.
LJM Aviation & Weather Station (1997)	La Junta Airport	1.93 inches	6/5/97 at 12 a.m. to 6/6/97 @ 12 a.m.
NOAA/NWS (1998)	Rocky Ford	1.64 inches	6/6/97 at 5 p.m. to 6/7/97 @ 5 p.m.
Colorado Climate Center (1998)	20 miles south of La Junta	1.42 inches	7/29/97@ 5 p.m. to 11 p.m.
Colorado Climate Center (1998)	Fowler	1.23 inches	7/29/97 @ 5:30 p.m. to 8:30 p.m.
Colorado Climate Center (1998)	Fowler	1.80 inches	8/4/97 @ 9 p.m. to 8/5/97 @ 8 a.m.
NOAA/NWS (1998)	Rocky Ford	1.84 inches	8/4/97 @ 5 p.m. to 8/5/97 @ 5 p.m.
Erickson (1997)	Swink	2.91 inches	12 hours starting the evening of 8/4/97
Erickson (1997)	Arkansas Valley Research Center	Approx. 2.0 inches	12 hours starting the evening of 8/4/97
Colorado Climate Center (1998)	Fowler	1.03 inches	8/10/97 @ 4 p.m. to 5 p.m.
Colorado Climate Center (1998)	20 miles south of La Junta	1.34 inches	8/10/97 @ 10 p.m. to 8/11/97 @ 12 a.m.
Rocky Ford Daily Gazette (1997)	Rocky Ford	Approx. 2.0 inches	evening hours on 8/11/97
NOAA/NWS (1998)	Rocky Ford	1.83 inches	8/11/97 @ 5 p.m. to 8/12/97 @ 5 p.m.

Figure 4.10-2 indicates that from 1 to over 2 inches of rain fell along the corridor of towns along Highway 50 during the evening of August 4 and into the morning of August 5. ***Figure 4.10-2*** depicts a rainfall total of 2.5+ inches just south of Swink. It is likely that the rainfall duration at the Rocky Ford NWS gage was less than 24 hours for each of the three readings listed in ***Table 4.10-3***, but no information is available to refine these time estimates.

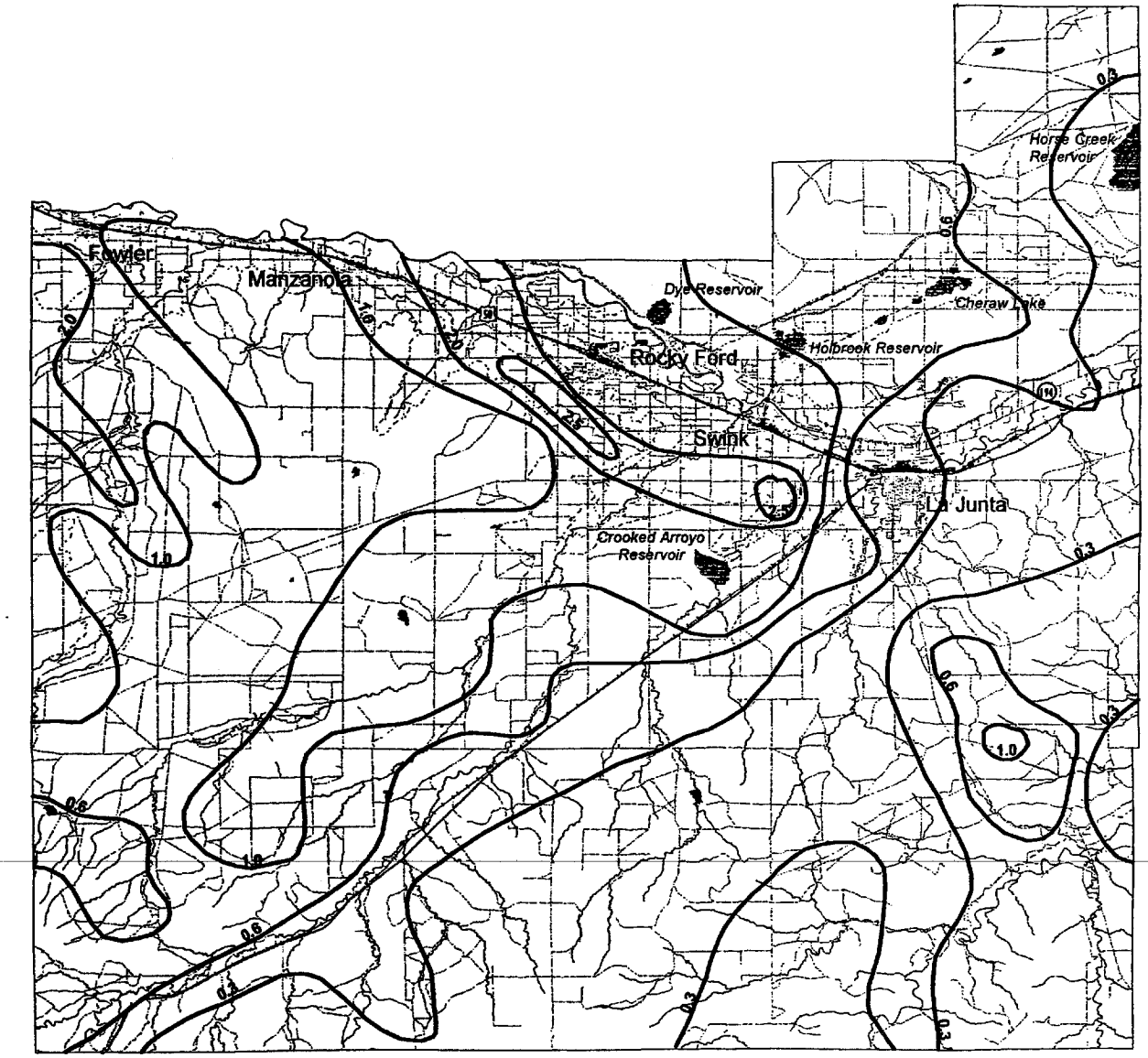
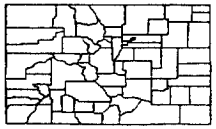


Figure 4.10-2

Otero County

Precipitation Map

11:59 a.m. August 4 -
7:16 a.m. August 5, 1997



- Rivers and Streams
- Canals and Ditches
- Interstate Highways
- Primary Roads
- Secondary Roads
- Railroads
- 2.5 Isohyetal Lines (Inches)
- Lakes and Reservoirs
- Municipal Boundaries

5 0 5 10 15
Miles

Riverside Technology, inc.

4.10.4.2 Estimated Point Precipitation Return Periods

The estimated precipitation return periods in Otero County are presented in ***Table 4.10-4***. The 6-hour, 12-hour, and 24-hour storm amounts for the 5-year, 10-year, and 100-year return period were taken from the maps and nomogram provided in NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado (1973).

Table 4.10-4
5-year, 10-year, and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	5-yr Precipitation	10-yr Precipitation	100-yr Precipitation
6 hours	2.2 inches	2.6 inches	3.7 inches
12 hours	2.4 inches	2.8 inches	4.1 inches
24 hours	2.7 inches	3.2 inches	4.5 inches

The magnitude of precipitation that fell over Otero County in August of 1997 produced damaging floods. However, these floods were not the result of a single storm; rather they resulted from a number of smaller storms occurring over a period of approximately 1 week. Consequently, none of the rainfall totals exceeded the 100-year estimates. ***Table 4.10-5*** shows rainfall amounts and duration compared with 5-year return period estimates for the four storm events that produced over 1 inch of rain.

Table 4.10-5
Summary of Storm Precipitation, Duration, and Return Period for Otero County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
NOAA/NWS (1998)	Northern Otero County	June 6	1.97 inches	4 hours	< 5-year, 6-hour event
NOAA/NWS (1998)	La Junta	July 29	1.42 inches	6 hours	< 5-year, 6-hour event
National Climatic Data Center (1998)	Across Otero County	August 4-5	2.50+ inches	19 hours	Approx. 5-yr, 24-hr event
Rocky Ford Daily Gazette (1997)	Rocky Ford	August 11	2.0 inches	12 hours	< 5-year, 12-hour event

According to the NOAA Atlas (1973), the rainfall totals on the evening of August 4 are approximately equal to or greater than the 2-year, 6-hour rainfall in central Otero County, which is 1.6 inches.

4.10.5 Hydrology and Hydraulic Findings

4.10.5.1 Locations/Reaches of Flooded Streams

A description of the locations and reaches of flooded streams within Otero County is presented for the storm events that occurred between August 4 through 5 only. Little information regarding the hydrologic response of the watersheds as a result of the storms occurring later in the month is available.

In general, the Horse Creek watershed and some unnamed arroyos experienced flooding conditions along several reaches. The flooding situation was complicated by the presence of county road embankments that transect these drainages. During the time of high flows in Horse Creek, most of the irrigation ditches were closed off (Taylor 1998).

Flood waters in the Horse Creek watershed began north of Otero County in Lincoln County near Karval and propagated south through Crowley County toward the Arkansas River in Bent County. Photographs taken on August 5 and 6 indicate flood waters continued to inundate land along the mainstem of Horse Creek near the Otero-Crowley county line and a reach a few miles downstream of this location (see ***Figures 4.10-3*** and ***4.10-4***). The Fort Lyon Storage Canal ran full to overtopping between just north of Holbrook Reservoir and past Horse Creek (see ***Figure 4.3-2***). High water also contributed to road damage along Timpas Creek near Timpas and a few spotty locations in some unnamed arroyos southeast of La Junta.

4.10.5.2 Channel Characteristics

The natural channels in Otero County drain agricultural lands and undeveloped rangeland. Upstream of the irrigated lands near the Arkansas River, channels are typically irregular in nature, have sandy bottoms and relatively mild slopes, and are only well-defined for low-flow conditions (Kipple 1998). Tributary channel reaches closer to the Arkansas River are well defined and deep. Unlike the reaches upstream, the areas near the Arkansas River run throughout the year with agriculture return flows and ground water emergence.

The Horse Creek channel near Cheraw is densely covered with sagebrush, which slowly thins out toward the Arkansas River confluence. At the Highway 194 streamflow gage, located just downstream in Bent County, the channel retains streamflow within its banks until approximately 60 to 70 cfs, when water begins to fan out into the floodplain (Kipple 1998).

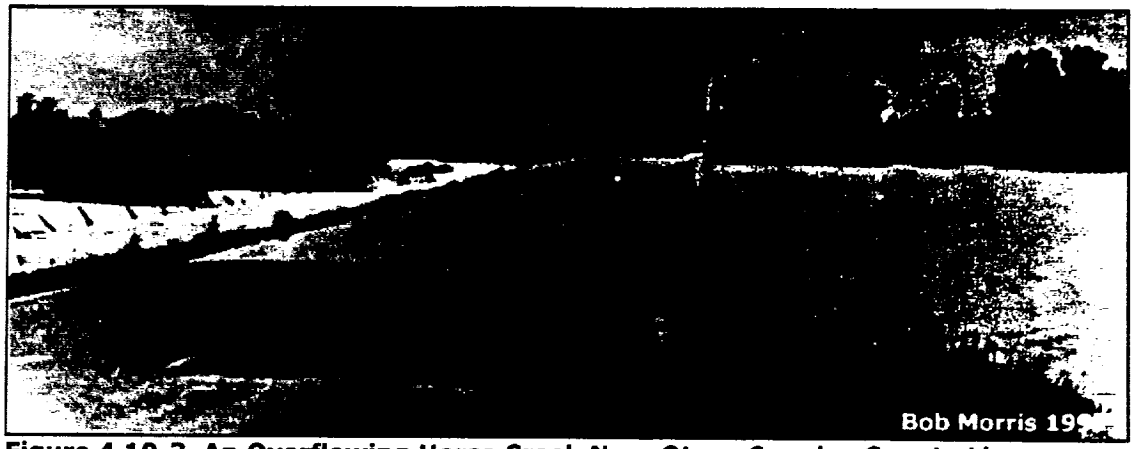


Figure 4.10-3 An Overflowing Horse Creek Near Otero-Crowley County Line

Figure 4.10-4 Horse Creek Below Osborn Ditch

Although road damage was observed near Timpas Creek and the Apishapa River, the channels contained the flows within their banks in these basins (Ehrlich 1998).

4.10.5.3 Peak Flows and Estimated Return Periods

Streamflow records are available for the Horse Creek watershed from the Colorado Department of Natural Resources gage, Horse Creek at Highway 194 (ID # HRC194CO), located near the Town of Las Animas in Bent County. However, no gages record streamflow data from runoff generated in the unnamed arroyos southeast of La Junta.

During the August 1997 storm events, the Horse Creek gage recorded an instantaneous peak discharge of 2,236 cfs on August 7 at 2:30 p.m. Although the CWCB has developed a procedure to compute the 100-year streamflow return period for the eastern plains within the Arkansas River basin, the maximum drainage basin size that is valid for this procedure is 1,125 square miles (CWCB 1997b); the drainage area for the Horse Creek is 1,403 square miles.

To compute the streamflow frequencies, the USGS PEAKFQ program was used to compute the Log Pearson III estimate (USGS 1998b). Annual peak flows from 1980 through 1993 were obtained from the USGS, which used to maintain this site as USGS ID # 07123675, and the Colorado Department of Water Resources. Using this program, the 100- and 500-year streamflow return periods at this location were estimated and are shown in ***Table 4.10-6***. Using the relatively small period of record as a basis for this statistical analysis, the peak flow in 1997 was between the 100- and 500-year events.

Table 4.10-6
Computed Peak Discharge for the Storm Events of August 1997

Location	Drainage Area (square miles)	Estimated Peak Flow (cfs)	Estimated 100-year Peak Flow (cfs)	Estimated 500-year Peak Flow[1] (cfs)
Horse Creek Gage at Highway 194	1,403	2,236	1,643	2,745

[1]Source: USGS 1998

4.10.5.4 Flood Hydrograph

The Colorado Department of Water Resources in Pueblo provided daily streamflow data during the first week of August 1997 for the Horse Creek gage. According to information provided by the Colorado Department of Water Resources' Water Commissioner in this region, the irrigation ditches were not diverting water during the flooding period in early August (Taylor 1998). However, the Fort Lyon Storage Canal attempted to contain the flood waters coming down from Crowley County, but its banks breached. Consequently, the natural runoff peak was delayed because of this canal.

Since streamflow information on Horse Creek is limited to the Horse Creek gage, its data provide the closest estimate of the natural runoff in Otero County that was produced from the August storms. ***Figure 4.3-8*** in Section 5.3.5.4 depicts Horse Creek's response to the early August storms.

While this streamflow response to rainfall events in early August is a direct result of the storm events that occurred during this period, not all of the rain fell in Otero County. However, no other streamflow records are available in

the other counties within the Horse Creek watershed that could separate their contribution to the gage readings at Highway 194.

4.10.6 Specific Flooded or Inundated Areas

Specific flooded or inundated areas are described only for the flooding resulting from the early August storm events. While individual flood areas generally have been located, little information regarding actual flood inundation boundaries is available.

The FEMA damage survey reports summarized the locations of the county road and bridge damage during this period of flooding. An overview of these damaged areas resulting from flood waters is presented in ***Figure 4.10-5.***

One of the most damaged areas occurred as a result of flood waters near County Road 31. ***Figure 4.10-6*** shows the aftermath of the Horse Creek flows that washed out this road crossing. ***Figure 4.10-7*** shows remnants of a bridge (#166) crossing the Fort Lyons Storage Canal north of Cheraw. Additional damage was reported within the Timpas Creek watershed, tributaries off the Apishapa River, southeast of La Junta, and along County Road 12 south of Manzanola.

Flooding also was reported along State Highway 50 east of Manzanola (Erickson 1997) and between the towns of Rocky Ford and La Junta (Gilman 1997a). In addition, Main Street in Rocky Ford was inundated for a brief time because of the rains on August 11 (Gilman 1997a and 1997b). Highway 194 in Bent County was closed from Wednesday (August 6) through Friday morning (August 8) because of flooding on Horse Creek (Hagenah 1997).

No additional information was available concerning potential flooding on other sections of state highways or the flooding extent in natural watersheds.

4.10.7 Emergency Response Effort

Since most flooding occurred on areas with limited population, the damage to habitable structures was minimal. Consequently, little information was available to describe the emergency response to the localized flooding. Otero County officials indicate that the county road and bridge crew erected barricades soon after the floods occurred (Parker 1998).

As a result of the August 11 flooding within Rocky Ford, the "City crews responded by cleaning out plugged sewer drains" (Gilman 1997a).

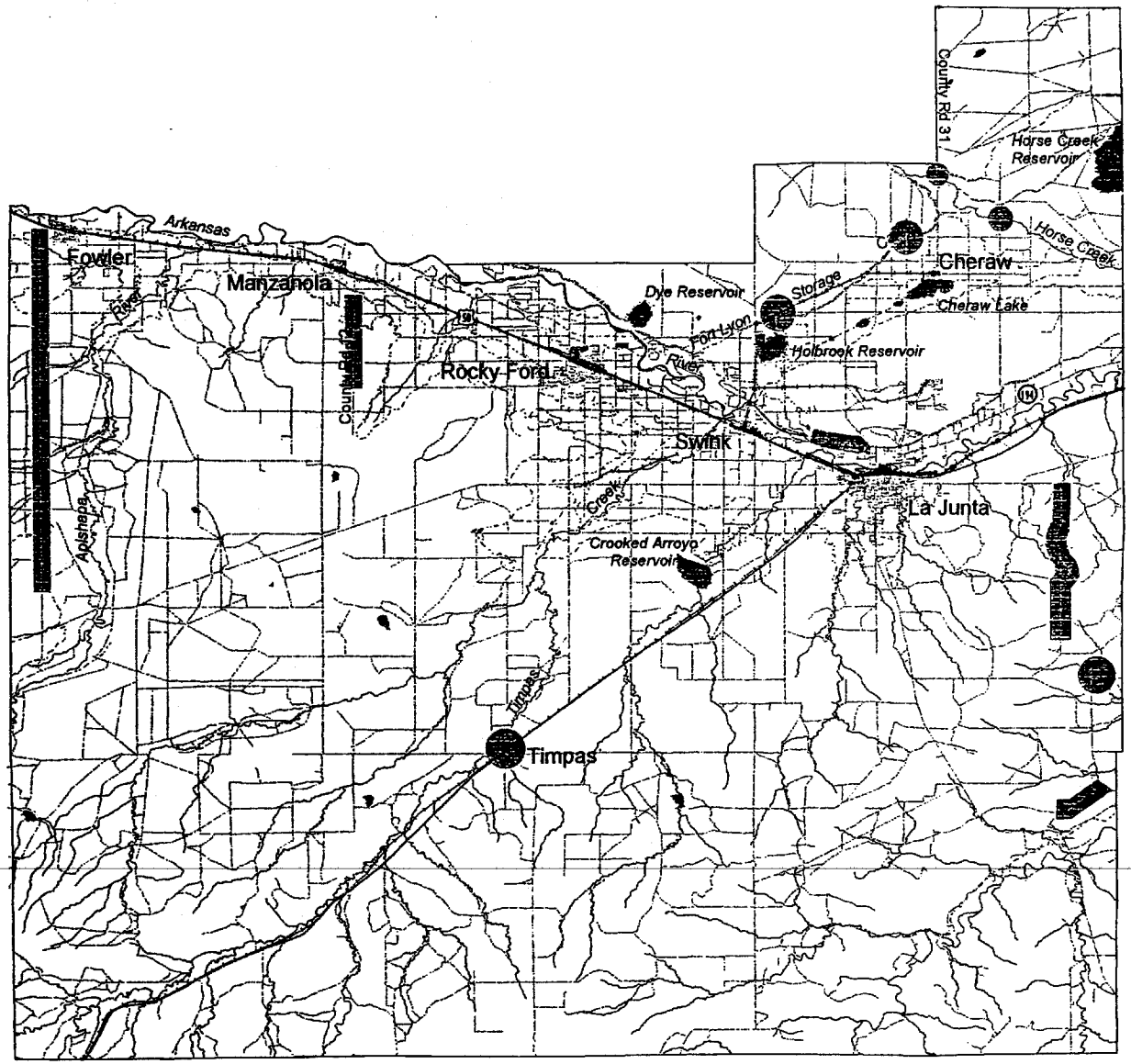


Figure 4.10-5

Otero County

Damage Areas

Riverside Technology, inc.

Figure 4.10-6 Horse Creek North of Cheraw

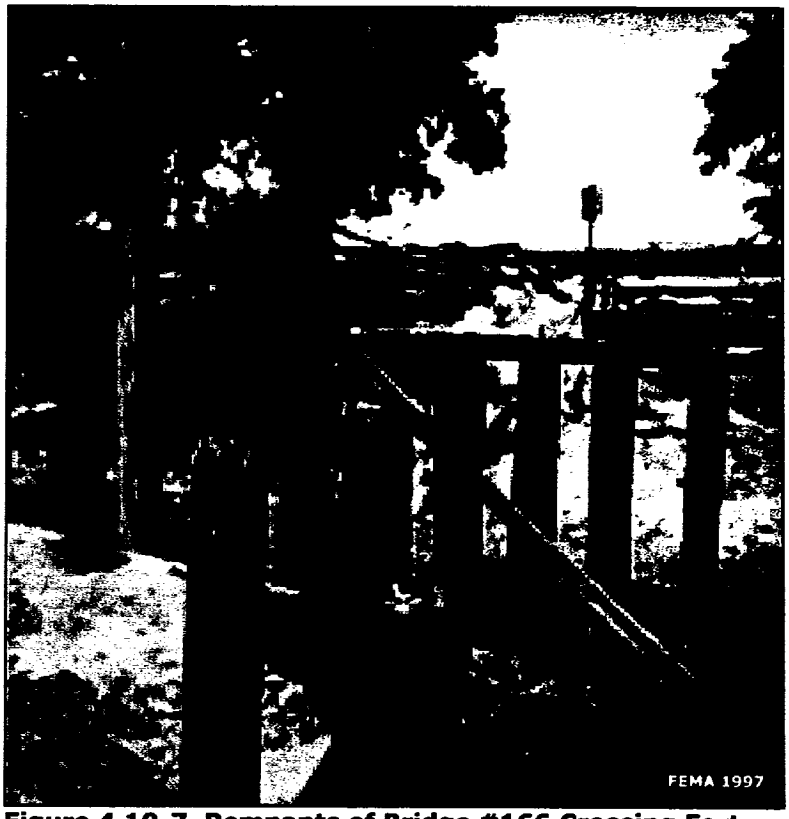


Figure 4.10-7 Remnants of Bridge #166 Crossing Fort Lyons Storage Canal

4.10.8 1997 Flood Damage

The available documentation indicates that damage from the 1997 floods in Otero County was primarily confined to county roads and bridges. The primary source of damage costs associated with the August storms is the FEMA damage survey reports. A summary of these damage estimates for Otero County is provided in ***Table 4.10-7***.

Table 4.10-7
Damage Estimates From the Early August 1997 Storm Events

Description	Damage Estimate	Source
Otero County - County damages only	$206,799[1,2]	*Rocky Ford Daily Gazette* (1997)
Fort Lyons Canal Company	$175,000[1,2]	*Rocky Ford Daily Gazette* (1997)
Agriculture	No dollar cost estimated	USDA-Farm Services Agency (Hammer 1998)
FEMA - countywide	$267,386[3]	FEMA Damage Survey Reports (1998)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include some overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

Although no dollar figures were determined for the damage sustained by agricultural crops, the USDA-Farm Services Agency in Crowley County, which oversees activities in Otero County as well, estimated unofficial damages that are summarized in ***Table 4.10-8***.

In addition to depositing silt in the fields, the flood waters caused vegetables to rot or diminished their quality such that they were not marketable (Hammer 1998).

4.10.9 Flood Hazard Mitigation

The County Commissioner's Office indicated that no formal flood mitigation efforts were implemented or are planned for those areas affected by the 1997 storm events (Ehrlich 1998). The County Road and Bridge Department repairs any damage to its roads when damaging floods occur. Flooding on Timpas Creek usually is minimal because of several small flood control dams in the basin that were constructed by the National Resources Conservation Service (Taylor 1998).

Table 4.10-8
Unofficial Crop Damage Associated with the July 28 - August 12, 1997, Storm Events

Crop	Affected Acres	Percent Loss
Cantaloupe	100	75
Honeydew	50	90
Watermelon	500	80
Pumpkin	120	95
Squash	20	70
Peppers	50	70
Tomatoes	50	70
Zinnia Seed	50	80
Alfalfa	21,000	30

Source: Hammer 1998

4.10.10 Special Circumstances

In general, all the tributaries in Otero County can experience flooding conditions along reaches where highway and railroad embankments transect the natural drainage paths. The criteria used to design these crossings were not investigated for this document.

The flooding problems that occurred in the Horse Creek basin were partly caused by breaches in the Fort Lyons Storage Canal (Taylor 1998). According to a local newspaper (*Rocky Ford Daily Gazette* 1997), the runoff generated by storms in Lincoln and Crowley counties caused two breaches in the canal: one 600 feet and a second 200 feet long (see ***Figure 4.3-6***). According to the Colorado Office of the State Engineer, the empty canal first began storing the storm runoff resulting from a plugged culvert than was intended to pass the Horse Creek flows underneath the canal embankment (Taylor 1998). After the canal reached its limit, it began overtopping on its downstream side and allowed water to flow back into Horse Creek.

No other information was available to indicate that unique circumstances existed in Otero County to cause flooding as a result of the 1997 storm events.

4.11 Phillips County

4.11.1 Study Area

From early June through mid August of 1997, Phillips County received heavy localized precipitation that produced considerable flood damage. The county is located in extreme northeastern Colorado (see ***Figure 1.1-1***). Both incorporated and unincorporated areas were affected by the flooding, especially the communities of Holyoke and Amherst.

The community of Amherst is approximately 12 miles northeast of Holyoke on Highway 23, and has a population of approximately 150. Holyoke, 60 miles east of Sterling, 18 miles west of the Colorado-Nebraska state line, and 30 miles south of the Colorado-Wyoming state line, has a population of approximately 2,500 (see ***Figure 4.11-1***).

In Phillips County, homes, commercial properties, county roads and bridges, and agricultural lands were seriously damaged as a result of runoff generated in Sandy Creek, Wildhorse Creek, and Frenchman Creek. The communities of Holyoke, Paoli, and Haxtun all are located in the Frenchman Creek drainage. Holyoke sits just downstream of the confluence of the North and South Fork of the Frenchman Creek.

Land use in Phillips County consists of cropland and open rangeland. Primary agricultural products consist of wheat, corn, millet, various legumes, and livestock. The mean annual precipitation for Phillips County is approximately 16 inches.

4.11.2 Watershed Description

The watersheds of interest include Frenchman Creek, Sandy Creek, Wildhorse Creek, and several unnamed watersheds. Wildhorse Creek and Frenchman Creek flow in a southeasterly direction eventually draining into the Republican River. The Republican River is a tributary to the Kansas River in Kansas. The watershed of primary interest is Frenchman Creek. Wildhorse Creek is the drainage immediately north of Frenchman Creek and Sandy Creek is the drainage immediately south of Frenchman Creek (see ***Figure 4.11-2***).

The headwaters of Frenchman Creek are located within Logan County approximately 20 miles west of Holyoke. The confluence of the North and South Fork of Frenchman Creek is located on the western edge of Holyoke. The North Fork of Frenchman Creek drains approximately 164 square miles (COE 1980). The total drainage area of Frenchman Creek below the confluence of the North and South Forks at U.S. Highway 385 is approximately 227 square miles (COE 1980). The topography in Phillips

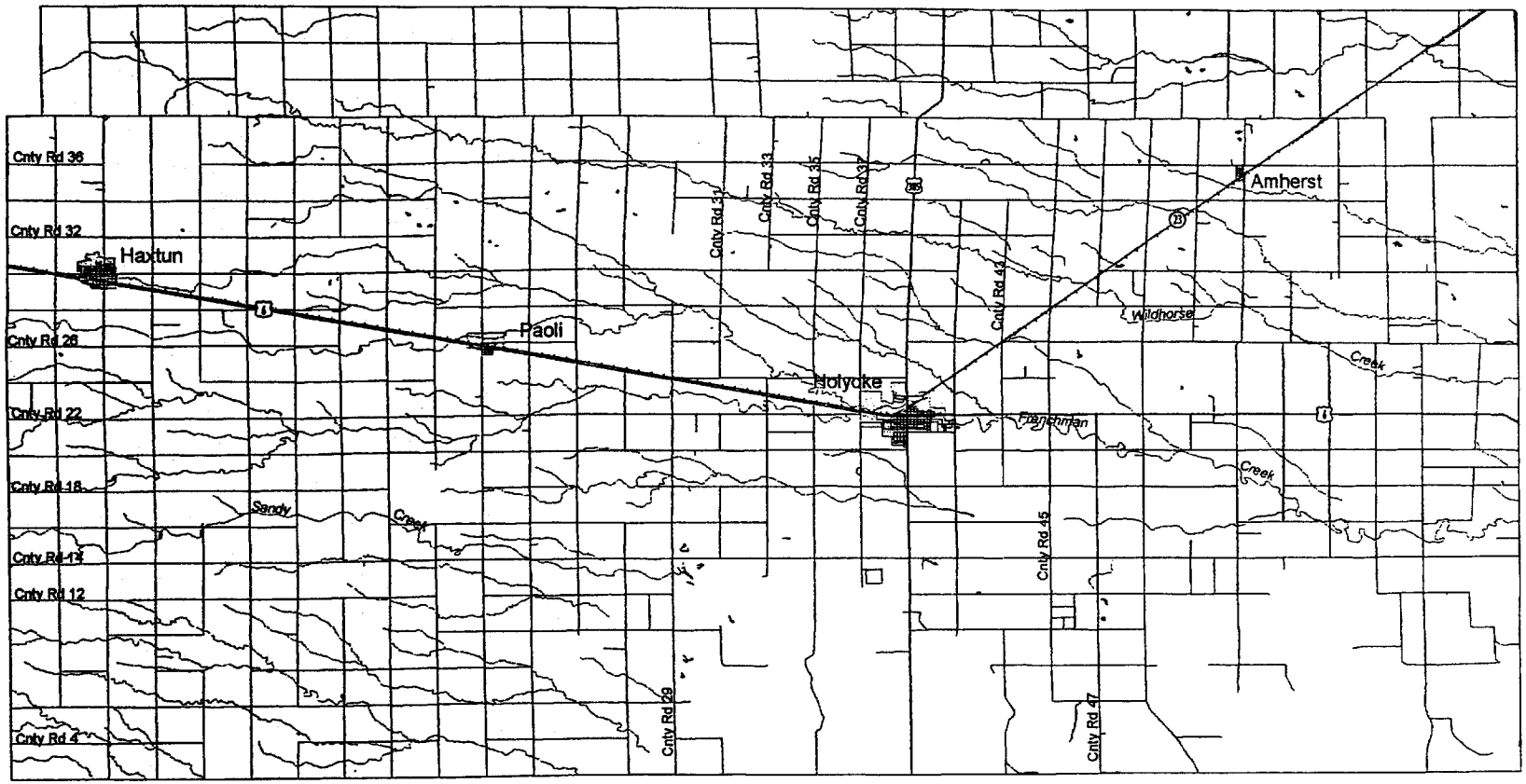
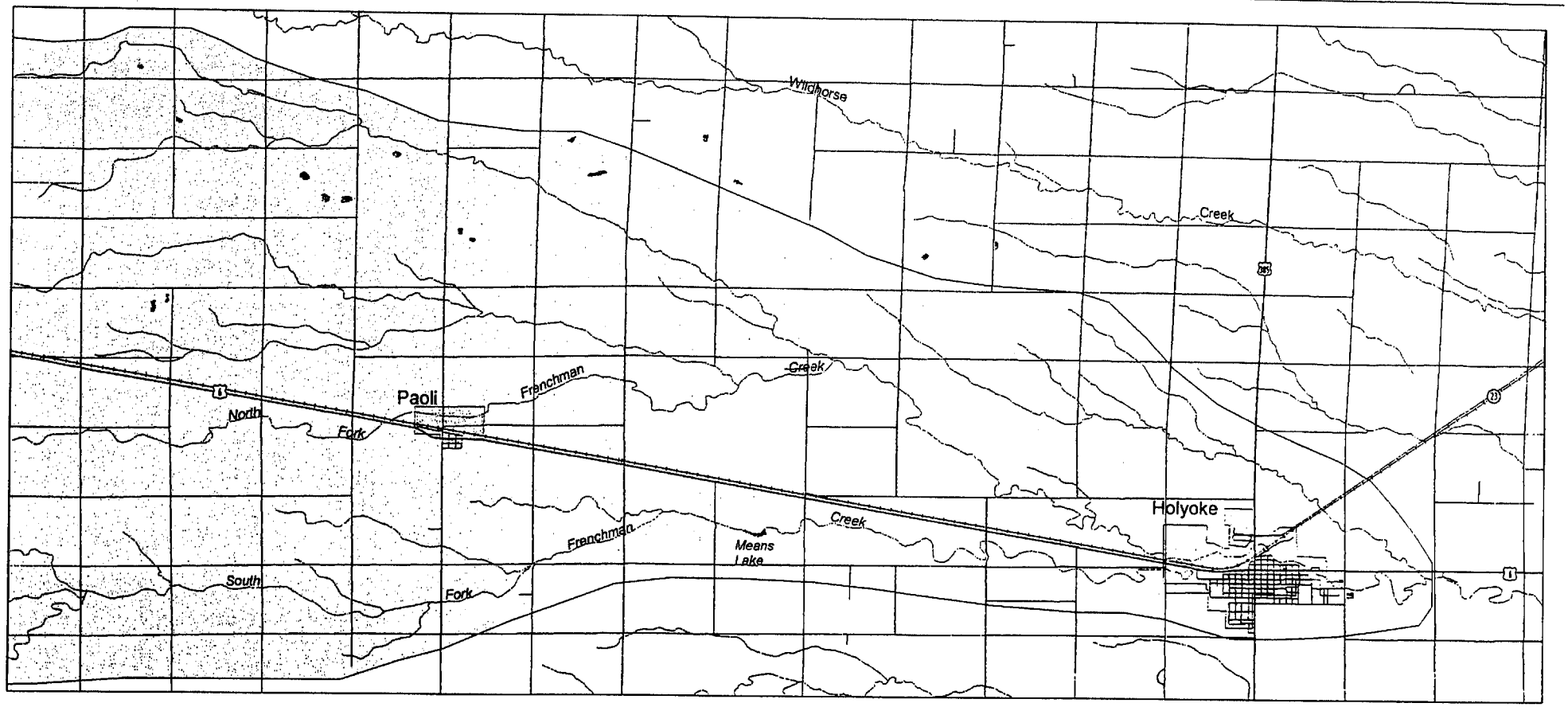


Figure 4.11-1

Phillips County

Vicinity Map

Riverside Technology, inc.



Rivers and Streams
Canals and Ditches
Primary Roads
Secondary Roads
Railroads
Lakes and Reservoirs
Municipal Boundaries
Frenchman Creek Watershed

2 0 2 4 6 8 10
Miles

N

Figure 4.11-2

Phillips County

Affected Watershed

Riverside Technology, inc.

County is relatively flat with low hills dividing the waterways. Larger waterways, such as Frenchman Creek, have well-defined channels. The watershed elevations in Frenchman Creek range from 3,700 feet at Holyoke to approximately 4,400 feet in the headwaters.

A small reservoir (Means Lake) exists on the South Fork of Frenchman Creek approximately 5 miles upstream of Holyoke. The Means Lake Dam, an earthen structure with a concrete spillway, was initially constructed in 1955 as a flood control structure to protect Holyoke and communities in Nebraska. Currently, the area is known as the Frenchman Creek State Wildlife Area and is used for recreational purposes. In 1955, the reservoir had a storage capacity of approximately 1,200 acre-feet (Colorado Division of Wildlife 1984). The current storage capacity may be less than 1,200 feet because of siltation.

The headwaters of Wildhorse Creek are located in northwestern Phillips County and eastern Logan County approximately 6 miles northwest of the community of Haxtun. Sandy Creek is an intermittent stream originating south of the community of Flemming. Sandy Creek flows in a southeasterly direction and terminates approximately 6 miles southeast of Holyoke.

4.11.3 Local Flooding Problems

Tributaries in Phillips County, including Sandy Creek, Wildhorse Creek, and Frenchman Creek, have historically experienced nuisance flooding during the summer months. The communities of Paoli and Holyoke both have histories of local flooding from high intensity, short duration, localized thunderstorms. Because of the nature of these highly localized storm events, typical storm runoff hydrographs are characterized by a steep rising limb to a peak then a gradual tapering off (COE 1980).

According to Phillips County officials, Sandy Creek is subject to annual flooding that causes major damage to county roads, as well as to agricultural lands. Sandy Creek has flooded 3 times during the past 2 years (1996 and 1997) (Shafer 1998a).

According to Colorado Division of Wildlife officials, Means Lake fills to near capacity with any significant storm event in the Flemming and Paoli areas.

4.11.4 Storm Characteristics

Heavy rains in northeastern Colorado in June, July, and August of 1997 caused significant flooding in several areas within Phillips County. During this period, Phillips County experienced several days of very heavy localized precipitation (***Table 4.11-1***).

Table 4.11-1
Dates of Significant Precipitation in Phillips County
During 1997

Date	Maximum Precipitation	Comments
June 2	2.9 inches	Haxtun to Holyoke
June 14-15	6 inches	Storm centered north of Holyoke and east of Amherst
July 28-30	0.5 – 1.5 inches	General rains over a large area; caused flooding of county roads around Holyoke; 1.6 inches measured in Haxtun on July 30
August 4-5	1.0-1.5 inches	General rains over a large area. 1.7 inches measured in Haxtun on August 5

Although not contained in the Presidential Disaster Declaration Period of July 28 through August 12, 1997, the precipitation events of June 2 and June 14 through 15 were the most significant in terms of total precipitation and damage from the subsequent flooding. The remaining portions of this report will therefore focus on these two events.

Thunderstorms producing heavy localized rainfall and large hail moved across eastern Larimer, northern Weld, Logan, Morgan, and Phillips counties on June 2. Although the majority of the precipitation and damage occurred in Weld and Logan counties, Phillips County received heavy local precipitation in and around the communities of Haxtun and Paoli.

A Pacific frontal system moved into Colorado on the afternoon of June 2 following several days of hot dry weather. Maximum daily temperatures on June 1 and 2 were in the mid 80s (°F), while minimum daily temperatures were in the mid 50s (°F). The nearest weather stations with relatively complete weather data are located in Sidney, Nebraska, and Akron, Colorado. Average dew points at these stations were 55 and 57°F, respectively. The average relative humidity ranged from about 65 to 70 percent. The prevailing wind direction was from the east or southeast.

The thunderstorms of June 14 and 15 were similar to those that developed on June 2. Maximum daily temperatures on June 13 and 14 were in the mid 70s (°F), while minimum daily temperatures were in the mid 50s (°F). The average dew point at the Sidney, Nebraska, and Akron, Colorado, weather stations ranged from 52 to 57°F. These stations recorded average relative humidities on these dates of approximately 58 to 66 percent, and the prevailing wind direction varied. ***Table 4.11-2*** summarizes the weather data at these two stations for June 2, 14, and 15.

Table 4.11-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from north)
Sidney, NB	6/2	56	73	25.54	70	55	10.6	130
Akron, CO	6/2	55	76	25.20	73	57	15.4	100
Sidney, NB	6/14	53	82	25.54	63	55	15.3	170
Akron, CO	6/14	55	79	25.20	70	57	15.7	120
Sidney, NB	6/15	52	76	25.50	65	52	11.5	320
Akron, CO	6/15	53	76	25.17	68	54	9.9	280

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C)

(Linsley et al. 1992)
Source: National Climatic Data Center 1998a

4.11.4.1 Storm Duration and Rainfall Quantities

A severe thunderstorm producing localized heavy precipitation in western Phillips County over Sandy Creek and Frenchman Creek developed on June 2. Rainfall totals of between 2 and 4.5 inches were reported in and around Haxtun for the 24-hour period extending from 7:00 a.m. on June 2 through 7:00 a.m. on June 3. The majority of rain fell within a 6-hour period on the evening of June 2 from approximately 4:00 p.m. to approximately 10:00 p.m. The CWCB did not conduct a rainfall bucket survey for this event, but several weather observers in Phillips County collected rainfall information that is summarized in ***Table 4.11-3***.

Neither a radar estimate of the total storm precipitation nor an isohyetal map were obtained for the June 2 event.

A severe thunderstorm producing extremely heavy precipitation over the Frenchman Creek and Wildhorse Creek watersheds developed on the evening of June 14. Rain began falling in Phillips County west of Holyoke around 9:45 p.m. on June 14 and ended at approximately 1:00 a.m. on June 15. Total storm duration was on the order of 3 hours with the most rainfall occurring in the first 2 hours. Rainfall amounts of up to 5.5 inches were reported by the NWS, and 6 inches were reported by the Phillips County Sheriff at a location near the community of Amherst. A NWS spotter in southwestern Phillips County reported an accumulation of 1.3 inches in a 30-minute period. The Associated Press reported a 5- to 6-inch rain occurring before dawn on June 15. The LaMunyon reported that a slow moving thunderstorm dropped up to 6 inches of rain on the area.

Table 4.11-3
Point Rainfall Amounts Recorded in Phillips County
for June 2, 1997

Source	Station	Amount	Recording Period
Mountain States Weather Services (1997)	Holyoke	1.85 inches	6/2/97 @ 6:30 p.m. to 6/3/97 @ 1:00 a.m.
Mountain States Weather Services (1997)	28170 County Rd. 13 (2 miles east of Haxtun)	2.8 inches	6/2/97 @ 4:00 p.m. to 6/3/97 @ 10:00 p.m.
Haynes and Haynes (1998)	24643 County Rd. 29 (5 miles west of Holyoke)	approximately 3 inches	6/2/97 @ 4:00 p.m. to 6/3/97 @ 1:00 a.m.
Gray (1998)	Haxtun	2.9 inches	6/2/97 @ 4:00 p.m. to 6/3/97 @ 1:00 a.m.
Schafer (1998d)	03105 County Rd. 14 (8 miles south of Haxtun)	4.5 inches	6/2/97 @ 4:00 p.m. to 6/3/97 @ 1:00 a.m.

A CWCB flood documentation team conducted a rainfall bucket survey on June 17 and June 18, 1997. Rainfall estimates were obtained through bucket surveys, interviews with local officials and residents, and field observations.

In addition to the rainfall bucket survey, the NWS computed the total storm precipitation using NWS radar data from June 13 at 10:00 a.m. through June 15 at 6:00 a.m. (the Technical Addendum contains a graphical image of the storm total precipitation). The radar data (see Technical Addendum for radar images) showed three bullseyes of heavy precipitation: the first was centered approximately 6 miles west of Amherst, the second was centered just south of Sedgwick County at the Colorado-Nebraska state line, and a third was centered in Nebraska. The peak storm total computed by the NWS from the radar data for each of the three bullseyes was approximately 5.5 inches. Using a storm duration of 3 hours (as reported by the CWCB flood documentation team), the average rainfall intensity was approximately 1.7 inches per hour.

The NWS storm total precipitation map for June 13 through 15 was digitized and overlaid on a map containing the point rainfall totals collected by the CWCB rainfall bucket survey team for July 14 through 15. Using both the NWS radar data and the rainfall bucket survey amounts, an isohyetal map

was generated for the period from June 14 at 9:45 p.m. through June 15 at approximately at 1:00 a.m. and is shown in *Figure 4.11-3*.

4.11.4.2 Estimated Point Precipitation Return Periods

The point precipitation totals for Frenchman Creek for storm durations of 6 hours, 12 hours, and 24 hours for return periods of 10 and 100 years (as developed from the NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado [1973]) are shown in *Table 4.11-4*.

Table 4.11-4
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation	100-yr Precipitation
6 hours	2.8 inches	4.2 inches
12 hours	3.1 inches	4.6 inches
24 hours	3.4 inches	5.0 inches

A summary of the point precipitation for the Phillips County storm events of June 2 and June 14 through 15, 1997, is shown in *Table 4.11-5*.

Table 4.11-5
Summary of Storm Precipitation, Duration, and Return Period for Phillips County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
Mountain States Weather Services (1997)	2 miles east of Haxtun	June 2	2.8 inches	6 hours	< 100-year
Gray (1998)	Haxtun	June 2	2.9 inches	9 hours	< 100-year
Schafer (1998d)	8 miles south of Haxtun	June 2	4.5 inches	6-9 hours	100-year
NOAA/ NWS (1997c)	Southwest Phillips County	June 14	1.3 inches	30 min	
National Climatic Data Center (1998b)	West of Amherst	June 14-15	5.5 inches	3 hours	> 100-year
CWCB (1997e)	West of Amherst	June 14-15	6.0 inches	3 hours	> 100-year

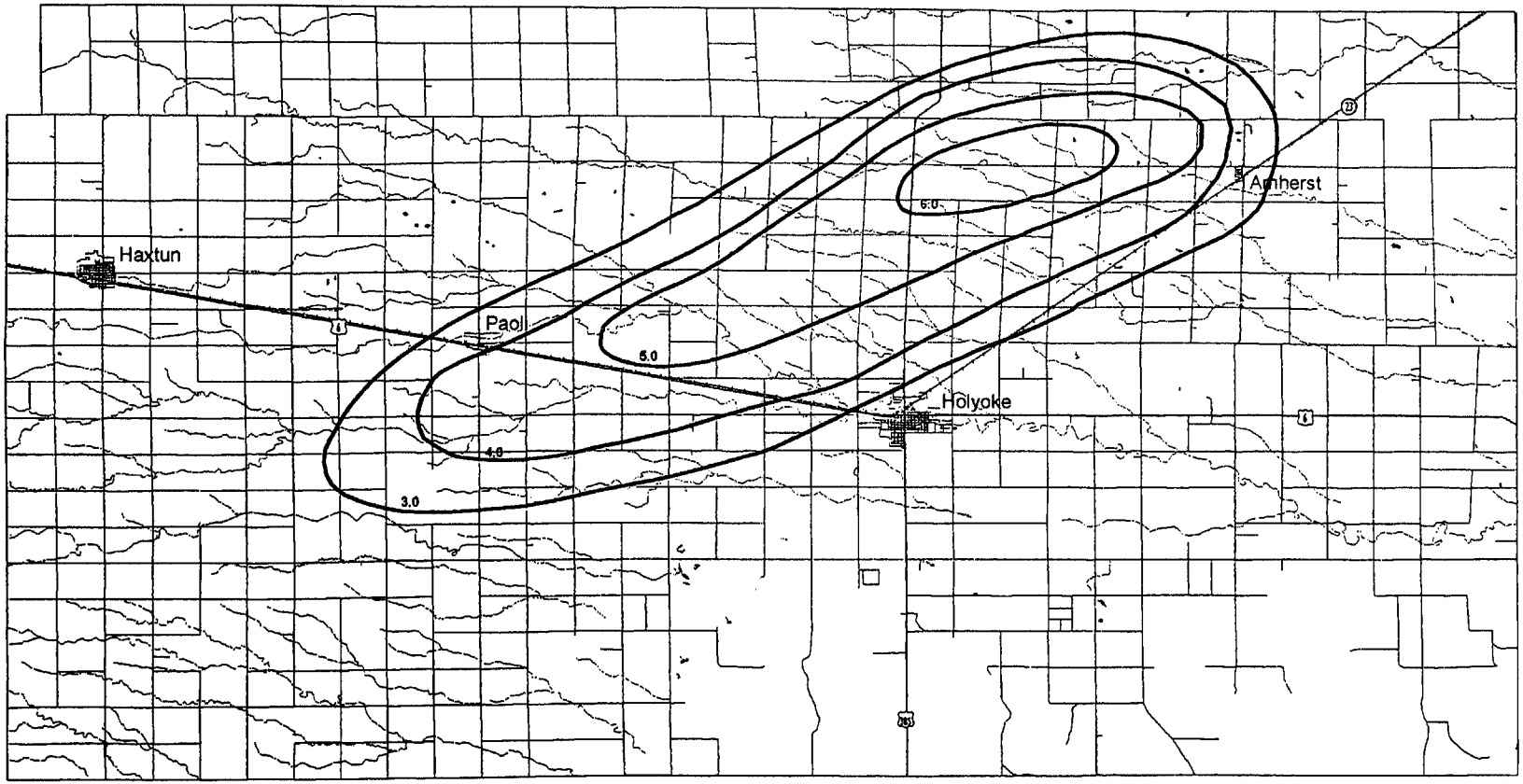


Figure 4.11-3

Phillips County

Precipitation Map

10:00 p.m. June 14 - 1:00 a.m. June 15, 1997
(3-hour Storm Total)

Rivers and Streams
Canals and Ditches
Primary Roads
Secondary Roads
Railroads

3.0 Isohyetal Line (Inches)
Lakes and Reservoirs
Municipal Boundaries

2 0 2 4 6 8 10
Miles

N

Riverside Technology, inc.

4.11.5 Hydrology and Hydraulic Findings

4.11.5.1 Locations/Reaches of Flooded Streams

June 2, 1997

In general, Sandy Creek experienced flooding conditions along several reaches because of the precipitation on June 2, 1997. The flooding situation was complicated by the presence of highway and railroad embankments that transect these drainages.

Figure 4.11-4 shows the flooding along Sandy Creek at Highway 59. *Figure 4.11-5* shows the flooding along an unnamed tributary to Sandy Creek.

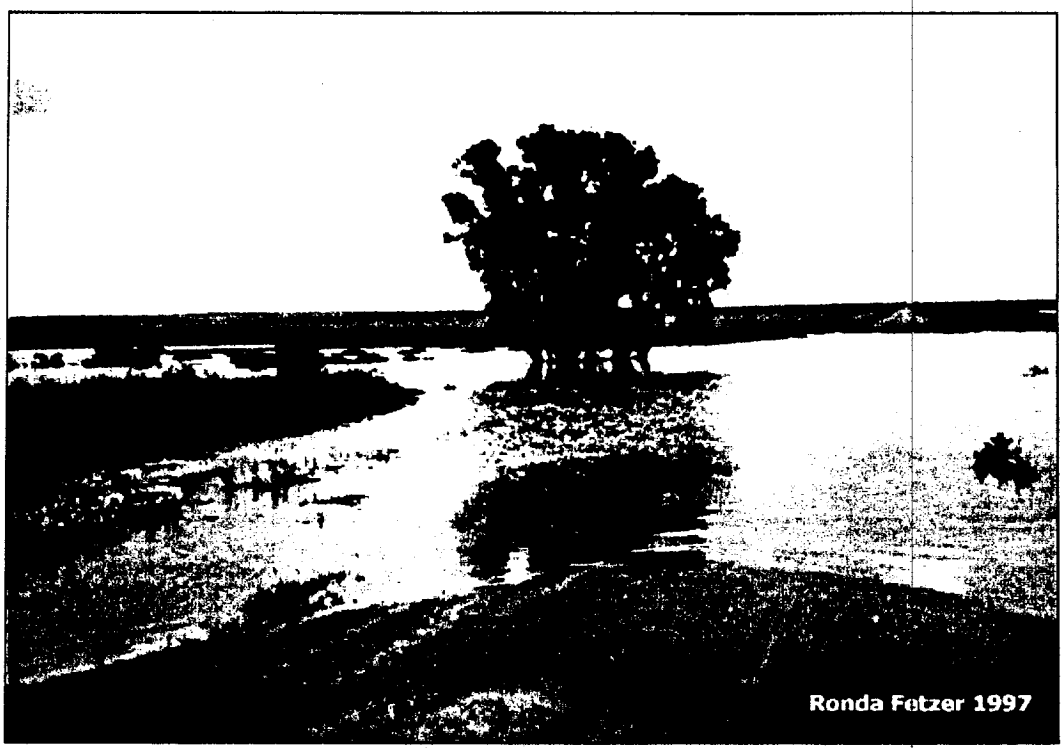


Figure 4.11-4 Flooding Along Sandy Creek at Highway 59

June 14 and 15, 1997

In general, all the tributaries between Holyoke and Amherst, including Frenchman Creek and Wildhorse Creek, experienced flooding conditions along several reaches. The flooding situation was complicated by the presence of highway and railroad embankments that transect these drainages. In addition, the Frenchman Creek State Wildlife Area (Means Lake) on the South Fork of Frenchman Creek affects the natural response of the watershed upstream of Holyoke.

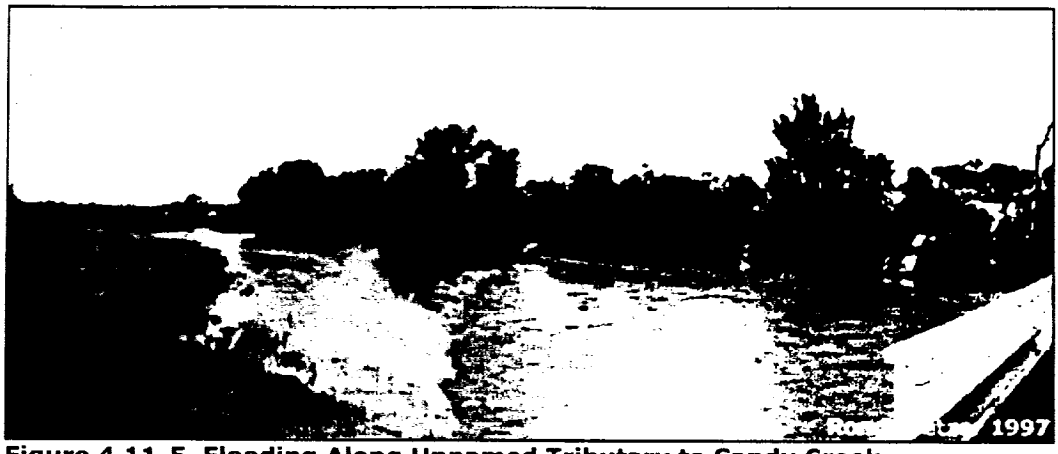


Figure 4.11-5 Flooding Along Unnamed Tributary to Sandy Creek

Flood waters along the South Fork of Frenchman Creek did not overtop the earthen dam at Means Lake. However, the debris line came within 2 inches of the top of the dam. The depth of water over the top of the spillway was approximately 2 feet (Wieland 1998).

Frenchman Creek from 4 miles east of Haxtun to the Colorado-Nebraska state line experienced out-of-bank flooding conditions at various locations. Flooding on Frenchman Creek downstream of Holyoke is shown in *Figure 4.11-6*. The photograph was taken looking southwest over Fish Pond and the sewage lagoons toward the community of Holyoke.

An unnamed drainage enters Frenchman Creek at Highway 6, approximately 2 miles east of Highway 385. This unnamed drainage experienced flooding conditions from its confluence with Frenchman Creek northwest to the Burlington Railroad. *Figure 4.11-7* shows the area at the confluence of Frenchman Creek with the unnamed drainage. The photo was taken looking west along Highway 6.

Wildhorse Creek at Highway 23/Burlington Railroad also experienced flooding conditions.

An unnamed drainage immediately north of Wildhorse Creek experienced flooding conditions that damaged the railroad embankment and Highway 23 where the creek crosses the highway/railroad. *Figures 4.11-8* and *4.11-9* show the flooding along Highway 23 and the associated damage to the railroad embankment from the flooding on this creek. Approximately 90 feet of railroad embankment were washed out.

The unnamed drainage that runs through the southern portion of the community of Amherst experienced flooding conditions for several miles on either side of Highway 23. *Figure 4.11-10* shows the flooding along Highway 23 just south of Amherst.

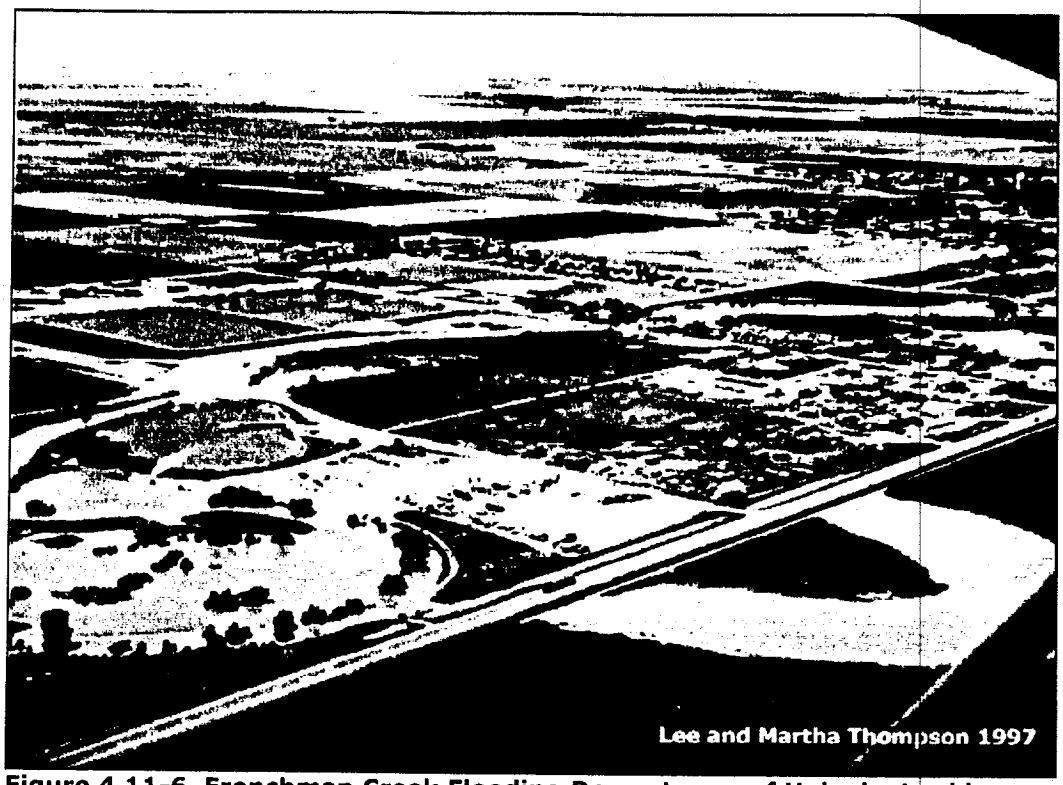


Figure 4.11-6 Frenchman Creek Flooding Downstream of Holyoke Looking Southwest Over Fish Pond and the Sewage Lagoons

Figure 4.11-7 Frenchman Creek Confluence With Unnamed Drainage Near Notters Dairy

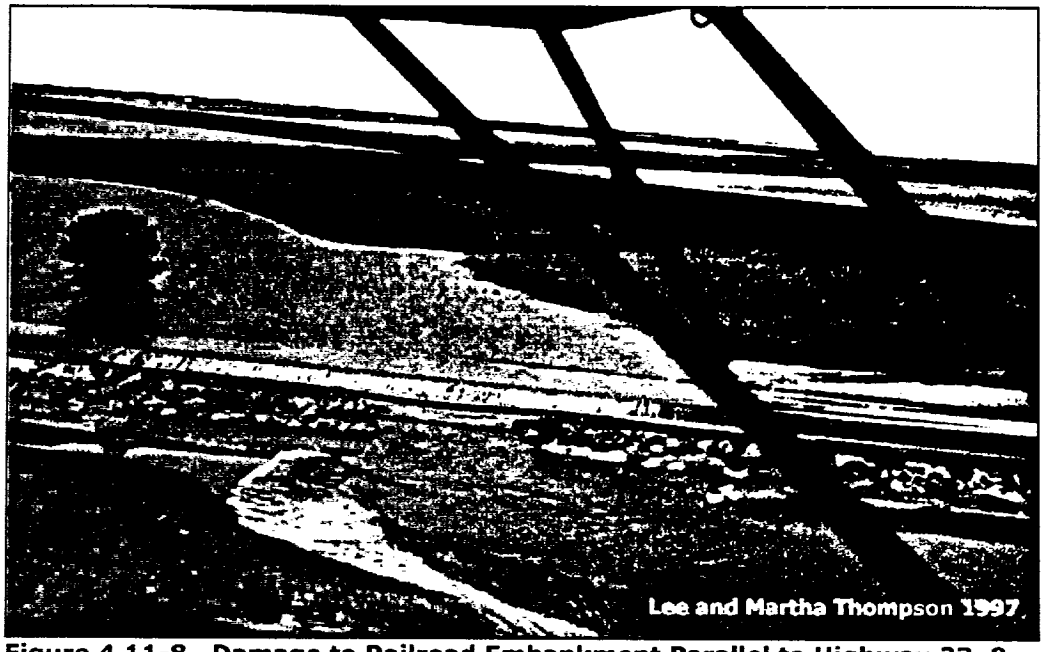


Figure 4.11-8 Damage to Railroad Embankment Parallel to Highway 23, 9 Miles Northeast of County Road 51

Figure 4.11-9 Damage to Railroad Embankment Near Intersection of Highway 23 and County Road 51

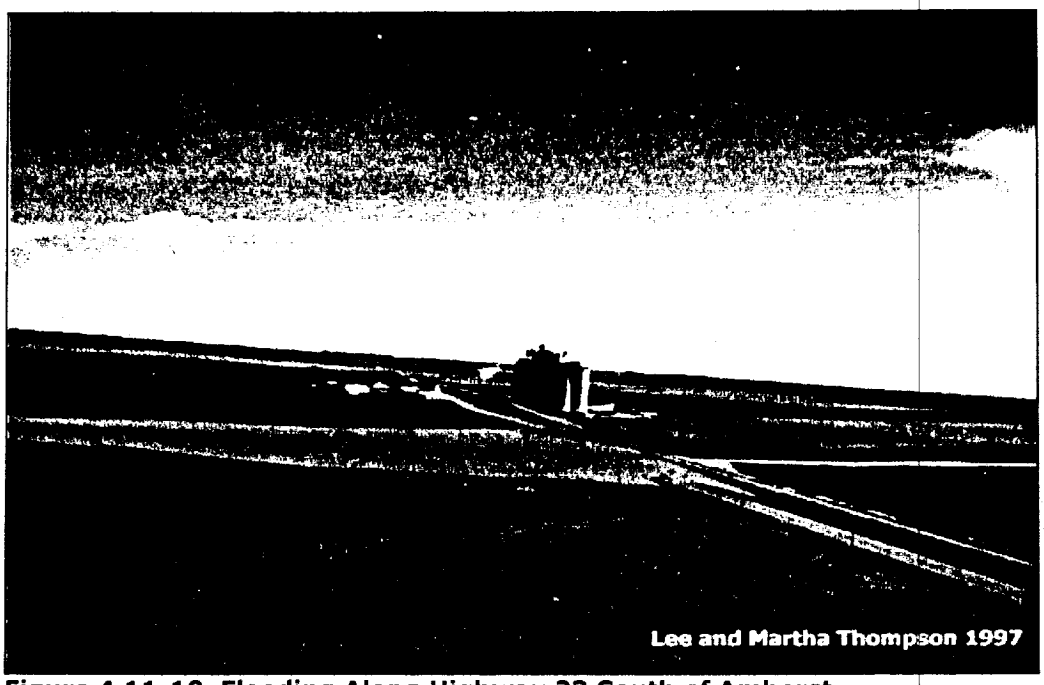


Figure 4.11-10 Flooding Along Highway 23 South of Amherst

4.11.5.2 Channel Characteristics

The natural channels in Phillips County, including Frenchman Creek and Wildhorse Creek, drain agricultural lands and undeveloped rangeland. These channels are irregular in nature, have relatively mild slopes, and are generally well defined. The channels consist of primary stream cross sections with overbank flood plains.

Frenchman Creek downstream of Highway 6 has an average depth of approximately 8.5 feet and an average width of approximately 160 feet. The North Fork of Frenchman Creek near Highway 6 just west of Paoli has an average depth of approximately 8.0 feet and average width of approximately 90 feet. The South Fork of Frenchman Creek near County Road 35 (2 miles west of Holyoke) has an average depth of approximately 7.0 feet and an average width of approximately 95 feet.

4.11.5.3 Peak Flows and Estimated Return Periods

Excessive runoff from the rainfall on June 14 through 15, 1997, caused several creeks within Phillips County to overflow their banks. The stage in Frenchman Creek rose to 10 feet above its normal level in the community of Holyoke (NOAA 1997b). A CWCB flood documentation team was dispatched to Phillips County on June 17, 1997, to perform field investigations, and to compute peak discharges for several locations along Frenchman Creek, and for a tributary to Wildhorse Creek.

In order to estimate peak discharges, the CWCB flood documentation team identified and surveyed cross section locations, flagged high water marks, and measured channel slopes. The team estimated peak discharges by employing Manning's equation under the assumption of normal flow.

Several indirect flow estimates were determined and averaged at each of the locations. The computed peak discharges for the study area are presented in ***Table 4.11-6.*** A range of flows is presented because of the inherent uncertainty in estimating peak discharges.

4.11.5.4 Flood Hydrograph

On the basis of information gathered from community residents, county officials, and CWCB flood documentation team members, the approximate chronology of flooding for Frenchman Creek near the community of Holyoke associated with the storm event of June 14 through 15, 1997, is shown in ***Table 4.11-7***.

Based on the chronological information contained in ***Table 4.11-7***, an approximate hydrograph can be established for Frenchman Creek in the community of Holyoke. This hydrograph is shown in ***Figure 4.11-11.***

A flood hydrograph was not estimated for Wildhorse Creek or the other unnamed tributaries in the County because a chronology of flood flows could not be established for these locations.

4.11.6 Specific Flooded or Inundated Areas

Specific flooded or inundated areas are documented only for the flooding resulting from the June 14 through 15 storm event. Little information regarding specific flood inundation boundaries for the other storm events was available.

Overall, flooding was extensive in Phillips County as a result of the storm event on June 14 through 15, 1997. The LaMunyon reported that the water "ran out of places to go" (LaMunyon 1997). As a result, water inundated fields, homes, and roads (see ***Figures 4.11-4*** through ***4.11-10***). All highways in and out of Holyoke and Amherst were closed on June 15, 1997 (LaMunyon 1997).

Flood waters from Frenchman Creek inundated a large area within the community of Holyoke. A CWCB flood documentation team delineated the approximate flood plain limits within Holyoke on June 17 and 18. Residents within Holyoke reported water levels as high as 4 to 5 feet within their homes and businesses (LaMunyon 1997). ***Figure 4.11-12*** shows the approximate extent of areas inundated by flood waters as documented

Table 4.11-6
Computed Peak Discharge for the Storm Event of June 14 - 15, 1997

Location	Drainage Area (square miles)	Estimated Peak Flow (cfs)	Estimated Return Period[1]
North Fork Frenchman Creek Near Highway 6, West of Paoli	Not estimated	250 to 350	Not estimated
North Fork Frenchman Creek Downstream of Road 37, West of Holyoke	163	1,600 to 2,000	10-year
South Fork Frenchman Creek Near Road 33, 3 miles West of Holyoke	62	1,800 to 2,200	25-year
South Fork Frenchman Creek Near Road 35, 2 miles West of Holyoke	63	1,800 to 2,200	25-year
Frenchman Creek Downstream of Highway 6 in Holyoke	228	3,600 to 4,000	25-year
Frenchman Creek at Golf Course in Holyoke	227	3,600 to 4,000	25-year
Left Bank Tributary to Frenchman Creek, 1.5 miles northeast of Holyoke Near Highway 23 and Road 41	9	600 to 800	50-100-year
Left bank Tributary to Wildhorse Creek at Amherst, Near Highway 23 and Road 51	16	1,800 to 2,200	100-year

[1]Return periods based on hydrology values published in COE 1980 where available; other frequency estimates based on CWCB regional regression equations for the Republican River basin.

by the CWCB flood team. The water receded considerably during June 15, and that evening as little as 6 to 12 inches of water was still present.

The flood waters from other inundated areas within the county also receded considerably on June 15; however, considerable ponding of agricultural lands continued for 3 to 5 days. This ponding contributed to the significant damage to crops sustained by agricultural interests in the county.

Table 4.11-7
Chronology of Flooding Near Holyoke
Along Frenchman Creek

Date/Time	Description of Event
June 14, 9:30 p.m.	Public reports hail southwest of Holyoke
June 14, 9:45 p.m.	Heavy rainfall (1.3 inches in 30 minutes) reported west of Holyoke
June 15, 00:32 a.m.	Reports of flooding on Highway 385 south of Holyoke (three girls rescued)
June 15, 1:00 a.m. to 2:00 a.m.	Rainfall ends
June 15, 5:16 a.m.	Sand bagging failing, evacuation of residents in Holyoke
June 15, 6:40 a.m.	Phillips County Sheriff reports flooding in Holyoke with 3 to 5 feet of water with Frenchman Creek still rising
June 15, 7:00 a.m. to 7:30 a.m.	Peak flood stage in Holyoke
June 15, 7:50 a.m.	Phillips County Sheriff reports that Frenchman Creek was beginning to recede
June 15, 8:00 p.m.	Frenchman had receded by 5 to 6 feet
June 17, 12:00 p.m.	Observed baseflow in creek of approximately 50 cfs

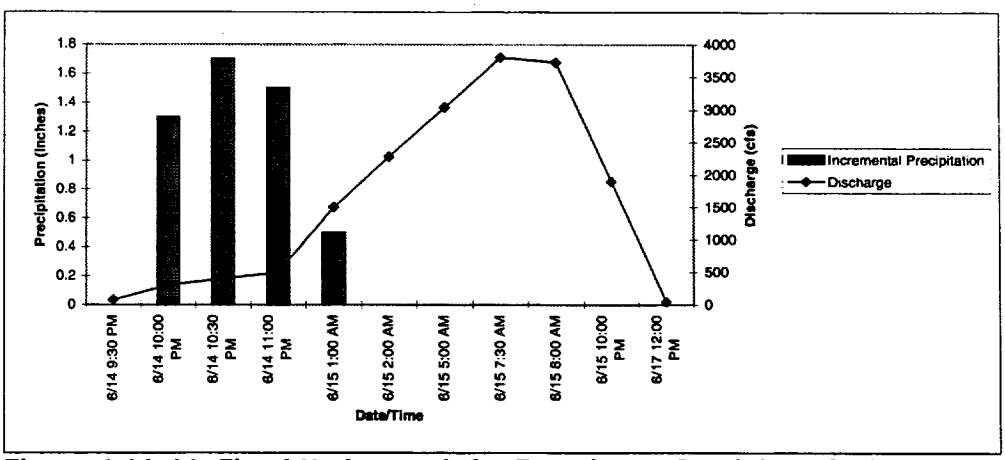


Figure 4.11-11 Flood Hydrograph for Frenchman Creek in Holyoke

4.11.7 Emergency Response Effort

In the early morning hours (just past midnight) of June 15, 1997, Holyoke police and a private citizen rescued three teenage girls from their car that had become stranded in flood water running across Highway 385 just south of Holyoke (NOAA 1997b). At about this same time, the Phillips County Sheriff put out a call for help over the police scanner. Within 45 minutes, 100 to 200 people were out bagging sand and helping (Associated Press 1997).

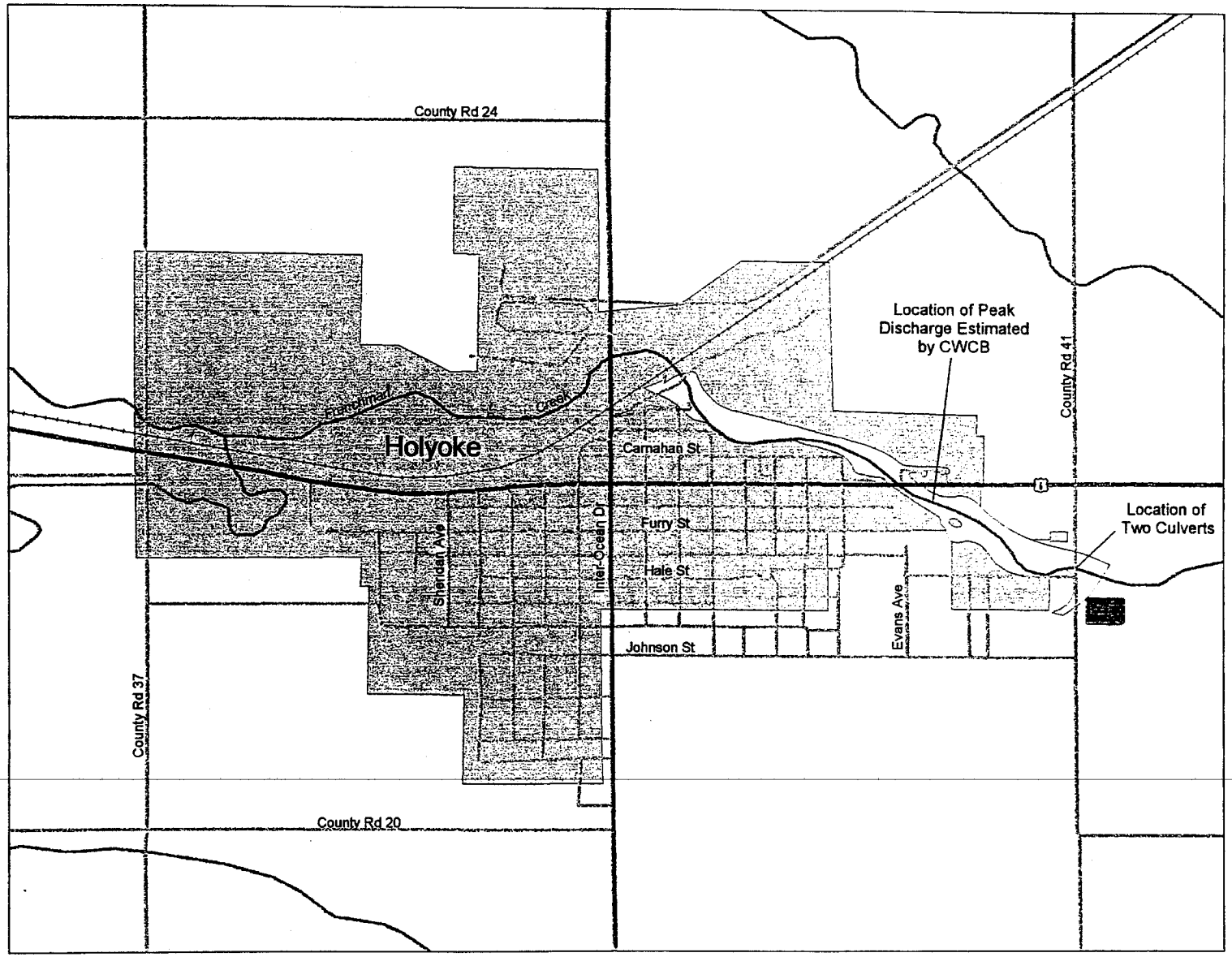


Figure 4.11-12

Phillips County

Flood Inundation Boundary

June 15, 1997

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County road crews and State Patrol officers were dispatched to close roads and alert motorists of the dangerous conditions.

Those responding to the local law enforcement call for help included the Red Cross, off duty dispatchers and officers, the fire department, EMS workers, the city and county, neighboring counties and cities, Colorado Department of Transportation, State Patrol, churches, businesses, and many private citizens (LaMunyon 1997).

At approximately 5:16 a.m. on June 15, 1997, the Phillips County Sheriff notified the NWS that sand bagging efforts were failing in the Town of Holyoke and residents of Holyoke were being evacuated.

At approximately 6:30 a.m. on June 15, 1997, the Red Cross had established its disaster headquarters in Holyoke. Red Cross volunteers opened a service center at the Holyoke VFW on June 15 to provide assistance to flood victims (LaMunyon 1997).

Flood waters began to recede in Holyoke beginning approximately 7:50 a.m. on June 15, 1997. Roads remained closed in and out of Holyoke on the morning of June 15, but by sundown of that day all roads had been reopened except Colorado Highway 23 (Associated Press 1997).

By the evening of June 15, Frenchman Creek had fallen by as much as 6 feet and community residents had returned to their homes.

4.11.8 1997 Flood Damage

Heavy precipitation on June 2 produced major storm runoff from Frenchman Creek and Sandy Creek. Damage to county roads and bridges that traverse these two creeks was not estimated, nor was damage to residential and commercial properties in Holyoke.

Heavy precipitation on June 14 through 15 produced major storm runoff from Frenchman Creek and Wildhorse Creek. Damage to county roads and bridges, residential and commercial properties in Holyoke, railroad embankments, and agricultural lands was recorded for this event.

The following properties in and around Holyoke were damaged by flood waters on June 15, 1997:

- Thirty-one homes in Holyoke and surrounding areas (seven are uninhabitable)
- Three businesses

- Three county bridges
- At least 15 to 20 major washouts on county roads
- Nearly 100 minor washouts on county roads
- Severe damage to railroad line along Colorado Highway 23
- Damage to the airport runway and washout of the culverts at the end of the runway
- Substantial damage to crops and fields
- Minor to moderate damage to the golf course

Total damage costs were estimated to be approximately $400,000. See ***Table 4.11-8*** for a summary of these costs.

The damage on the golf course mainly consisted of debris on the course and minor damage to the golf cart path crossings of the creek. These items were taken care of by the entity responsible for maintaining the course.

The two culverts located north of the airport at the end of the runway were not replaced after the flood on June 15, 1997. Therefore no costs were estimated for this damage.

Although no dollar figures were determined for the damage sustained by agricultural crops, the USDA-Farm Service Agency (T. King 1998) estimated unofficial damages that are summarized in ***Table 4.11-9***.

During the Presidential Disaster Declaration period of July 28 through August 8, 1997, Phillips County also experienced storm runoff from precipitation on July 29 through 30, 1997. Damage to county roads and bridges from this period was estimated to be approximately $50,746 (FEMA 1998). No damage estimates were prepared for residential and commercial properties, railroads, and agricultural lands.

4.11.9 Flood Hazard Mitigation

4.11.9.1 Previous Efforts

Previous flood mitigation efforts within Phillips County consisted of constructing Means Lake in 1955 and a state funded structural flood control project in Paoli. The project in Paoli consisted of enlarging a highway/railroad underpass and removing silt and debris. The community of Paoli did not experience flooding in 1997.

Table 4.11-8
Damage Estimates From the June 15, 1997, Storm Event

Description	Damage Estimate	Source
County roads	$258,885[1,2]	Phillips County (Schaefer 1998c)
County bridges	$5,226[1,2]	Phillips County (Schaefer 1998c)
Residential properties	$91,078[1,2]	Phillips County (Schaefer 1998c)
Commercial properties	$0	Phillips County (Schaefer 1998c)
Railroad	$43,000[1,2]	NKC Railnet (Lavalley 1998)
Agriculture	No dollar cost estimated	USDA-Farm Service Agency (T. King 1998)
Golf course	$2,000[1,2]	CWCB (Browning 1998b)
FEMA - countywide	$78,470[3]	FEMA Damage Survey Reports (1998)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include some overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

Table 4.11-9
Unofficial Crop Damage Associated With the June 15, 1997, Storm Event

Crop	Affected Acres	Percent Loss
Wheat	8,000	85
Corn	6,000	80
Millet	15,000	95
Beans	1,000	50
Sugar Beets	200	50

Source: T. King 1998

4.11.9.2 Future Needs

The community of Holyoke and Phillips County are cooperatively funding a project to clean and repair Frenchman Creek where it sustained damage in the community of Holyoke. The community also has established a Blue Ribbon Committee to mark trees and bushes that need to be removed from

the channel and floodplain in order to increase channel conveyance. The City of Holyoke is in the process of developing a master drainage plan for the community.

The flood storage capacity in Means Lake could be increased by dredging out the silt and gravels that have accumulated. The increased flood storage could potentially reduce flood volumes on the South Fork of Frenchman Creek during extreme events.

4.11.10 Special Circumstances

In general, all the tributaries in Phillips County can experience flooding conditions along reaches where highway and railroad embankments transect the natural drainage paths. The criteria used to design these crossing were not investigated for this document.

The flooding situation in the community of Holyoke was complicated by the presence of a bicycle bridge and two large culverts installed just north of the airport runway to pass flow from Frenchman Creek under County Road 41. These culverts (approximately 48 inches in diameter each) may have been undersized for the flows experienced in June of 1997 and may have restricted the flow of water.

4.12 Prowers County

4.12.1 Study Area

Climatic conditions over Prowers County produced several powerful thunderstorms during a 2-week period in late July and early August 1997. Prowers County is located on the eastern plains of Colorado, adjacent to the Colorado-Kansas state line along the Arkansas River (see ***Figure 1.1-1***). The area north of the Arkansas River received the brunt of the precipitation and damages that occurred as a result of these storm events. However, a few localized regions south of the river also experienced some flooding. Although the majority of the damages were located in the unincorporated areas of the county, the towns of Lamar, Holly, and Wiley all experienced minor flood damages as a result of localized heavy precipitation. ***Figure 4.12-1*** is a general vicinity map of county.

In Prowers County, county roads and bridges sustained the most serious damage as a result of the runoff generated in the Wiley Drainage Ditch, Wild Horse Creek, and Plum Creek drainages. Lamar, the Prowers County seat (population 8,400), is located approximately 30 miles from the Colorado-Kansas state line and is positioned at the confluence of Willow Creek and the Arkansas River. The Town of Wiley (population 450), is located 8 miles northwest of Lamar and is drained by the Wiley Drainage Ditch. The water from this basin eventually joins the Arkansas River west of Lamar (Town of Wiley 1998). Holly (population 900) is located along the Arkansas River 4 miles west of the Colorado-Kansas state line, where both Wild Horse Creek and Two Butte Creek meet the river.

Land use in Prowers County is predominantly agricultural and includes grazing livestock and cultivating corn, alfalfa, and wheat. The topography of Prowers County is relatively flat with low hills dividing watersheds. The mean annual precipitation for the county is approximately 13 inches.

4.12.2 Watershed Description

The watersheds of interest in Prowers County include the Arkansas River, Wiley Drainage Ditch, Wild Horse Creek, and Plum Creek. The Arkansas River, which runs through the northern half of Prowers County, is the primary drainage of local runoff in the area. Flows down in this reach of the River are partially regulated by John Martin Dam, located approximately 18 miles upstream in Bent County. Water in the Wiley Drainage Ditch flows southeast through Prowers County and, during high flows, eventually drains into the Arkansas River a few miles west of Lamar. Wild Horse Creek meanders south from Kiowa County and drains into the Arkansas River at the Town of Holly. Plum Creek, located in the south-central part of the county, flows northeast into Two Butte Creek, approximately 10 miles southwest of the Town of Holly.

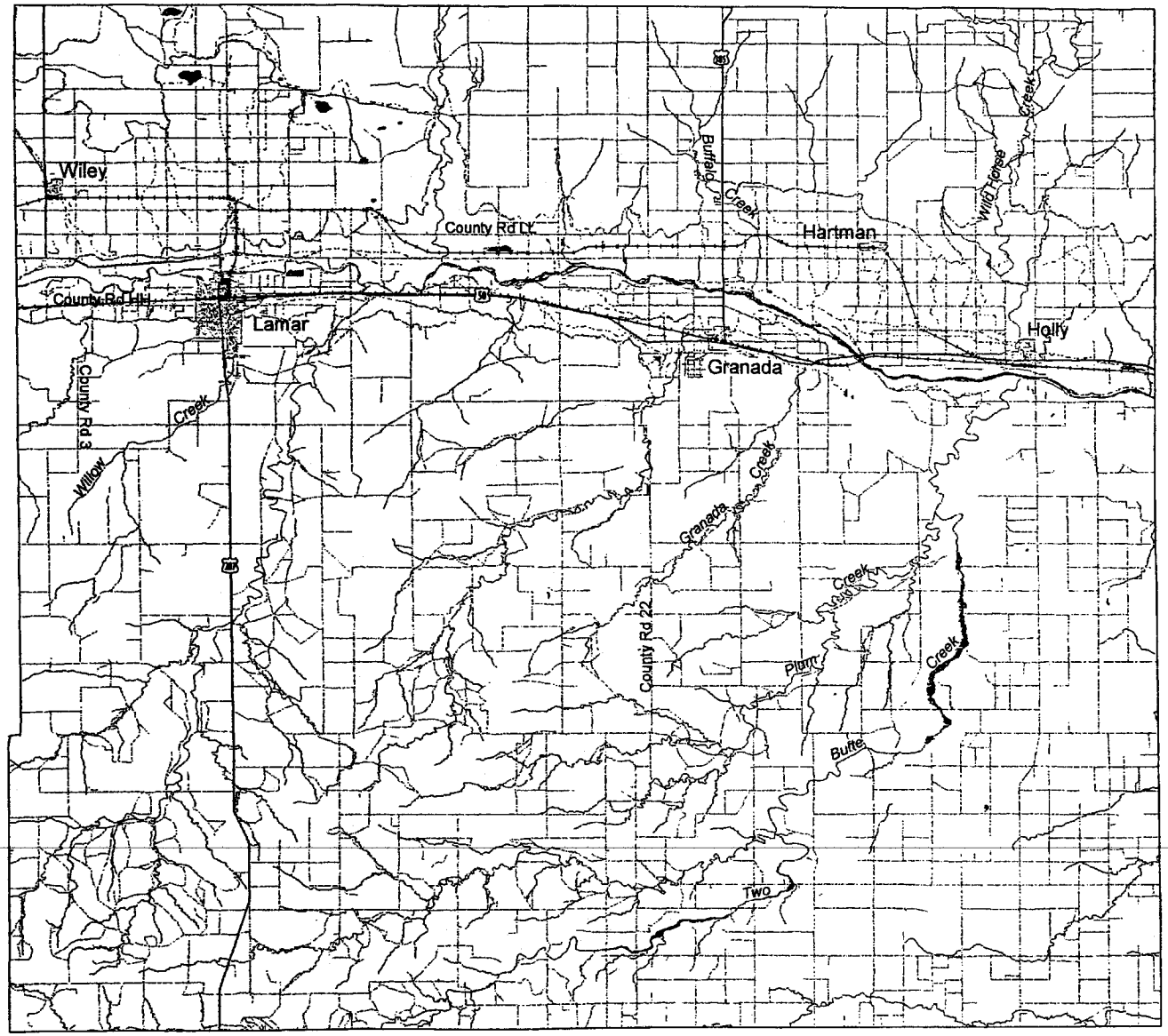
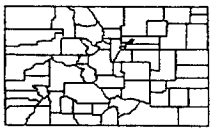


Figure 4.12-1

Prowers County

Vicinity Map



- Rivers and Streams
- Canals and Ditches
- Interstate Highways
- Primary Roads
- Secondary Roads
- Railroads
- Lakes and Reservoirs
- Municipal Boundaries

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Miles

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The headwaters of the Wiley Drainage Ditch begin approximately 8 miles northwest of Wiley in Bent County, just below the Fort Lyons Storage Canal. The total drainage area of this Ditch is 74 square miles (Town of Wiley 1998). The elevation of the basin ranges from approximately 3,700 to 4,000 feet.

Both Wild Horse and Two Butte creeks flow into the Arkansas River along the eastern edge of Prowers County near the Town of Holly. The headwaters of Wild Horse Creek originate 20 miles north of Holly in Kiowa County. The records for the USGS gage near the mouth of Wild Horse Creek (Wild Horse Creek above Holly, Colorado (ID # 07134990), indicate a drainage area of 270 square miles. The elevation of the drainage ranges from 3,405 to approximately 4,000 feet.

Two Butte Creek begins in Baca County (see Section 5.1.2) and drains 812 square miles. This creek is partially regulated by Two Butte Reservoir, located just south of the Prowers-Baca County line. Within Prowers County, the elevation of Two Butte Creek ranges from approximately 3,415 feet at the USGS gage near Holly (Two Butte Creek near Holly, Colorado; ID # 07135000) to 4,200 feet.

4.12.3 Local Flooding Problems

Typical flooding problems in Prowers County originate from flash floods on the tributaries of the Arkansas River. In the western portion of the county, the most frequent flooding occurs within the Wiley Drainage Ditch basin. When flash floods occur in this watershed, the houses on the north end of the Town of Wiley, upstream of Highway 196, occasionally experience flooding problems (Town of Wiley 1998). In addition, low-lying areas along the Arkansas River west of Lamar also experience frequent flooding.

In eastern Prowers County, areas that typically experience flooding are located in rural parts of the county. However, in Holly, low elevation areas along and south of Highway 50 are more likely to experience flooding problems.

4.12.4 Storm Characteristics

While other counties described in this report experienced damaging storm events throughout the summer of 1997, heavy rainfall in Prowers County was concentrated during early August. Similar to conditions in other southeastern counties, the type of storms in this region of Colorado differed significantly from those observed in the northeastern counties. While areas such as Larimer and Logan counties experienced 10+ inches of rainfall in 24-hour storm events (or less), the summer storm pattern in Prowers County produced numerous storms with moderately heavy rainfall and a few days of intense precipitation, primarily over a course of 1 week.

Table 4.12-1 summarizes those intense storms that produced over 1 inch of rain recorded at 2 or more NWS cooperative or spotter stations during a 24-hour period in July and August of 1997.

Table 4.12-1
Dates of Significant Precipitation in Prowers County During 1997

Date	Maximum Precipitation	Comments
July 28-29	1.05 inches	Heavy rains over areas near Wiley and Lamar
August 4-5	3.0+ inches	Heavy precipitation throughout rural areas south of Lamar and Granada
August 5-6	3.16 inches	Damaging storms producing 2.0+ rainfall amounts at NWS Lamar and Holly gages
August 10	1.85 inches	Rainfall observed in eastern part of Prowers County near Holly

Although the NWS Cooperative stations at Lamar and Holly recorded over an inch of precipitation in no more than 24-hours on July 28 and August 10, no additional information is available to further document these storms. Therefore, the primary focus of this discussion is on the storms that produced rainfall over the first few days of August, specifically the evenings of August 4 and 5. While the entire county witnessed some rainfall, the strongest precipitation intensity on the evening of August 4 occurred south of Granada. Data recorded at NWS stations during the evening of August 5 suggest that towns along the Arkansas River corridor received considerable amounts of precipitation.

The nearest weather station that recorded multiple types of atmospheric data is located in Lamar. Daily data was collected at this station for each of the four events identified in ***Table 4.12-1***. A summary of this meteorological data is presented in ***Table 4.12-2***.

Although this gage provides a good estimate of meteorological conditions in western Prowers County, the data presented in ***Table 4.12-2*** may not completely represent those conditions on the eastern side of the county. This is primarily because of the convective nature of thunderstorms on the eastern plains of Colorado, which produce significant spatial variability within a region.

Table 4.12-2
Summary of Meteorological Data

Location	Date	Minimum Temp. (°F)	Maximum Temp. (°F)	Average Barometric Pressure (inches of Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
Lamar, CO	7/29	64	85	26.37	74	66	13.4	130
Lamar, CO	8/4	66	90	26.43	64	65	6.5	90
Lamar, CO	8/5	64	73	26.38	84	64	10.9	120
Lamar, CO	8/6	57	66	26.37	90	59	9.8	70
Lamar, CO	8/10	60	68	26.26	90	61	11.1	120

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C)

(Linsley et al. 1992)
Source: National Climatic Data Center 1998a

4.12.4.1 Storm Duration and Rainfall Quantities

The storm precipitation estimates for the events on the evening of August 4 were based on NWS radar data from the Pueblo Weather Service Office (see Technical Addendum for radar images). The radar data of precipitation totals and the NWS cooperative ground-level 24-hour observer data (***Table 4.12-3***) were converted to isohyets, which are displayed in ***Figure 4.12-2***. As observed from this map, the largest pocket of rainfall, 3.0+ inches, fell over southern regions of Prowers County, near the towns of Lamar and Granada. A summary of the point precipitation collected for all storm events greater than 1 inch is presented in ***Table 4.12-3***.

Table 4.12-3
Point Rainfall Amounts Recorded in Prowers County for August 4-6, 1997

Source	Location	Amount	Recording Period
Colorado Climate Center (1998)	Lamar	1.05 inches	7/28/97 @ 7 a.m. to 7/29/97 @ 7 a.m.
Colorado Climate Center (1998)	Lamar	0.82 inches	8/4/97 @ 7 a.m. to 8/5/97 @ 7 a.m.
Colorado Climate Center (1998)	Lamar	2.12 inches	8/5/97 @ 7 a.m. to 8/6/97 @ 7 a.m.
Colorado Climate Center (1998)	Holly	3.16 inches	8/5/97 @ 7 a.m. to 8/6/97 @ 7 a.m.
Colorado Climate Center (1998)	Holly	1.85 inches	8/10/97 @ 7 a.m. to 8/11/97 @ 7 a.m.

During the evening of August 5 and into the morning hours of August 6, radar estimates indicate no more than 1.5 inches fell over the county near the Arkansas River, despite significantly greater rainfall observed by NWS

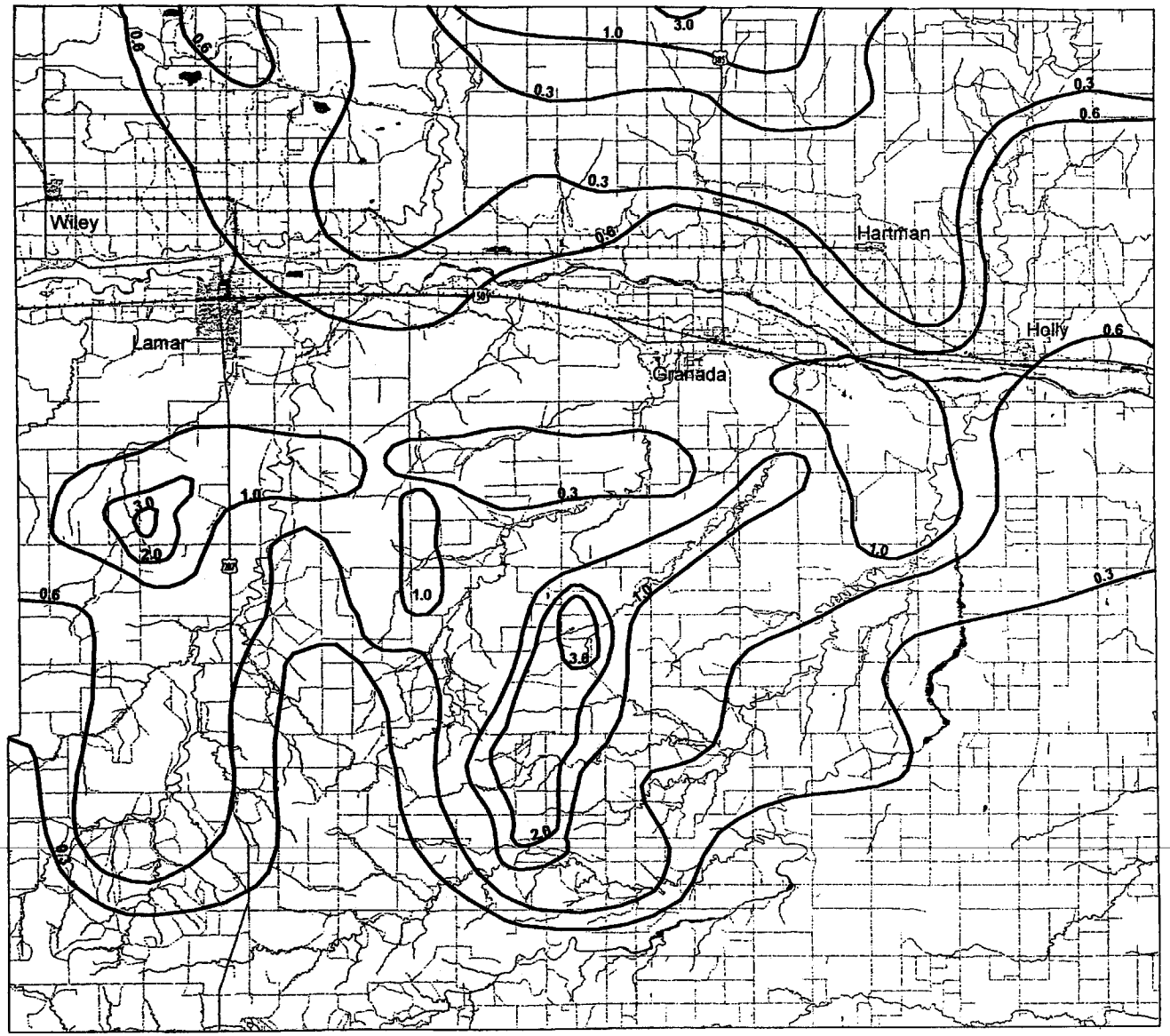
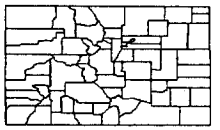


Figure 4.12-2

Prowers County

Precipitation Map

11:59 a.m. August 4 -
7:16 a.m. August 5, 1997



Rivers and Streams
Canals and Ditches
Interstate Highways
Primary Roads
Secondary Roads
Railroads
Isohyetal Line (Inches)
Lakes and Reservoirs
Municipal Boundaries

N

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Miles

Riverside Technology, inc.

cooperative stations in Lamar and Holly. The radar image (see Technical Addendum) displays the time duration in Coordinated Universal Time, which is 6 hours ahead of local time (Mountain Daylight Time).

4.12.4.2 Estimated Point Precipitation Return Periods

The estimated precipitation amounts in Prowers County are presented in ***Table 4.12-4***. The 6-hour, 12-hour, and 24-hour storm durations for the 10-year and 100-year return periods were taken from the maps and nomogram provided in NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado (1973).

Table 4.12-4
10-year and 100-year Point Precipitation Values for Various Storm Durations

Storm Duration	10-yr Precipitation	100-yr Precipitation
6 hours	3.2 inches	5.0 inches
12 hours	3.6 inches	5.4 inches
24 hours	3.9 inches	5.8 inches

The magnitude of precipitation that fell over Prowers County in July and August of 1997 produced damaging floods; however, the flooding in this county resulted not from a single large storm but from several storm events over several days (primarily August 4 through 6). Consequently, none of the individual rainfall totals exceeded the 100-year estimates. ***Table 4.12-5*** shows rainfall amounts and durations compared with 10-year estimates for all four storm events that produced over 1 inch of rain.

The radar estimate of rainfall totals between noon on August 4 through 7 a.m. on August 5 indicate the highest rainfall amount. However, neither this event nor any others shown in ***Table 4.12-5*** exceeded the 10-year, 24-hour estimate.

According to the NOAA Atlas (1973), the biggest storms in 1997 are approximately equal to the 5-year, 24-hour rainfall in Prowers County, which is 3.3 inches. This assumes that the rain fell over the entire 24-hour period; however, the actual storm duration (which could have been less than 24 hours) cannot be ascertained with the available information.

4.12.5 Hydrology and Hydraulic Findings

4.12.5.1 Locations/Reaches of Flooded Streams

A description of the locations and reaches of flooded streams within Prowers County is only presented for the storm events that occurred between

Table 4.12-5
Summary of Storm Precipitation, Duration, and Return Period for Prowers County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
Colorado Climate Center (1998)	Lamar	July 28	1.05 inches	24 hours	< 10-year, 24-hour event
National Climatic Data Center (1998)	South of Lamar and Granada	August 4	3.00+ inches	19 hours	< 10-year, 24-hour event
Colorado Climate Center (1998)	Lamar	August 5	2.12 inches	24 hours	< 10-year, 12-hour event
Colorado Climate Center (1998)	Holly	August 5	3.16 inches	24 hours	< 10-yr, 24-hr event
Colorado Climate Center (1998)	Holly	August 10	1.85 inches	24 hours	< 10-year, 24-hour event

August 4 through 6. Little information regarding the hydrologic response of the watersheds as a result of the storms occurring later in the month is available.

Most of the information known about flooded stream reaches in Wild Horse Creek and Plum Creek stems from FEMA damage survey reports concerning the county roads and bridges. Road damages occurred along the entire length of Wild Horse Creek from the northern boundary of Prowers County to Holly, where flood waters remained for a couple of days before receding (Garcia 1998). At a minimum, inundated areas of Plum Creek included the reach where County Road 22 traverses the watershed.

Flooded reaches of the Wiley Drainage Ditch extended from Highway 196 and County Road LL. Water continued to overtop this ditch for approximately 9 hours (D. King 1998).

4.12.5.2 Channel Characteristics

The natural channels in Prowers County drain agricultural lands and undeveloped rangeland. These channels typically have mild slopes and sandy soils (Neuhold 1998).

The Wiley Drainage Ditch has an average channel slope of 0.2 percent (Town of Wiley 1998). As with other tributaries in the area, its low-flow channel is

well-defined, while the floodplain is flat and poorly-defined. Channel characteristics in Wild Horse Creek are similar, but its channel in the lower reach near Holly is more well-defined and experiences a constant flow rate of approximately 10 cfs (Neuhold 1998).

4.12.5.3 Peak Flows and Estimated Flood Return Periods

Daily streamflow records are available for the Wild Horse Creek watershed from the USGS gage located near the Town of Las Animas in Bent County. However, no gages record streamflow data from runoff generated in the Wiley Drainage Ditch or the Plum Creek basins. The original USGS gage on Wild Horse Creek (ID # 0713600) recorded data from 1923 through 1950. The current USGS gage (ID # 07134990) began monitoring streamflow in this creek in 1995. Both gages indicate drainage areas of 270 acres.

During the peak of the August 1997 streamflow in the Wild Horse Creek basin, the gage did not record data because of an electrical problem with its transducer. However an instantaneous peak flow of 874 cfs on August 7 was computed based on high water marks. Using the drainage area of 270 square miles and the CWCB procedure for the eastern plains within the Arkansas River basin (CWCB 1997b), the 100-year event on Wild Horse Creek is estimated at 33,622 cfs.

Verifying this estimated flow rate with other frequency techniques is difficult since the gage's period of record is very short (only 3 years of annual peak flow are available). Daily streamflow values at this gage have only been recorded since June of 1995. Thus, assuming the 33,662 cfs is the best estimate of the 100-year event, the peak flow recorded on August 7 on Wild Horse Creek was only a fraction of the 100-year event.

4.12.5.4 Flood Hydrograph

The USGS office in Pueblo provided hourly and daily streamflow data during the first week of August 1997 for the Wild Horse Creek gage. Information obtained from the Colorado Department of Water Resources' Water Commissioner in this region indicates that significant diversion headgates exist that would affect the natural runoff from precipitation events (Neuhold 1998).

Since streamflow information on Wild Horse Creek is limited to this gage, its data provides the closest estimate of the natural runoff in Prowers County that was produced from the August storms. ***Figure 4.12-3*** depicts Horse Creek's response to the early August storms, based on daily average flows. As described previously, the instantaneous peak flow is estimated at 874 cfs.

While this streamflow response to rainfall events between August 4 through 6 is a direct result of the storm events that occurred during this period, not all

of the rain fell in Prowers County. The headwaters of Wild Horse Creek in Kiowa County also received a significant amount of rain during this time period (see Section 4.5.4.1). However, no streamflow records are available in the other counties within the Wild Horse Creek watershed that could separate their contribution to the gage readings near Holly.

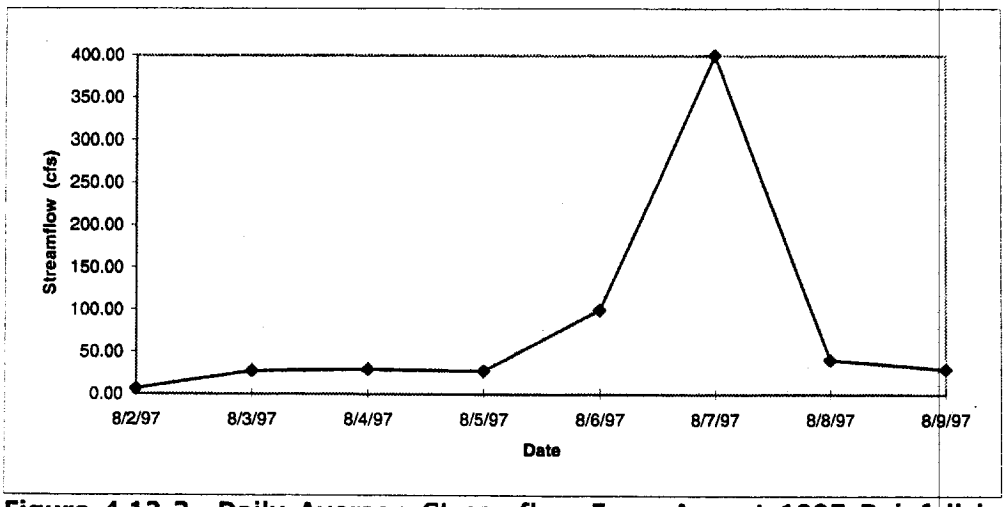


Figure 4.12-3 Daily Average Streamflow From August 1997 Rainfall in Wild Horse Creek Above Holly (USGS ID 071134990)

4.12.6 Specific Flooded or Inundated Areas

Specific flooded or inundated areas documented here resulted from the flooding caused by early August storm events only. While individual flood areas have been located, little information regarding specific flood inundation boundaries is available.

The FEMA damage survey reports summarize the locations of the road and bridge damage that occurred on county roads during this period of flooding. An overview of these damaged areas is presented in ***Figure 4.12-4.***

Damages to County roads and bridges were concentrated near the Wiley area and north of Holly. Flood waters washed out the approaches to the section of the road that traverses the drainages along County Road MM and County Road 3. The bridge on Road LL, originally 14 feet high, also was washed out by storm runoff (D. King 1998). Inundated areas west of Lamar, including County Road HH.5, were confirmed by a private homeowner who lives in the area (D. Fac 1998). Both he and his neighbors experienced some flooding during this time.

Near Holly, one concrete and two oversized rock crossings were damaged on county roads that traverse drainages in the Wild Horse Creek basin. Additional damage was reported within the Buffalo Creek north of Hartman and along County Road 22 within the Plum Creek watershed.

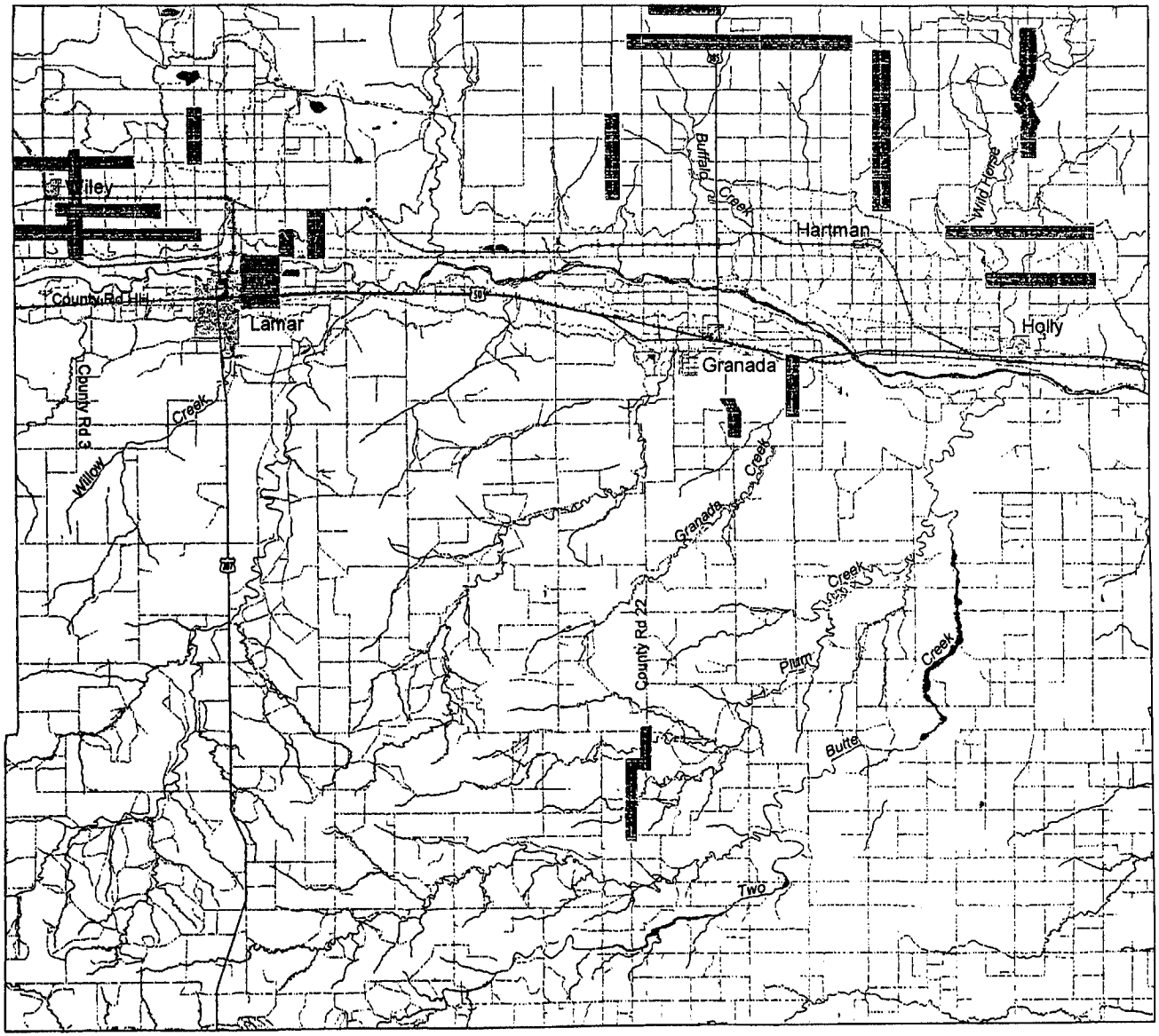


Figure 4.12-4

Prowers County

Damage Areas

Riverside Technology, inc.

Flooding also was reported along Highway 50 in the Town of Holly (McCormick 1998) and along Highway 287 outside of Lamar (D. King 1998). No additional information was available concerning potential flooding on other sections of state highways or the flooding extent in natural watersheds.

4.12.7 Emergency Response Effort

Since most flooding occurred in areas with limited population, the potential damage to habitable structures was minimal. Consequently, little information was available to describe the emergency response to the localized flooding. Prowers County road and bridge officials indicated that County employees erected barricades to close damaged sections of the road and detour signs soon after the floods occurred.

The Road and Bridge Department on the west side of the County had seven people out all night responding to the flooding problems (D. King 1998). State Patrol and County Sheriff officers, as well as County Fire Department employees, also were out to help with traffic control along stretches of road that were still passable in the area near Wiley and Lamar.

In Holly, a house on the north side of town experienced flooding problems (McCormick 1998). To alleviate some of the potential damages at this structure, nine town citizens volunteered to help bail water, while another volunteer ran a County-donated grader to erect a temporary berm to stop additional water from entering this property. Town employees also set up barricades on some inundated streets in the south side of town. In addition, State Patrol officers were out on Highway 50 providing traffic control to reduce the possibility of hydroplaning.

4.12.8 1997 Flood Damage

The available documentation indicates that damages from the 1997 floods in Prowers County were primarily confined to county roads and bridges. The primary source of damage costs associated with the August storms are the FEMA damage survey reports, although some County and town estimates also were available. A summary of these damage estimates for Prowers County are provided in ***Table 4.12-6***.

Although no dollar figures were determined for the damage sustained by agricultural crops, the USDA-Farm Services Agency in Prowers County indicated that the rains disrupted normal farming practices for approximately 2 weeks, causing the quality of some harvested alfalfa to diminish (Hart 1998).

Damages caused by flood waters in west Lamar prompted the city to re-grade some of the alleys, and gas and telephone service were temporarily cut

off because of the damaging storms. At this time, no costs associated with these damages are available (Ward 1998).

Table 4.12-6
Damage Estimates From the Early August 1997 Flood Events

Description	Damage Estimate[1,2]	Source
Prowers County - county roads, west district	$44,106	Prowers County Administrator (1998)
Prowers County - county roads, east district	$90,632	Prowers County Administrator (1998)
Town of Holly	Approx. $900	Town Administrator (McCormick 1998)
Holly private residence	Approx. $4000	Town Administrator (McCormick 1998)
City of Lamar	No dollar cost estimated	City Building Inspector (Ward 1998)
Agriculture	No dollar cost estimated	USDA-Farm Services Agency (Hart 1998)
FEMA - countywide	$102,496[3]	FEMA Damage Survey Reports (1998)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include some overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

4.12.9 Flood Hazard Mitigation

Presently, two sets of flood mitigation measures help alleviate some of the damages that follow flash floods in Prowers County. Within the Wiley Drainage Ditch basin, two irrigation canals, Fort Lyon and Kicking Bird, traverse the watershed upstream of Wiley and reduce some of the runoff volume (Town of Wiley 1998). Levees also have been constructed to reduce flood damages in Lamar and Holly. In Lamar, an earthen levee protects the city from Willow Creek flows, which drains water from land south of the city up to the 100-year flood frequency event (FEMA 1982). At Holly, a 2-mile levee nearly encircles the town to protect it from flash floods on Wild Horse Creek and high flows along the Arkansas River (Garcia 1998).

The COE attempts to minimize the flooding potential along the Arkansas River near Lamar by controlling releases out of John Martin Reservoir. Once flows in the river begin to reach 3,000 to 4,000 cfs, flooding begins in Lamar (Sidebottom 1998).

County officials indicated that a formal flood mitigation plan currently is being drafted. The county is considering all types of passive and active mitigation strategies to help alleviate the flooding problems (Devere 1998). Examples of the active measures being considered include enlarging culverts and adopting channel improvement techniques, such as designing riprap and levees. Alternatively, passive techniques (e.g., park development, wetland enhancement, conservation easements, and development rights) are attractive mitigation measures because they may provide longer-term protection against floods than some active solutions.

In the Town of Wiley, a plan has been recommended to build a new levee just upstream of Highway 196 along the Wiley Drainage Ditch. This mitigation effort will help reduce the flood hazards the nearby homes face each time this drainage overtops.

4.12.10 Special Circumstances

In general, all the tributaries in Prowers County can experience flooding conditions along reaches where highway embankments transect the natural drainage paths. The criteria used to design these crossings were not investigated for this document.

However, the inundation problems experienced in the western part of Prowers County were complicated when flood waters caused the Amity Canal to overtop (D. King 1998). Along with the local runoff, this additional volume covered roads in this vicinity with 2 feet of water at the peak of the flooding event.

In Holly, a new housing development in the north end of town has altered the timing of storm runoff in this area by reducing the ponding time that normally takes place after storms (McCormick 1998). This phenomenon causes stormwater runoff to affect local areas more quickly and at higher flow rates. This condition compounded the problem experienced by the homeowner in northern Holly during these heavy rainfall events.

No other information was available to indicate that unique circumstances existed in Prowers County to cause or exacerbate flooding as a result of the 1997 storm events.

4.13 Routt County

4.13.1 Study Area

Routt County was one of the first of many Colorado communities to experience flooding problems during the summer of 1997. Although the county did not request and did not receive a State or Presidential Disaster Declaration, flood hazards and the threat of high water during early June were quite noteworthy. Unlike the serious flash flooding along the Front Range and eastern plains of Colorado, the higher elevations of the mountains and the mountain valleys in central Routt County mainly experienced snowmelt flooding caused by rapid runoff of the mountain snowpack.

Routt County is located in northwestern Colorado adjacent to the Wyoming border (see ***Figure 1.1-1***) and encompasses an area of 2,367 square miles. Steamboat Springs, the county seat, sits at an elevation of approximately 6,700 feet on the western slope of the Continental Divide. The 1995 population in Steamboat Springs was approximately 8,200. The population of the entire county, including Steamboat Springs, is approximately 16,600 according to 1995 estimates. The Colorado counties that border Routt County include Jackson, Grand, Eagle, Rio Blanco, Garfield, and Moffatt. ***Figure 4.13-1*** is a vicinity map of Routt County.

4.13.2 Watershed Description

The Yampa River, a northerly flowing stream in the area of interest, is a tributary to the Colorado River via the Green River. Its upper drainage basin is bounded by the Elkhead Mountains on the north, the Park Range on the east, and the White River Plateau on the south and west (see ***Figure 4.13-2***). Elevations range from approximately 6,500 feet in the western part of the county to over 12,000 feet in the upper watershed mountain peaks. The climate of the region is characterized by cool summers and cold, snowy winters. Vegetation in the basin varies according to elevation, precipitation, and soils. Much of the Yampa Valley is used to cultivate hay, with the native vegetation being drastically modified by farming practices (COE 1976).

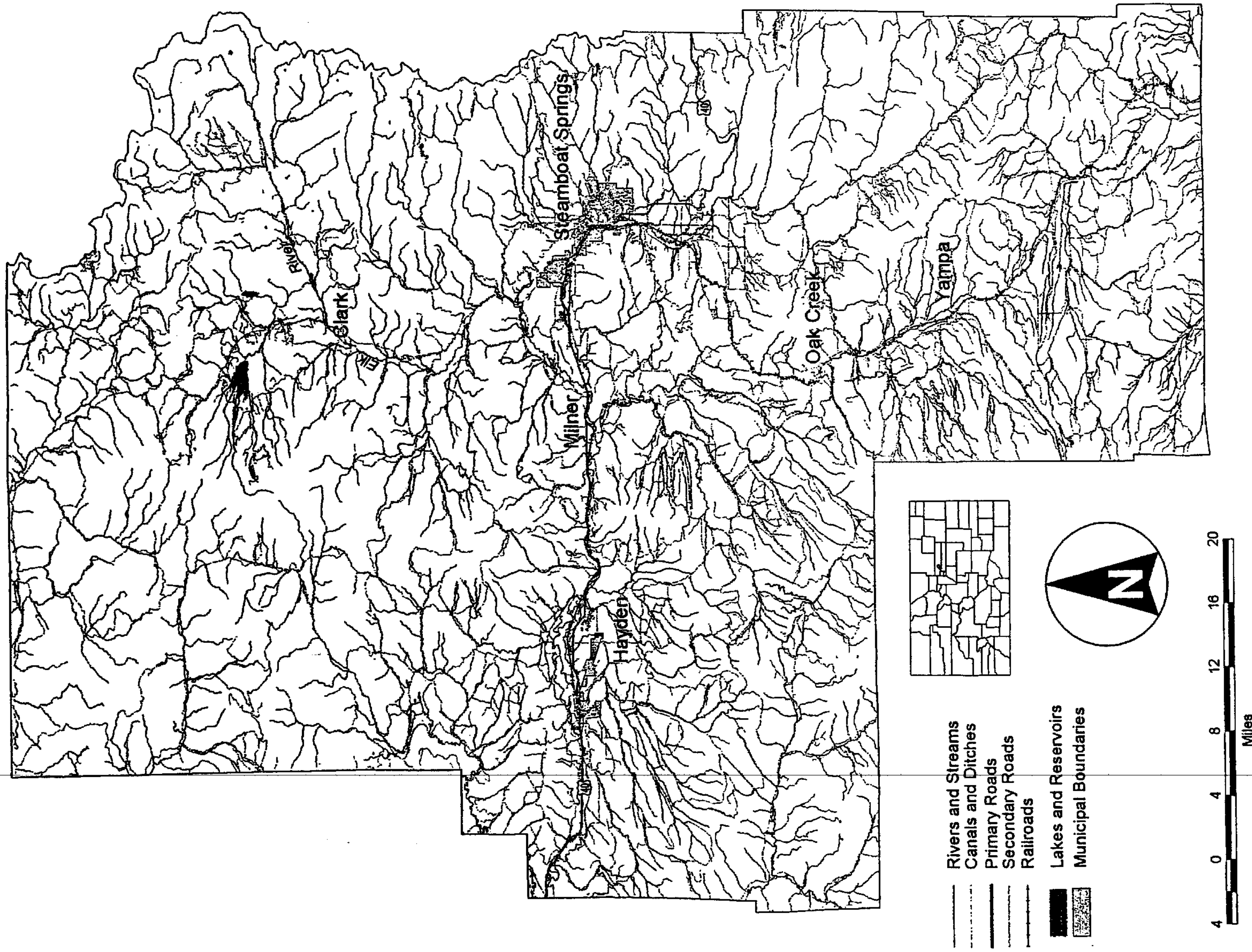
4.13.3 Local Flooding Problems

Most of the annual precipitation in the Yampa River basin occurs as snow, which creates a deep mountain snowpack in the high elevations. General rainstorms covering large areas for extended periods can occur in the Steamboat Springs region from late spring through early fall (COE 1976). Convective type cloudburst storms of small areal extent can be expected frequently during the summer months.

Figure 4.13-1

Routt County

Vicinity Map



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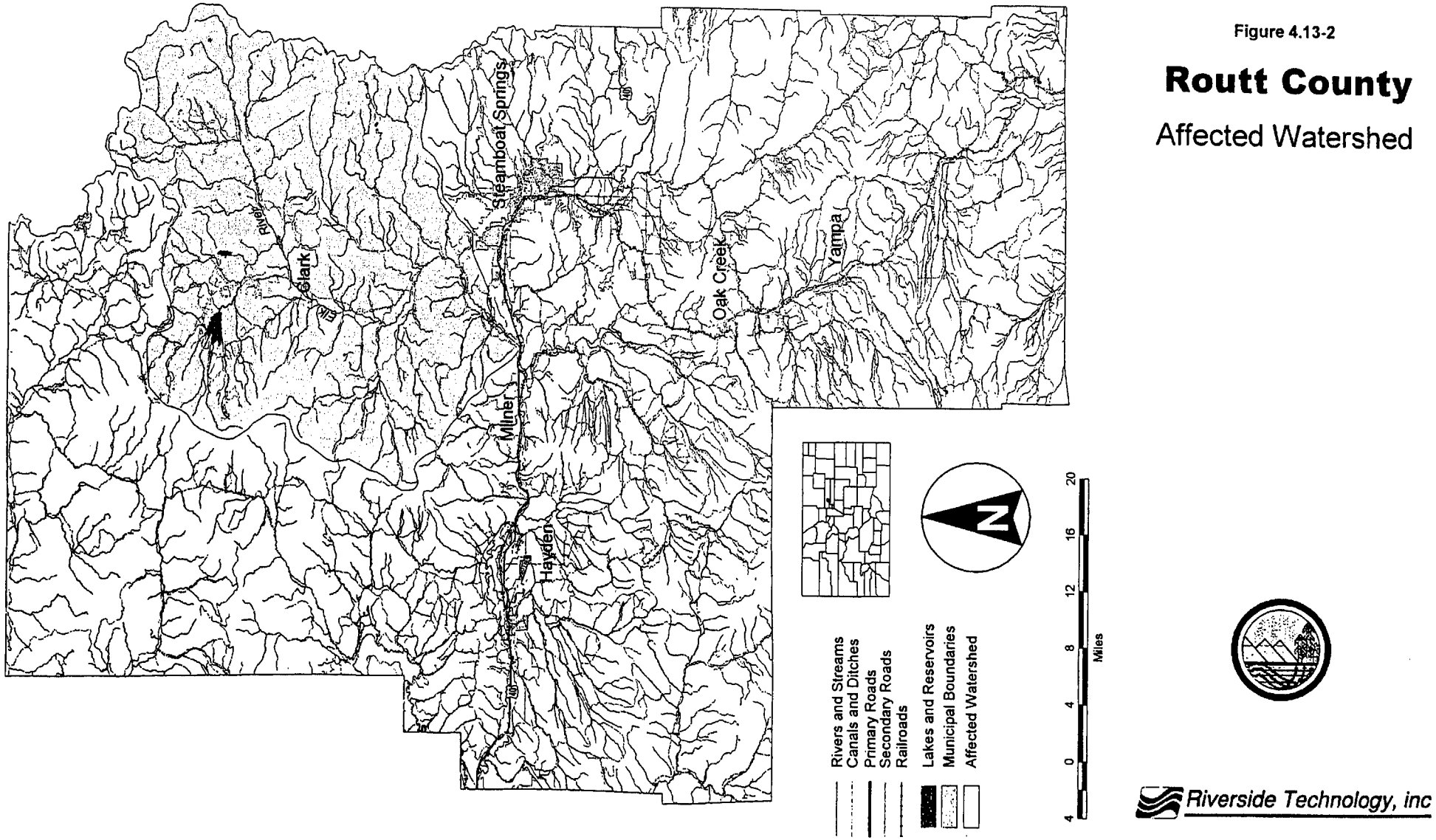

Figure 4.13-2

Routt County

Affected Watershed

Riverside Technology, inc

In general, snowmelt during the spring or early summer constitutes a recurring but relatively minor flood threat. Major floods in Steamboat have been caused by snowmelt augmented by rain. General rains historically have not caused floods in the Yampa River basin (COE 1976).

The worst known flooding in the Yampa Valley occurred in 1921 and 1974. A rainstorm caused the flood of 1921, which may have been a cloudburst event that dropped more than 2.5 inches of rain on the Yampa mainstem and Soda Creek. The 1974 flooding was caused by rapid snowmelt augmented by a heavy rain on April 25 of that year. Damage mainly occurred along Butcherknife Creek, but flooding of disastrous proportions along the Yampa River and Fish Creek was prevented by several hundred volunteer floodfighters who filled and place sandbags (COE 1976).

4.13.4 Description of 1997 Flood Events

In June of 1997, the CWCB received verbal notification from Routt County officials and the Colorado Office of Emergency Management that rapid snowmelt from mountain snowpack was causing the streams and rivers in Routt County to swell. In particular, drainages in the upper Yampa River basin were threatening to cause the most problems in Steamboat Springs, Milner, Hayden, and surrounding areas.

A moderate rainstorm occurred on the evening of June 2, which produced 0.3 inch of rain in Steamboat. Heavier rain was reported northwest of Steamboat, but an official measurement is unavailable. Following this rainstorm, the Lower Elk River experienced a noticeable increase in flow above the already high discharge from the snowmelt runoff.

Significant flows occurred on the Elk River on June 2 and 3 (see ***Figure 4.13-3).*** The gaging station near Milner recorded a peak flow of more than 5,000 cfs during that time. However, a portion of the flood flow (as much as 300 to 400 cfs) bypassed the gage and was diverted across the overbank area (Jarrett 1998/1997). The USGS has conducted field investigations on the Elk River to estimate the lost flow, and will make an official determination of the instantaneous peak flow in the near future. Initial streamflow estimates flagged the Elk River peak flow as the flood of record, exceeding a 100-year flood frequency. However, preliminary revised estimates by the USGS now place the Elk River flood at a 25-year to 50-year event.

Steamboat Springs experienced additional flooding problems shortly after the Elk River flooding. Burgess Creek, a right bank tributary to the Yampa River whose confluence is near downtown Steamboat Springs, experienced high flows from rapid snowmelt runoff. A majority of the Burgess Creek watershed lies within the adjacent ski area. As floodwaters from Burgess Creek rose rapidly, they flowed into a small detention pond located near Ski

Time Square (CWCB 1997f). The inlet to the outflow pipe became clogged with debris and the pond quickly filled and overtopped the embankment. This overflow caused the embankment, which is used as an access road to a condominium complex, to partially fail. The failure washed out a large portion of the access road on the downstream side (CWCB 1997f).

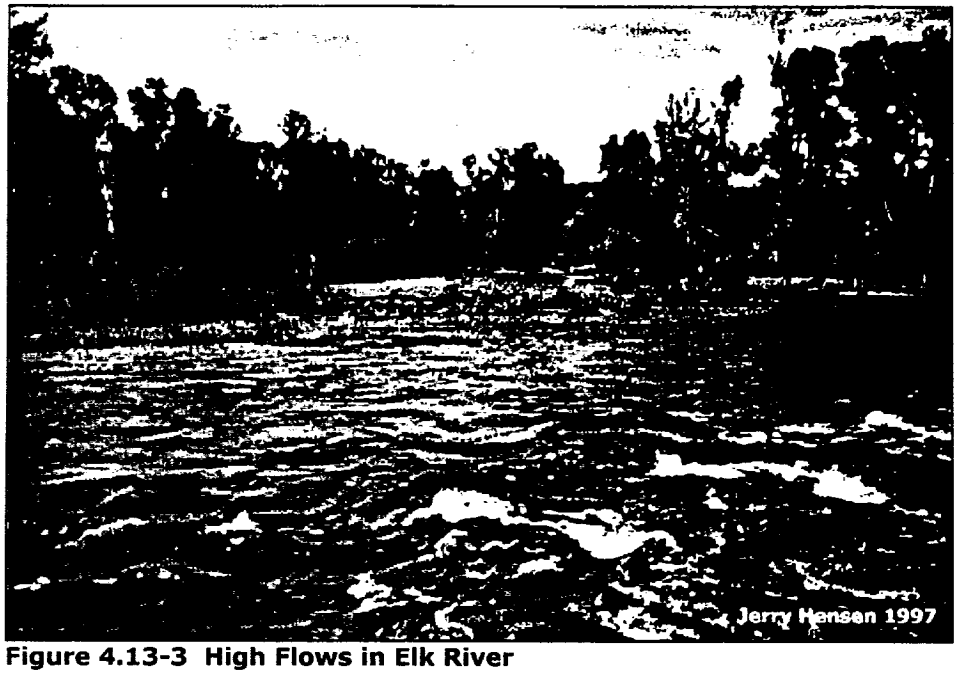

Figure 4.13-3 High Flows in Elk River

High water on Walton Creek, which also is a right bank tributary to the Yampa River, threatened structures near the floodplain near Highway 40. In particular, the Holiday Inn and Comfort Inn motels would have been affected if the floodwaters had reached higher stages. Fortunately, no major problems were experienced.

Downstream from Steamboat Springs and Milner, there were reports of two homes being threatened and cattle trapped by high water near Hayden. No livestock casualties were reported.

4.13.5 Emergency Response Effort

The Routt County Office of Emergency Management, Sheriff's Office, and the Road and Bridge Department all participated in flood response activities during June of 1997. Likewise, the Steamboat Springs Fire Department, Police Department, various town officials, and the National Guard actively responded to various flood-related situations. CWCB staff reported to the Emergency Operations Center in Steamboat Springs on June 3 to assist with flood fighting efforts and streamflow predictions. A brief description of the most notable incidents is provided below.

Sandbags were placed along the right bank of the Yampa River to protect homes in the Dream Island mobile home park. High water threatened a number of mobile homes adjacent to the stream bank. Portable pumps were used to evacuate ponded water from low-lying areas and from behind the sandbag levees. Sandbags also were placed along the right bank of the Yampa to protect several residential and commercial structures in the downtown area along Yampa Drive (Vale 1997).

Several families were evacuated in the lower Elk River basin during the night of June 2 (Vale 1997). A number of county roads had to be closed because of the high water (see ***Figure 4.13-4***) and the dangerous conditions that existed at the bridge crossings of the river.

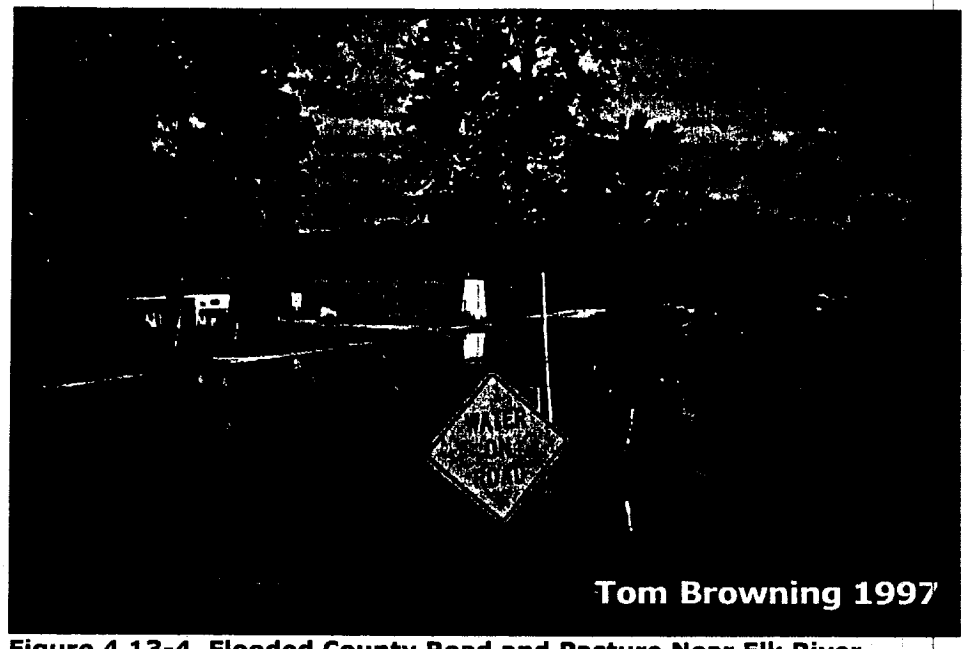

Figure 4.13-4 Flooded County Road and Pasture Near Elk River

On Burgess Creek, public officials and fire department personnel set up portable pumps to help drain the overfilled detention pond. The pond's outlet pipe was cleared of debris, and the pond was allowed to drain naturally with assistance from the portable pumps. Once the pond was relieved, no further emergency action was required.

4.13.6 1997 Flood Damage

As a result of the overbank flows on the Elk River, flooding problems occurred in the early morning hours of June 3, 1997. Homes, property, bridges, and roads were threatened or were subject to minor damage (see ***Figures 4.13-5*** and ***4.13-6***). The area within the watershed that was subject to minor damage is shown in ***Figure 4.13-7***. Specific damage values were not tabulated for this event.

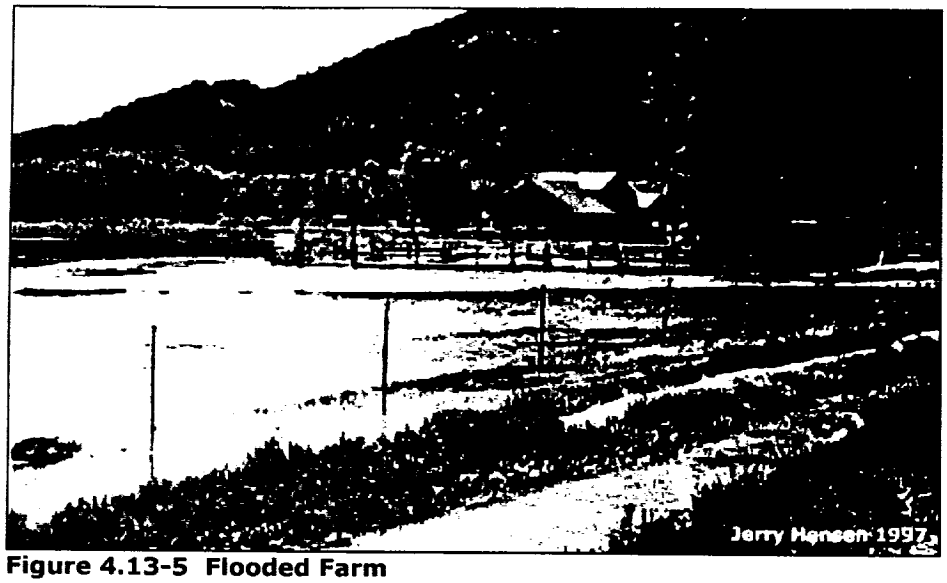

Figure 4.13-5 Flooded Farm

Figure 4.13-6 Inundated Pasture

The overtopping of the Burgess Creek detention pond damaged or threatened a number of utility lines. The access road across the detention embankment was heavily damaged. Repairs to the embankment, road surface, and utilities likely exceeded $100,000.

Along the Yampa River mainstem, no major damage to inhabitable structures was reported. Adverse affects of the high water were limited to farm inundation, minor street flooding, damage to landscaping, nuisance flooding in rural and developed areas, and dangerous conditions for rafters, kayakers, and recreationists.

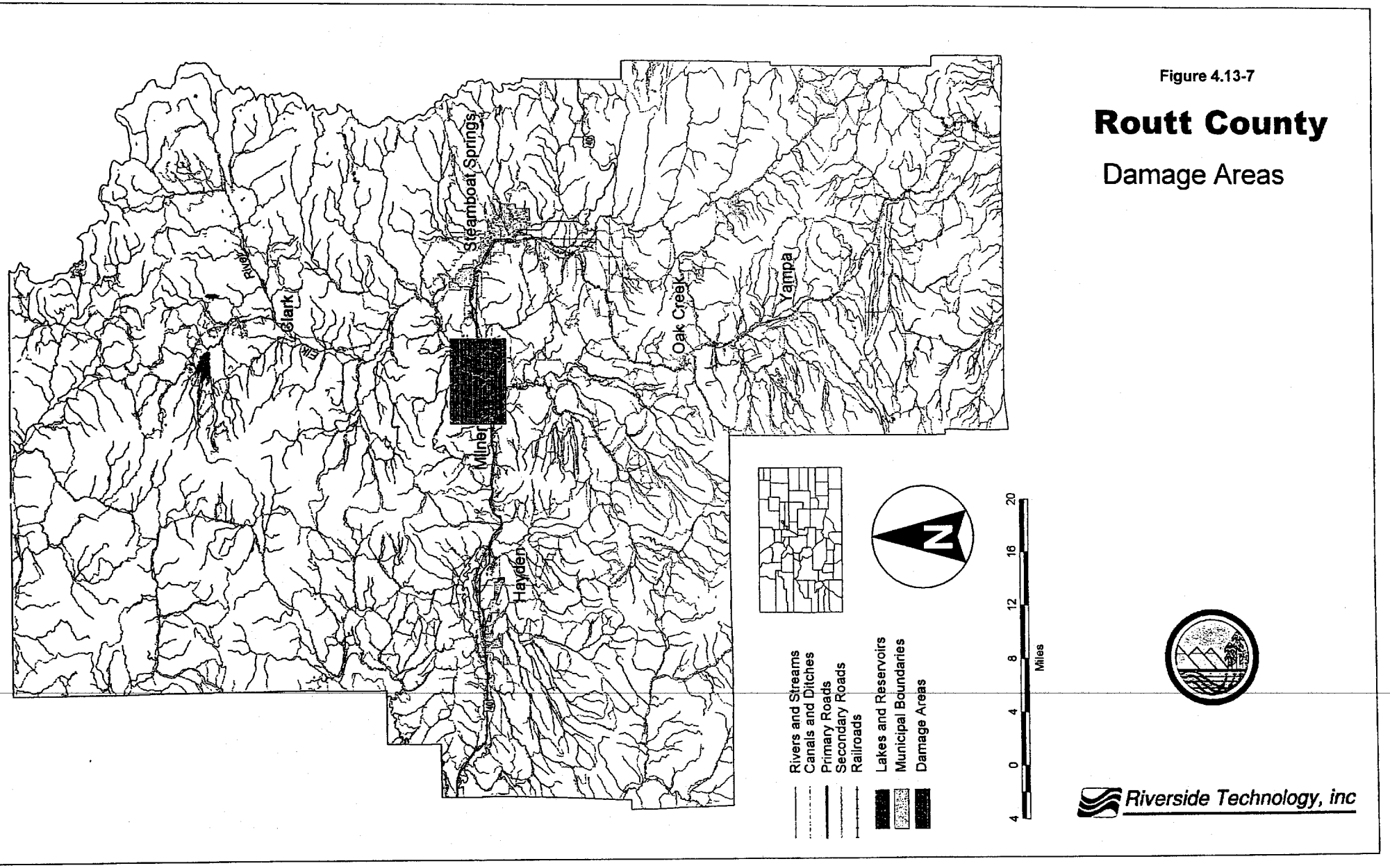

Figure 4.13-7

Routt County

Damage Areas

4.14 Weld County

4.14.1 Study Area

From late May through mid August of 1997, Weld County, located in northern Colorado, received heavy localized precipitation that produced considerable flood damage. Both incorporated and unincorporated areas of the county were affected by the flooding. Localized precipitation and the resulting flooding were scattered throughout Weld County in predominantly rural areas. However, Greeley and surrounding communities did receive flood damage on several occasions during June, July, and August of 1997.

The County seat is located in Greeley which is approximately 50 miles north of Denver (see ***Figure 1.1-1*** for county location). Greeley is the most populous community in Weld County with approximately 72,000 residents, followed by the communities of Windsor and Evans, which each have approximately 8,000 residents. The total population within Weld County was estimated in 1996 to be approximately 151,100 (Greeley/Weld County Economic Development Partnership, Inc. 1998).

Weld County is within the South Platte River basin, which flows in an easterly direction through the county (see ***Figure 4.14-1***). Greeley is located near the confluence of the Cache la Poudre, Big Thompson, and South Platte river basins. The Cache la Poudre River drains into the South Platte River as a left bank tributary approximately 5 miles east of Greeley. The Big Thompson River drains into the South Platte River as a left bank tributary approximately 5 miles southwest of Greeley.

In Weld County, homes, commercial properties, county roads and bridges, and agricultural lands were seriously damaged as a result of runoff generated by localized storm events in several drainages, including Pawnee Creek, Crow Creek, Lone Tree Creek, Sidney Draw, and Sheep Draw.

Land use in Weld County includes cropland and open rangeland activities. Primary agricultural products consist of wheat, corn, sugar beets, alfalfa, barley, onions, livestock, and various legumes (Germann 1998). The mean annual precipitation for Weld County ranges from approximately 12.2 inches in Greeley to 10 inches in northeastern Weld County (COE 1981).

In addition, the northern portion of Weld County is dominated by the Pawnee National Grassland, a national wildlife and recreation area that has been managed by the U.S. Forest Service since 1954 (U.S. Forest Service date unknown [a]). All of the major drainages (Pawnee Creek, Crow Creek, and Lone Tree Creek) flow through this national recreation area. The Pawnee National Grassland encompasses 193,000 acres of undeveloped rangeland. Approximately 192,600 acres are used to graze livestock (Pawnee National Grassland Fact Sheet 1998). The primary grazing vegetation is crested

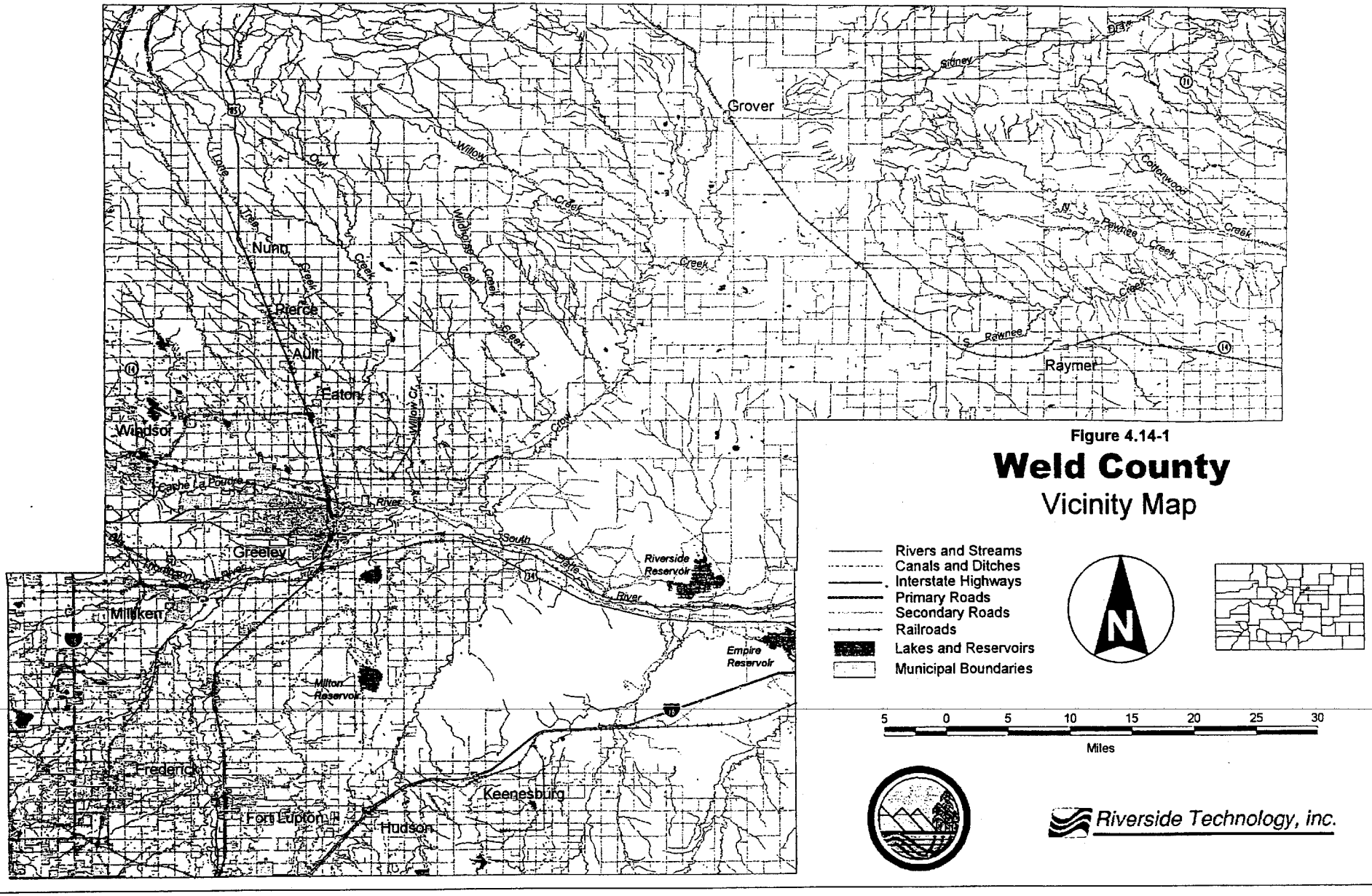

Figure 4.14-1

Weld County

Vicinity Map

wheatgrass, an introduced species from Russia that is well adapted to the Colorado climate and is palatable to livestock. The average elevation of the grassland is approximately 5,500 feet. The most notable topographic features in the grassland are the Pawnee Buttes located in northern Weld County approximately 13 miles south of the Wyoming-Colorado border. The Pawnee Buttes rise approximately 200 to 300 feet above the local topography (U.S. Forest Service date unknown [b]).

4.14.2 Watershed Description

Weld County lies within the Great Plains Province of the Interior Plains. The topography of the Interior Plains is characterized by rolling hills interspersed with extensive areas of gently sloped plains. Elevations in the Weld County plains watersheds range from approximately 5,300 feet in the headwaters to 4,400 feet where the South Platte River flows into Morgan County.

The major watersheds that were affected by the storm events in 1997 include Pawnee Creek, Coal Creek, Crow Creek, Lone Tree Creek, Sidney Draw, and Sheep Draw. The headwaters of Pawnee Creek are located in northeastern Weld County in the Pawnee National Grassland. Pawnee Creek flows in an easterly direction, eventually draining into the South Platte River as a left bank tributary approximately 5 miles southwest of Sterling in Logan County.

The headwaters of Coal Creek are located within northern Weld County in the Pawnee National Grassland. Coal Creek flows in a southerly direction toward Crow Creek and eventually flows into several small lakes approximately 14 miles east of the community of Eaton. Under high flow conditions, Coal Creek flows into Crow Creek northeast of the community of Barnesville. Wildhorse Creek, a minor tributary to Coal Creek, experienced flooding in 1997 (see ***Figure 4.14-1***).

The headwaters of Crow Creek are located in Wyoming. Crow Creek flows in a southerly direction and enters Weld County from Laramie County, Wyoming, near the community of Hereford. Crow Creek continues its southward progression and eventually drains into the South Platte River as a left bank tributary approximately 11 miles east of Greeley (see ***Figure 4.14-1***).

The headwaters of Lone Tree Creek also are located in Wyoming. Lone Tree Creek flows in a southerly direction and enters Weld County from Laramie County, Wyoming, near where Interstate 25 crosses the Colorado-Wyoming border. Lone Tree Creek continues its southward progression and eventually drains into the South Platte River as a left bank tributary approximately 6 miles east of Greeley (see ***Figure 4.14-1***). Minor tributaries to Lone Tree Creek that experienced flooding in 1997 include Owl Creek and Willow Creek.

Sidney Draw is an intermittent drainage whose headwaters are located in the Pawnee National Grassland. Sidney Draw flows into Nebraska almost directly north of the community of Raymer. The draw continues its northeastward progression, eventually draining into Lodgepole Creek, which drains into the South Platte River as a left bank tributary.

Sheep Draw is located in western Weld County approximately 10 miles west of Greeley. Sheep Draw flows in a northeasterly direction, eventually draining into the Cache la Poudre River as a right bank tributary approximately 4 miles northwest of Greeley (see ***Figure 4.14-1***). The Sheep Draw watershed has experienced significant development over the past several years because of the increased population within Greeley. It is expected that this entire watershed will be annexed by Greeley over the next 15 to 20 years (Sheltinga 1998).

4.14.3 Local Flooding Problems

In response to flooding, Weld County has been declared a disaster area four times in the last 18 years. Flooding caused by significant storms in the Ault and Eaton area in June of 1973 caused significant damage (COE 1981). Then, in the 1980s, Lone Tree Creek and Crow Creek experienced extensive flooding from severe storms in southern Wyoming. In 1983, flooding along the Cache la Poudre River caused damage to the community of Greeley.

In addition, tributaries in Weld County, including Pawnee Creek, Lone Tree Creek, Crow Creek, Sheep Draw, Eaton Draw, and the Cache la Poudre River, historically have experienced nuisance flooding during the summer months. The community of Greeley also typically experiences local flooding from high intensity, short duration, localized thunderstorms. Because of the nature of these highly localized storm events, typical storm runoff hydrographs are characterized by a steep rising limb to a peak, then a gradual tapering off (COE 1980). According to Greeley Public Works officials, Sheep Draw is subject to annual flooding that causes damage to residential properties and city and county roads and bridges (Bagley 1998, Tellez 1998).

Eaton Draw north of Greeley experienced flooding conditions in 1935, 1951, 1954, 1961, 1965, 1972, and 1974. In addition, a major flood occurred in this draw on May 1, 1977 (COE 1981).

4.14.4 Storm Characteristics

In May, June, July, and August of 1997, Weld County experienced several periods of very heavy localized precipitation. ***Table 4.14-1*** documents these precipitation events.

Table 4.14-1
Dates of Significant Precipitation in Weld County
During 1997

Date	Maximum Precipitation	Comments
May 24	2.58 inches; one unofficial measurement of 7.0+ inches in a 6-hour period	Northern Weld County, New Raymer 21N, Colorado-Nebraska border
June 2	4.0 inches	15 miles northeast of Greeley
June 13	5.0+ inches; 4.0+ inches in Greeley in 1.5 hours	Sheep Draw west of Greeley to Milliken
June 15	2.0 inches in 1 hour	Southwestern Weld County; no flooding was reported
June 23	1.5 inches, started at 8:00 p.m.	West Greeley, golf-ball-size hail, moved toward Lucerne
June 24	1.0 inch 10 minutes	South Greeley to Evans
July 27-28	Windsor 0.62 inches; 1.5 inches at Wyoming border in northern Weld County	General heavy rains, Larimer County, Windsor to Hereford in Weld County,
July 28	7.6 inches	Northwest of Hudson
July 29	3.6 inches in Raymer; as much as 15 inches of rain to the northeast of Raymer; started approximately 10 p.m.	Northeast Weld County, Raymer and Stoneham, Pawnee National Grassland and Pawnee Creek and Cotton Wood Creek; caused severe flooding in Logan County
July 30	1.12 inches in 1 hour; started just after 5:00 p.m.	Greeley
August 3	3.0+ inches east of Hillrose 11:00 p.m. to 1:00 a.m.	Southeastern Weld and eastern Morgan County, Stoneham to Hillrose; produced flooding in Morgan County
August 4	Greeley 0.48 inch; Windsor 0.72 inch; Fort Lupton to Brighton 0.92 inch; Hudson 0.47 inch	General rains in western Weld County
August 5	up to 3.0 inches; 2.84 inches recorded 6 miles northwest of Hudson	General rains over eastern Larimer County and western Weld County
August 16	2.0 inches in 20 minutes; started approximately 10:00 p.m.; Greeley reported 0.56 inches	Northern Weld County, West Greeley to Rockport, flooding on Crow Creek

Although not contained in the Presidential Disaster Declaration period of July 28 through August 12, 1997, the precipitation events of May 24, June 2, and June 13 were significant in terms of total precipitation and damage from subsequent flooding. The precipitation events on July 27 through 29 and August 3 also generated damage within Weld County; however, the most significant damage from these storms was sustained in Larimer, Logan, and Morgan counties. Please see the Larimer, Logan, and Morgan County sections of this report (5.6, 5.8, and 5.9, respectively) for the meteorological, hydrologic, and hydraulic aspects of the events on July 27 through 29 and August 3.

The remainder of the this section will focus on describing the meteorology, hydrologic/hydraulic aspects, and damages associated with the storm events experienced in Weld County on May 24, June 2, June 13, and July 28, 1997.

Table 4.14-2 summarizes the atmospheric conditions present in Weld County for those periods during which extreme thunderstorms developed.

Table 4.14-2
Summary of Meteorological Data

Location	Date	Minimum Temp (°F)	Maximum Temp (°F)	Average Barometric Pressure (inches of Hg)	Average Relative Humidity[1] (%)	Average Dew Point (°F)	Average Wind Speed (mph)	Average Wind Direction (deg. from North)
Sydney, NE	5/24	45	69	25.42	80	51	16.3	130
Cheyenne, WY	6/2	50	67	23.91	84	54	11.0	160
Akron, CO	6/14	55	79	25.20	70	57	15.7	120
Akron, CO	6/29	61	79	25.47	79	63	16.6	110

[1]Calculated from $f \approx 100 \left(\frac{112 - 0.1T + Td}{112 + 0.9T}\right)^8$ where T = average air temperature (°C), T_d = average dew point (°C) (Linsley et al. 1992)
Source: National Climatic Data Center 1998a

4.14.4.1 Storm Duration and Rainfall Quantities

A severe thunderstorm producing localized heavy precipitation in northern Weld County developed on the afternoon of May 24, 1997. Rainfall totals of between 2 and 7 inches were reported approximately 25 miles north of Raymer. The majority of rain fell within a 6-hour period on the evening of May 24 from approximately 4:00 p.m. to approximately 10:00 p.m. The period of heaviest rainfall extended from approximately 4:00 p.m. to 7:00 p.m. The CWCB did not conduct a rainfall bucket survey for this event, but several weather observers in Weld County collected rainfall information that is summarized in ***Table 4.14-3.*** A total storm precipitation NWS radar image was obtained from the NWS (see the Technical Addendum for the radar image) and is summarized in ***Table 4.14-3.***

Table 4.14-3
Point Rainfall Amounts Recorded in Weld County
for May 24, 1997

Source	Location	Amount	Recording Period
Mountain States Weather Services (1997)	21 miles north of Raymer, South Route Box 66	2.58 inches	5/24/97 4:00 p.m. to 10:00 p.m.
CWCB (1998c)	26.5 miles north of Raymer	7.00+ inches	5/24/97 4:00 p.m. to 10:00 p.m.
NOAA/NWS (1997c)	Northern Weld County	9.70 inches	5/25/97 11:00 a.m. May 24 to 1:00 a.m.

An isohyetal map was generated for May 24 at 4:00 p.m. to May 24 at 10:00 p.m. using the NWS storm total radar image and the point quantities of precipitation measured by the weather observers. This isohyetal map is shown in ***Figure 4.14-2***.

Another severe thunderstorm producing extremely heavy precipitation northeast of Greeley developed on the evening of June 2. Flooding occurred in the late evening hours of June 2 and into the early morning hours of June 3. Most or all of the rain fell within 30 to 45 minutes (CWCB 1997c). Several weather observers in the area collected rainfall information that is summarized in ***Table 4.14-4.*** A total storm precipitation NWS radar image was not obtained for this storm event.

A CWCB flood documentation team conducted a rainfall bucket survey on June 11, 1997. In addition to the bucket survey, rainfall estimates were based on interviews with local officials and residents, and field observations. An isohyetal map was generated for June 2 at 4:30 p.m. through June 2 at approximately at 8:30 p.m. and (***Figure 4.14-2***).

Using a storm duration of 1 hour (the CWCB flood documentation team reported that the majority of precipitation occurred within a 30- to 45-minute period), the peak rainfall intensity was approximately 4.0 inches per hour.

On the evening of June 13, another severe thunderstorm producing extremely heavy precipitation developed west of Greeley. Rain began falling at approximately 3:30 p.m., and flooding occurred in the late evening hours of June 13. Most or all of the rain fell within a 60-minute period. Several weather observers in the area collected rainfall information that is summarized in ***Table 4.14-5.*** A total storm precipitation NWS radar image was not obtained for this storm event.

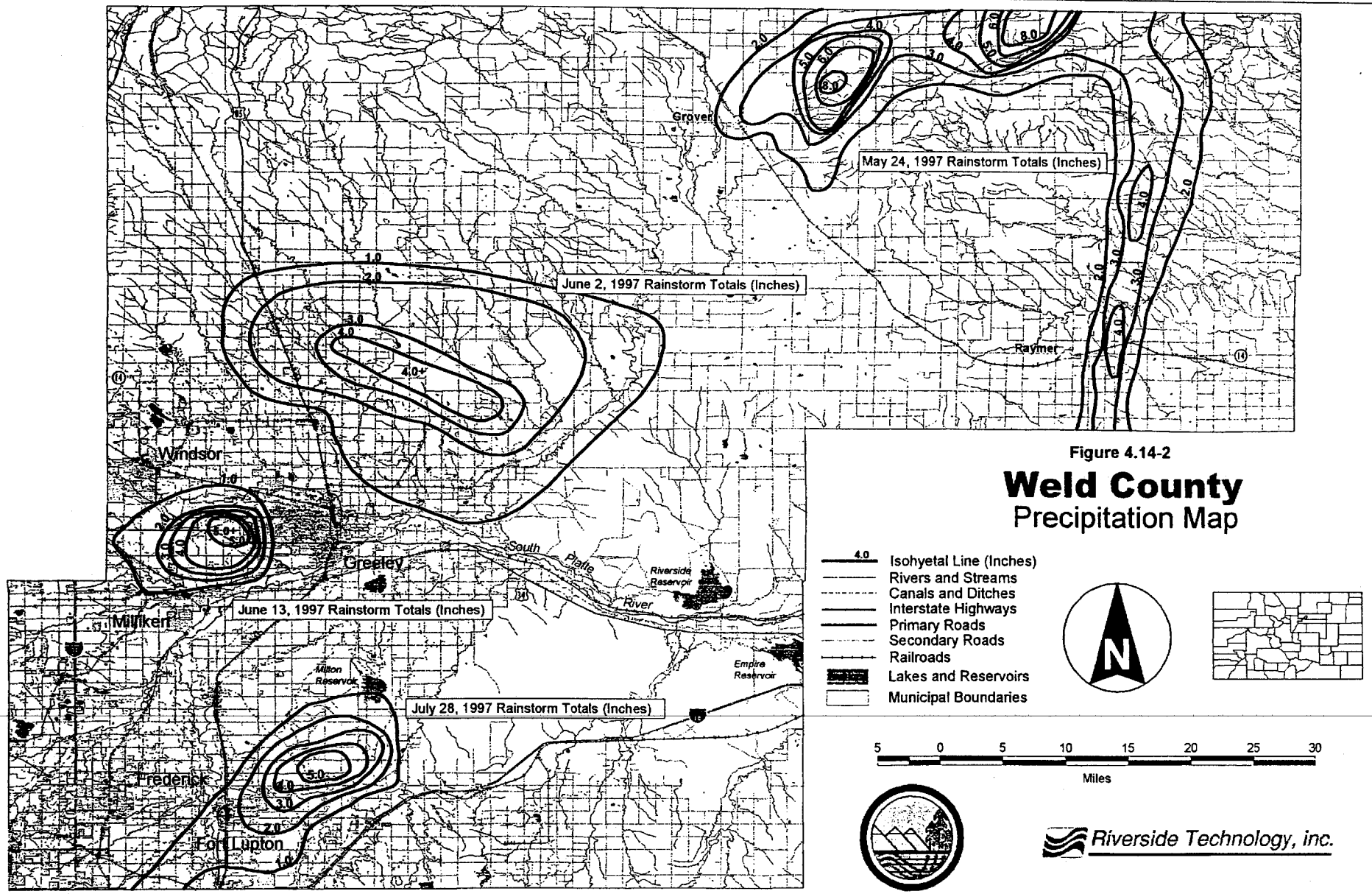

Figure 4.14-2

Weld County
Precipitation Map

Table 4.14-4
Point Rainfall Amounts Recorded in Weld County for June 2, 1997

Source	Location	Amount	Recording Period
Mountain States Weather Services (1997)	10 miles northeast of Nunn, 19412 CR 108	1.70 inches	Not recorded
Mountain States Weather Services (1997)	13 miles east-northeast of Nunn, 54068 W. CR 55	2.08 inches	Not recorded
Mountain States Weather Services (1997)	2 miles northeast of Severance, 12528 W. CR 76	0.67 inch	6/2/97 4:30 p.m. to 8:30 p.m.
Mountain States Weather Services (1997)	2 miles west-southwest of Gill, 24576 W. CR 64	0.77 inch	6/2/97 4:30 p.m. to 8:30 p.m.
CWCB (1997c)	12 miles northeast of Greeley	4.0+ inches	Late evening (30-45 minute period)

In response to the heavy precipitation on June 13, a CWCB flood documentation team conducted a rainfall bucket survey. Rainfall estimates were obtained based on this bucket survey, interviews with local officials and residents, and field observations. An isohyetal map was generated for June 13 at 3:30 p.m. through June 13 at approximately at 6:30 p.m. (***Figure 4.14-2***).

Using a storm duration of 1 hour (the CWCB flood documentation team reported that the majority of precipitation occurred within a 60-minute period), the peak rainfall intensity was approximately 5.0 inches per hour.

Finally, a severe thunderstorm producing extremely heavy precipitation approximately 7 miles northwest of Hudson developed on the evening of July 28. This storm event developed during the same time as the devastating storm event experienced in Fort Collins. Weather observers in the area collected rainfall information that is summarized in ***Table 4.14-6.*** In addition to these weather observations, the NWS radar that captured the Fort Collins storm event also captured this event (see the technical addendum for the radar image). The precipitation information from the radar is included in ***Table 4.14-6.***

Table 4.14-5
Point Rainfall Amounts Recorded in Weld County for June 13, 1997

Source	Location	Amount	Recording Period
Mountain States Weather Services (1997)	2 miles west of Greeley, 2209 Mountain Ln.	0.77 inch	Not recorded
Mountain States Weather Services (1997)	3 miles west-northwest of Greeley, 126 N 42nd St.	1.03 inches	6/13/97 3:30 p.m. to 7:00 p.m.
Mountain States Weather Services (1997)	UNC Campus	0.70 inch	Not recorded
Mountain States Weather Services (1997)	4 miles northwest of Greeley, 616 44th Ave.	1.29 inches	6/13/97 3:30 p.m. to 5:00 p.m.
Mountain States Weather Services (1997)	Half mile south of Greeley, 2630 12th Ave Crt.	0.67 inch	Not recorded
Mountain States Weather Services (1997)	4 miles northwest of Greeley, 4934 W 6th St. Rd.	1.64 inches	6/13/97 3:00 p.m. to 5:30 p.m.
Greeley Tribune (1997c)	Arrowhead subdivision	4.0 inches	6/13/97 2:00 p.m. to 3:00 p.m.
Mountain States Weather Services (1997)	5 miles south of Windsor, 28980 W CR 15	0.91 inch	6/13/97 5:30 p.m. to 6:30 p.m.
CWCB (1997c)	Sheep Draw	5.0+ inches	6/13/97 5:00 p.m. to 6:00 p.m.

A CWCB flood documentation team was not dispatched to conduct a rainfall bucket survey for this event. However, an isohyetal map was generated for the period from July 28 at 4:00 p.m. to July 28 at 11:00 p.m. using the NWS storm total radar image and the point quantities of precipitation measured by the weather observers (***Figure 4.14-2***).

4.14.4.2 Estimated Point Precipitation Return Periods

The point precipitation totals for areas in Weld County for storm durations of 6 hours, 12 hours, and 24 hours for return intervals of 10 years and 100 years (as developed from the NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume III - Colorado [1973]) are shown in ***Table 4.14-7.***

Table 4.14-6
Point Rainfall Amounts Recorded in Weld County for July 28, 1997

Source	Location	Amount	Recording Period
NOAA/NWS (1997b)	Storm center, 6 miles northwest of Hudson	8.00 + inches	Total accumulation through 11:00 p.m.
Mountain States Weather Services (1997)	9061 Weld CR 41	7.55 inches	4:00 p.m. through 11:00 p.m.
CWCB (1998b)	17977 Weld CR 20	4-6 + inches	4:00 p.m. through 11:00 p.m.
CWCB (1998b)	6261 Weld CR 41	0.75 inch	4:00 p.m. through 11:00 p.m.
CWCB (1998b)	20520 Weld CR 20	6-8 + inches	4:00 p.m. through 11:00 p.m.
CWCB (1998b)	8627 Weld CR 41	6 + inches	4:00 p.m. through 11:00 p.m.

Table 5.14-7
10-year and 100-year Point Precipitation Values for Various Storm Durations

Location	Storm Duration	10-yr Precipitation	100-yr Precipitation
Sheep Draw, West Greeley	6 hours	2.2 inches	3.3 inches
Sheep Draw, West Greeley	12 hours	2.4 inches	3.7 inches
Sheep Draw, West Greeley	24 hours	2.6 inches	4.0 inches
Northwest of Greeley	6 hours	2.2 inches	3.3 inches
Northwest of Greeley	12 hours	2.4 inches	3.6 inches
Northwest of Greeley	24 hours	2.6 inches	3.8 inches
Colorado Nebraska Border	6 hours	2.2 inches	3.3 inches
Colorado Nebraska Border	12 hours	2.4 inches	3.7 inches
Colorado Nebraska Border	24 hours	2.6 inches	4.0 inches

For comparative purposes, for the Denver area the point precipitation total for a storm duration of 1 hour for a return interval of 100 years is approximately 2.6 inches (UDFCD 1984)–much lower than the totals shown in ***Table 4.14-7***.

A summary of the point precipitation for the Weld County storm events of May 24, June 2 and June 13, and July 28, 1997, are shown in ***Table 4.14-8***.

Table 4.14-8
Summary of Storm Precipitation, Duration, and Return Period for Weld County

Source	Location	Date	Maximum Point Precipitation	Duration	Estimated Return Period
NOAA/ NWS (1997b)	21 miles north of Raymer	May 24	9.7 inches	12 hours	> 100-year
CWCB (1998c)	26.5 miles north of Raymer	May 24	7.0+ inches	6 hours	> 100-year
Mountain States Weather Services (1997)	13 miles east-northeast of Nunn	June 2	2.08 inches	1 hour	20-year to 50-year
CWCB (1997c)	12 miles northeast of Greeley	June 2	4.0+ inches	1 hour	> 100-year
CWCB (1997c)	Sheep Draw	June 13	5.0 + inches	1 hour	> 100-year
Mountain States Weather Services (1997)	7 miles northwest of Hudson	July 28	7.55 inches	7 hours	> 100-year

4.14.5 Hydrology and Hydraulic Findings

4.14.5.1 Locations/Reaches of Flooded Streams

May 24, 1997

The severe thunderstorm that developed in the afternoon of May 24, 1997, caused flooding on several unnamed tributaries in extreme northern Weld County. In general, out-of-bank conditions were experienced on drainages along the Colorado-Nebraska state line 25 miles north of Raymer. The flooding situation was complicated by the presence of county road embankments that transect these drainages.

June 2, 1997

The severe thunderstorm that developed in the late evening of June 2, 1997, caused flooding on several tributaries to the northeast of Greeley. In general, several drainages, including Coal Creek, Wildhorse Creek, Sand Creek, Crow

Creek, Willow Creek, Owl Creek, and Lone Tree Creek between the communities of Ault and Briggsdale, experienced flooding conditions along several reaches. The *Greeley Tribune* (1997d) reported pasture flooding as far away as 20 miles northeast of Ault and basement flooding in the communities of Eaton and Ault. Damage to Colorado Highway 14 between Ault and Briggsdale also was reported (NOAA Storm Data 1997b). The flooding situation was complicated by the presence of highway embankments, bridges, and irrigation ditches that transect these drainages.

Lone Tree Creek experienced out-of-bank conditions at various locations from Antelope Reservoir near County Road 92 south to its confluence with the South Platte River. Flooding of Lone Tree Creek and surrounding pasture land was reported on June 2 through June 3 (Mountain States Weather Service 1997). In addition, the NWS reported that Lone Tree Creek east of Lucerne experienced out-of-bank conditions that flooded several homes.

Owl Creek experienced out-of-bank conditions at various locations from Owl Creek Reservoir south to its confluence with the South Platte River. Willow Creek also experienced out-of-bank conditions at various locations from its headwaters north of Galeton south to its confluence with the South Platte River.

Coal Creek experienced out-of-bank conditions at various locations from Thomas Lake Reservoir south to its confluence with the South Platte River. The *Greeley Tribune* reported the closure of Colorado Highway 14 (8 miles west of Briggsdale) when high water in Coal Creek began washing around the bridge (June 3, 1997). Flooding also was reported along Weld County Road 392 south of Briggsdale because of high waters in Coal Creek (*Greeley Tribune*, 1997d).

June 13, 1997

The severe thunderstorm that developed in the evening of June 13, 1997, caused flooding along the Cache la Poudre River, Sheep Draw, Ashcroft Draw, several drainages in western Greeley, in the community of Evans, and in the community of Milliken.

The *Greeley Tribune* reported that, "In west Greeley, the rains bloated small creeks and irrigation ditches, flooding areas along Sheep Draw near 59th Avenue and F Street." The paper also reported that the Hunter's Cove subdivision at the northwest intersection of 4th Street and 59th Avenue experienced flooding from the excess runoff from Sheep Draw (*Greeley Tribune* 1997c). ***Figure 4.14-3*** shows the flooding along Sheep Draw looking to the northeast from the 4th street bridge toward the newly developed Hunter's Cove subdivision.

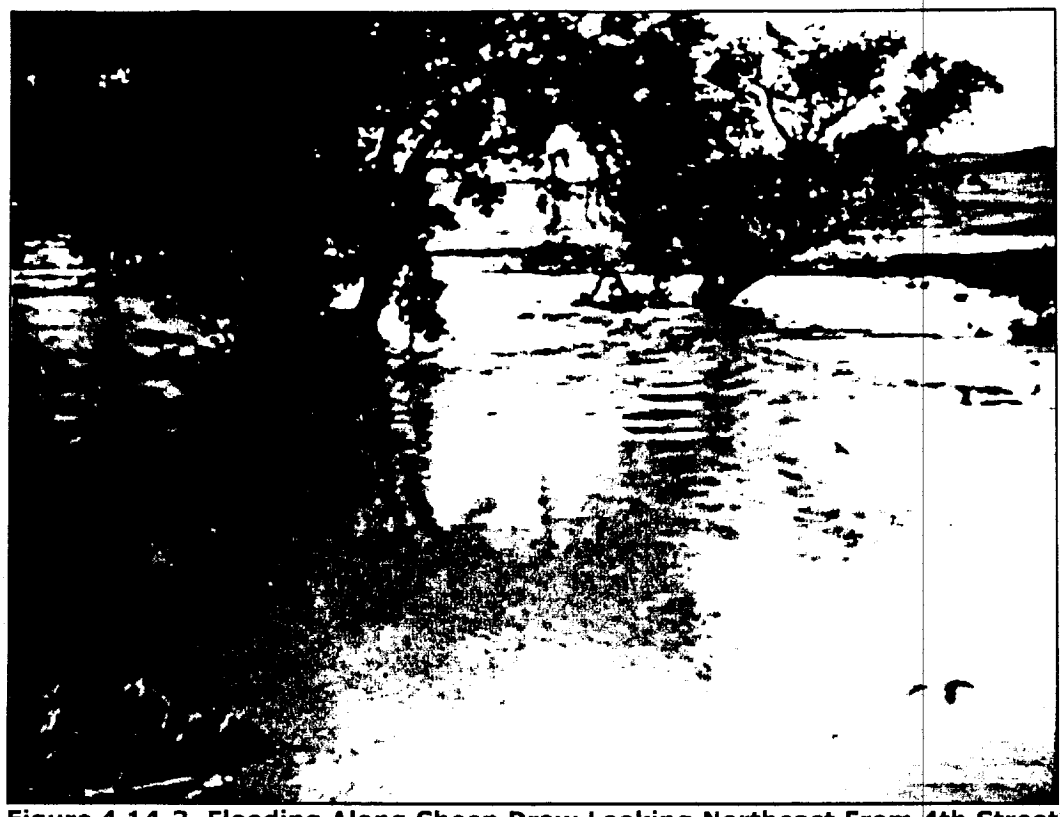

Figure 4.14-3 Flooding Along Sheep Draw Looking Northeast From 4th Street Bridge

As a result of the same storm event, the *Greeley Tribune* also reported that, "A bridge near 83rd Avenue and 20th Street was damaged, causing officials to divert traffic" (*Greeley Tribune* 1997c). ***Figure 4.14-4*** shows some of the damage sustained by the 83rd Avenue bridge. In the Arrowhead Subdivision southwest of Evans, at least one home was damaged by waters that spilled out of a nearby irrigation ditch (*Greeley Tribune* 1997c).

Ashcroft Draw, located just north of the Arrowhead subdivision southwest of Evans, experienced out-of-bank conditions near 37th street. Ashcroft Draw flows into Arrowhead Reservoir, which was close to capacity on Friday, June 13. The reservoir was reported to be approximately 4 feet above normal at that time (*Greeley Tribune* 1997c).

The *Greeley Tribune* reported that the Cache la Poudre River experienced out-of-bank conditions near 71st Avenue in western Greeley as well as in the community of Kersey (*Greeley Tribune* 1997c). ***Figure 4.14-5*** shows flooding northeast of 6th Avenue on the north side of the Cache la Poudre River. The Cache la Poudre River did not experience out-of-bank conditions at the 59th Avenue bridge; however, ***Figure 4.14-6*** shows the extent of flooded lands downstream of the bridge along the Cache la Poudre River.

Figure 4.14-4 Damage to 83rd Avenue Bridge

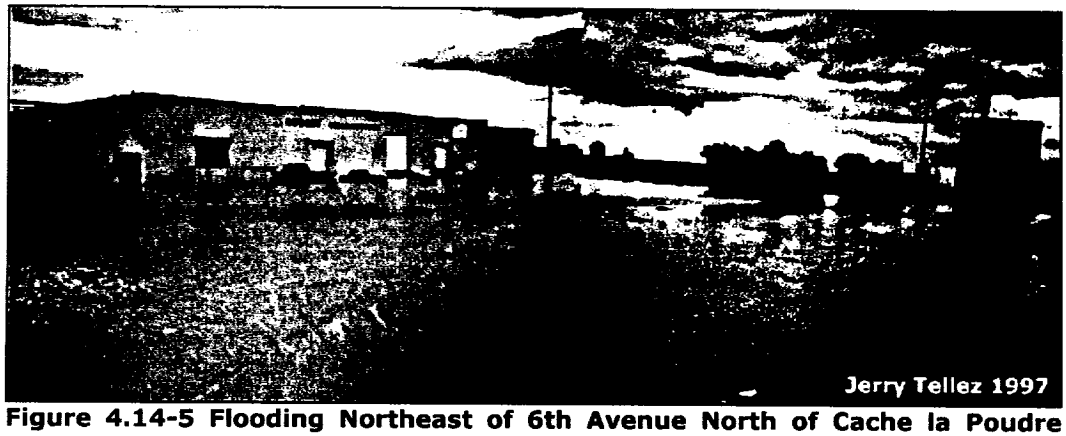

Figure 4.14-5 Flooding Northeast of 6th Avenue North of Cache la Poudre River

The City of Greeley dispatched a flood documentation team to Sheep Draw to evaluate some of the flooding experienced in the watershed. The flood documentation team took photographs and documented high water marks at all major stream crossings along the draw.

Figure 4.14-7 shows the debris collected by the guard rail on the F Street bridge–flood waters topped the bridge. This bridge crosses Sheep Draw just west of 59th Avenue. The F Street bridge sustained substantial erosion damage.

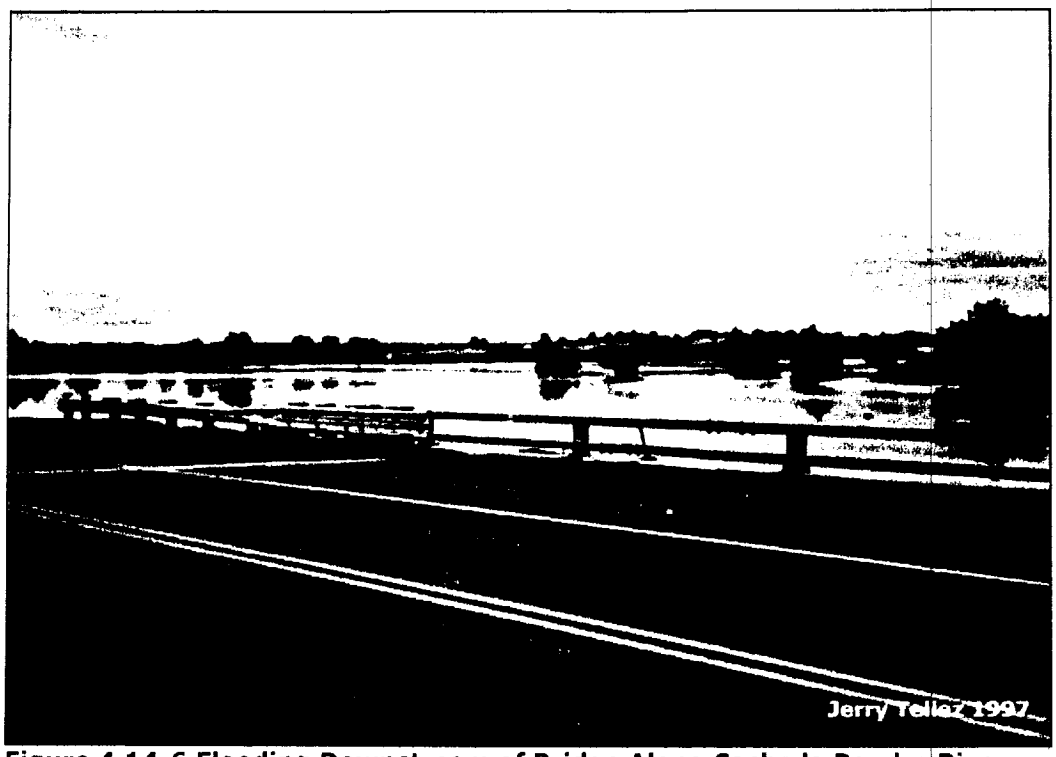

Figure 4.14-6 Flooding Downstream of Bridge Along Cache la Poudre River

Figure 4.14-7 Debris on F Street Bridge

Figure 4.14-8 is a photograph taken at the 10th Street bridge looking to the south along Sheep Draw. *Figure 4.14-9* shows the 71st Avenue bridge along Sheep Draw with some of the debris and erosion damage associated with the flooding.

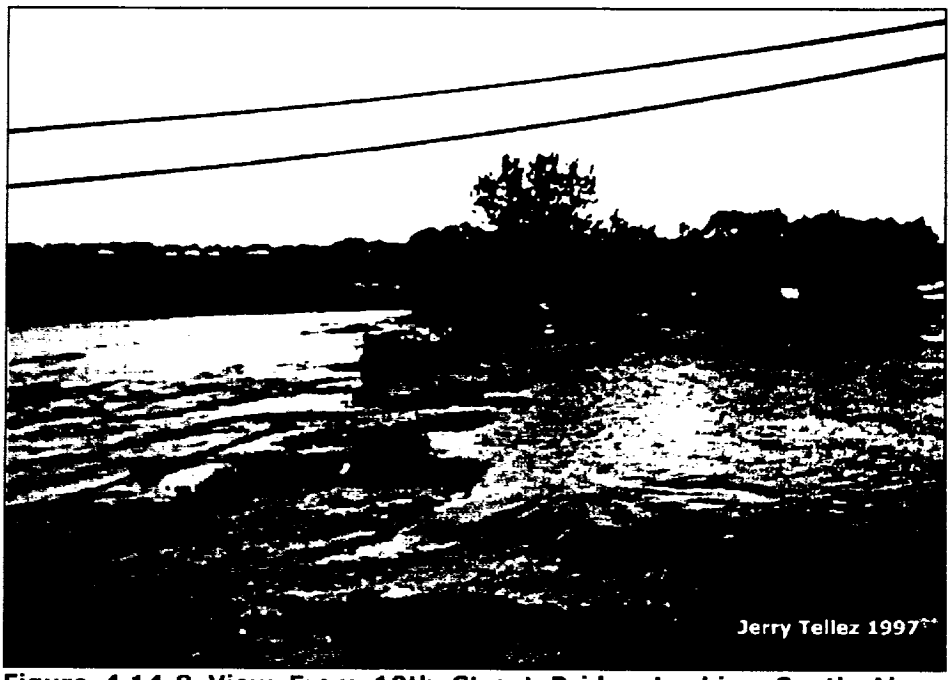

Figure 4.14-8 View From 10th Street Bridge Looking South Along Sheep Draw

Figure 4.14-9 71st Avenue Bridge Along Sheep Draw

July 28, 1997

The severe thunderstorm that developed in the late afternoon and evening of July 28, 1997, caused general flooding in low lying areas in southwestern Weld County. More specifically, an area approximately 6 miles northwest of Hudson experienced the heaviest precipitation and resulting flooding. ***Figure 4.14-10*** shows the affected watershed and general flow paths of overland flow. The area of heaviest precipitation was bounded generally by County Road 31 to the west, County Road 41 to the east, County Road 18 to the south, and County Road 22 to the north.

Flood waters caused two breaches in the Speer irrigation canal, washouts and damage to County Roads 20 and 22, and overtopping of County Road 41 on the evening of July 28, 1997. Several private residences and a church experienced severe flooding and damage along County Road 41.

In general, flood waters flowed in an easterly direction from the Speer canal to the Beebe Seep canal. Water from the two breaches of the Speer canal combined with overland flow west of County Road 41. The embankment of County Road 41 restricted the natural drainage path of the flood waters. Culverts in place under County Road 41 to pass flow were undersized for the extreme runoff generated by the storm event on July 28. For this reason, the water backed up and eventually overtopped the road at the intersection of County Road 22. Reports from local residents who live at the intersection indicate that up to 8 inches of water flowed over County Road 41 (CWCB 1997c). The total width of the overtopping water was approximately 1,200 feet, which caused several car accidents on the roadway.

The flood waters eventually flowed into the Beebe Seep canal. Reports from local residents indicate that the Beebe Seep canal contained all the overland flow. Both the Beebe Seep and the Speer canals are owned by the Farmers Irrigation Company. The irrigation company does not record flow in these two canals. However, the Beebe Seep canal flows into Milton Reservoir, and the irrigation company does keep records of stage within Milton Reservoir.

Figure 4.14-11 shows overtopping on County Road 41 near the intersection with County Road 20. Flood waters attained a depth of approximately 32 inches in the house shown in ***Figure 4.14-12***. ***Figure 4.14-13*** also shows the flooding outside and around this residence.

The washout on County Road 20 occurred approximately 1 mile west of County Road 41 and is shown in ***Figure 4.14-14***.

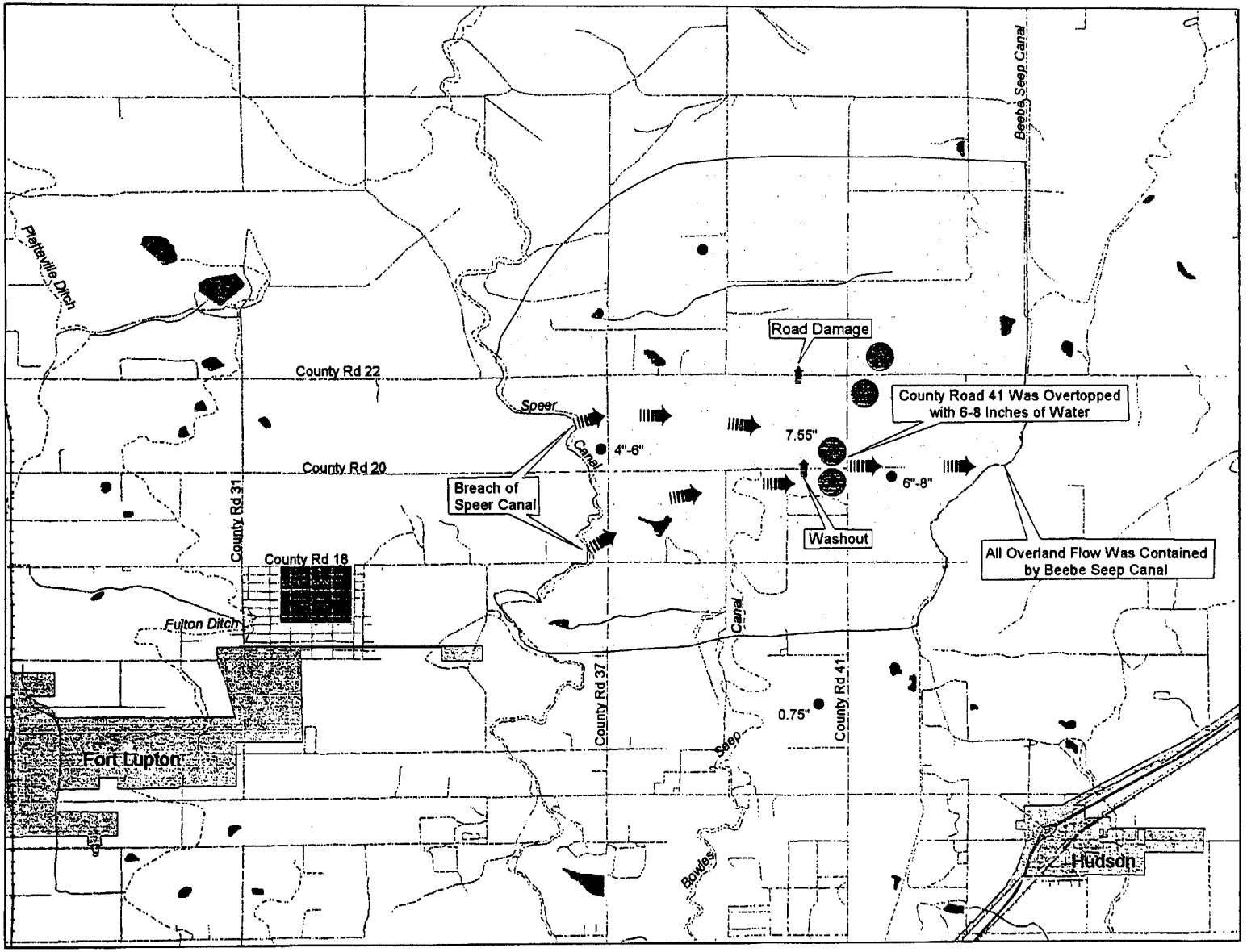

Figure 4.14-10

Weld County

Affected Watershed Map

Northwest of Hudson
Storm of July 28, 1997

N

- Rivers and Streams
- Canals and Ditches
- Interstate Highways
- Primary Roads
- Secondary Roads
- Railroads
- Lakes and Reservoirs
- Municipal Boundaries
- Basin
- Flood Damage to Residential Structures
- Rainfall Bucket Survey
- Direction of Overland Flow

0.5 0 0.5 1 1.5 2 2.5
Miles

Riverside Technology, inc.

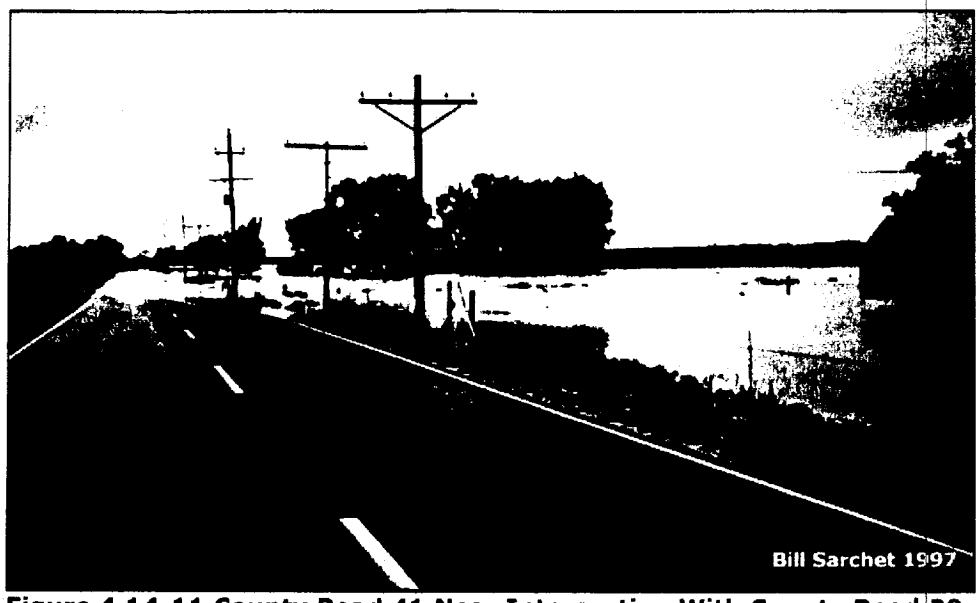

Figure 4.14-11 County Road 41 Near Intersection With County Road 20

Figure 4.14-12 High Water Mark of 32 Inches Inside Sarchet Residence

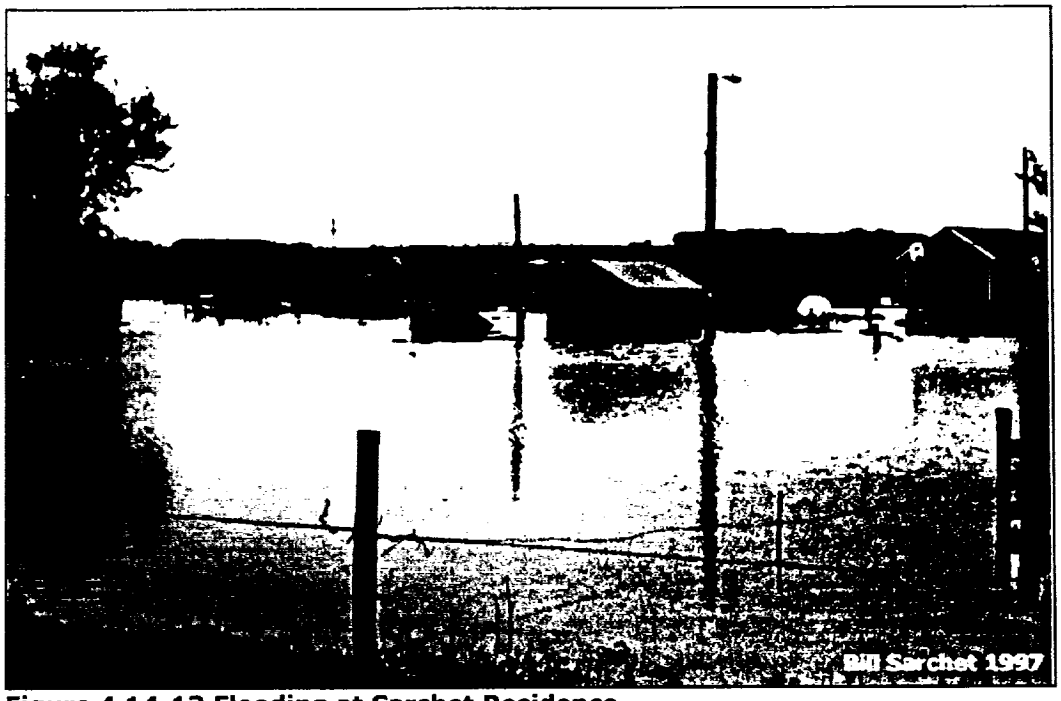

Figure 4.14-13 Flooding at Sarchet Residence

Figure 4.14-14 Washout on County Road 20 West of County Road 41

A smaller storm occurred in the same general area on the evening of August 5, 1997. A total accumulation of 2.84 inches was measured by an observer (Mountain States Weather Services 1997) for this storm. Even though this event was much smaller than the event on July 28, the extent of flooding was almost identical because the land in the surrounding areas was completely saturated.

4.14.5.2 Channel Characteristics

The natural channels in Weld County, including Lone Tree Creek, Crow Creek, Pawnee Creek, and Sheep Draw, drain agricultural lands and undeveloped rangeland. These channels are irregular in nature, have relatively mild slopes, and are generally well defined. The channels consist of primary stream cross sections with overbank flood plains. The average width and depth of the primary stream cross sections for various channels in Weld County range from a depth of 4 to 12 feet and a width of 10 to 70 feet.

4.14.5.3 Peak Flows and Estimated Return Periods

May 24, 1997

Excessive runoff from the rainfall on May 24, 1997, caused several unnamed creeks in northern Weld County to overflow their banks. An RTi flood documentation team was dispatched to northern Weld County to conduct field investigations and to compute peak discharges for several locations.

In order to estimate peak discharges, the RTi flood documentation team identified and surveyed cross section locations, flagged high water marks, and measured channel slopes. The team estimated peak discharges by employing Manning's equation assuming normal flow. Several indirect flow estimates were determined and averaged. The computed peak discharge for the study area is presented in ***Table 4.14-9.*** A range of flows are presented because of the inherent uncertainty in estimating peak discharges.

Table 4.14-9
Computed Peak Discharge for the Storm Event of May 24, 1997

Location	Drainage Area (square miles)	Estimated Peak Flow (cfs)	Estimated 100-year Peak Flow[1] (cfs)
1,000 feet downstream of Kimball, CR 25 (unnamed tributary north of Sidney Draw)	22.6	1,800 to 2,400	5,400

[1]CWCB 1997b

June 2, 1997

Excessive runoff from the rainfall on June 2, 1997, caused several creeks, including Crow Creek, Willow Creek, Owl Creek, and Lone Tree Creek, in Weld County to overflow their banks. A CWCB flood documentation team was dispatched to Weld County on June 11, 1997, to perform field investigations and to compute peak discharges for several locations.

In order to estimate peak discharges, the flood documentation team identified and surveyed cross section locations, flagged high water marks, and measured channel slopes. The team estimated peak discharges by employing Manning's equation assuming normal flow. Several indirect flow estimates were determined and averaged at each of the locations. The computed peak discharges are presented in ***Table 4.14-10.*** A range of flows are presented because of the inherent uncertainty in estimating peak discharges.

Table 4.14-10
Computed Peak Discharge for the Storm Event of June 2, 1997

Location	Estimated Peak Flow (cfs)	Estimated 100-year Peak Flow[1] (cfs)
Crow Creek at Cornish	150-250	Not estimated
Crow Creek at Barnesville	900-1,200	Not estimated
Willow Creek at Galeton	30-50	3,800
Owl Creek at CR 90, upstream of Owl Creek Reservoir	600-900	19,500
Lone Tree Creek at Highway 14	150-250	12,000-28,000
Lone Tree Creek near intersection of CRs 43 and 74	400-600	12,000-29,000
Lone Tree Creek near Greeley	Not estimated	14,000-35,000

[1]CWCB 1997b

June 13, 1997

Excessive runoff from the rainfall on June 13, 1997, caused several creeks, including Sheep Draw and the Cache la Poudre River near Greeley, to overflow their banks. A CWCB flood documentation team was dispatched to Weld County on June 24, 1997, to perform field investigations and to compute peak discharges for several locations.

In order to estimate peak discharges, the flood documentation team identified and surveyed cross section locations, flagged high water marks, and measured channel slopes. The team estimated peak discharges by employing Manning's equation assuming normal flow. Several indirect flow estimates were determined and averaged at each of the locations. The computed peak discharges for the study area are presented in ***Table 4.14-11.*** Again, a range of flows are presented because of the inherent uncertainty in estimating peak discharges.

Table 4.14-11
Computed Peak Discharge for the Storm Event of June 13, 1997

Location	Estimated Peak Flow or Bridge Capacity (cfs)	Estimated Return Period
Sheep Draw, F Street Bridge[1]	Bridge capacity = 1,330[2]	100-year existing condition discharge is 5,075 cfs[4]
Sheep Draw, 71st Avenue Bridge[1]	Bridge capacity = 4,175[2]	100-year existing condition discharge is 4,155 cfs[4]
Sheep Draw, 83rd Avenue Bridge[1]	Bridge capacity = 3,820[2]	100-year existing condition discharge is 3,803 cfs[4]
Sheep Draw, 4th Street Bridge	Bridge capacity = 19,075[2]	100-year existing condition discharge is 5,040 cfs[4]
Sheep Draw, 10th Street Bridge	Bridge capacity = 11,365[2]	100-year existing condition discharge is 4,930 cfs[4]
Sheep Draw, 300 ft downstream of Highway 34	Estimated peak flow = 3,200[3]	50-year discharge = 3,100 cfs[5]
Cache la Poudre River near Greeley (06752500)	3,670 (measured by USGS)	100-year discharge = 9,400 cfs (at mouth)[5]

[1]Bridges that were overtopped during the flooding associated with the June 13 storm event.

[2]Existing bridge capacities were obtained from the Sheep Draw Master Drainage Plan (Lidstone & Anderson, Inc. 1997). The capacity of bridge crossings were calculated using the HEC-2 Water Surface Profile program using the normal bridge option and represent the capacities of the structures prior to overtopping the roadway.

[3]Discharge measured by the CWCB flood documentation team.

[4]Return periods taken from the Sheep Draw Master Drainage Plan (Lidstone & Anderson, Inc. 1997). These return periods represent existing conditions.

[5]Return periods based on hydrology values found in COE 1981.

Instantaneous flows for June 13 were obtained from the Colorado Division of Water Resources for the USGS gage Cache la Poudre River near Greeley, Colorado (06752500). The peak instantaneous discharge for the Cache la Poudre River near Greeley was measured to be 3,670 cfs on June 13 at midnight.

Two bridges along Sheep Draw were not overtopped during the flooding of June 13: the bridge at 4th Street and the bridge at 10th Street. The flows experienced at these two bridges were less than their design discharges. For comparative purposes, the capacities of these two structures as developed in

the Sheep Draw Master Plan (Lidstone & Anderson, Inc. 1997) are presented in ***Table 4.14-11***.

Three bridges along Sheep Draw overtopped during the flooding of June 13: the bridge at F Street, the bridge at 71st Avenue, and the bridge at 83rd Avenue. The flow experienced at these three bridges was more than their estimated discharge capacity. For comparative purposes, the capacities of these three structures as developed in the Sheep Draw Master Plan (Lidstone & Anderson, Inc. 1997) also are presented in ***Table 4.14-11***.

Figure 4.14-15 shows the locations and estimated peak flows for various locations along Sheep Draw as a result of the storm event of June 13, 1997.

July 28, 1997

Excessive runoff from the rainfall on July 28, 1997, caused severe flooding in southwestern Weld County. An RTi flood documentation team was dispatched to southwestern Weld County on June 4, 1998, to conduct field investigations and a rainfall bucket survey. Peak discharges were not estimated for the flows resulting from this storm event because the flow occurred as general overland flow and was not confined to a well defined channel.

Reports from local residents indicate that the Seep canal contained all the overland flow. As mentioned previously, the Farmers Irrigation Company does not record flow in this canal. However, the Beebe Seep canal flows into Milton Reservoir, and the irrigation company does keep records of stage within Milton Reservoir. An estimate of the peak discharge resulting from the July 28 storm into Milton Reservoir was not available from the irrigation company.

4.14.5.4 Flood Hydrograph

Because of the limited availability of chronological information, flood hydrographs were developed only for the storm events of June 13 on Sheep Draw and the Cache la Poudre River just downstream of Sheep Draw and July 28 for the area northwest of Hudson.

June 13, 1997

On the basis of information gathered from community residents, county officials, city officials, state officials, and CWCB flood documentation team members, the approximate chronology of flooding for Sheep Draw near Greeley associated with the storm event of June 13 is shown in ***Table 4.14-12***.

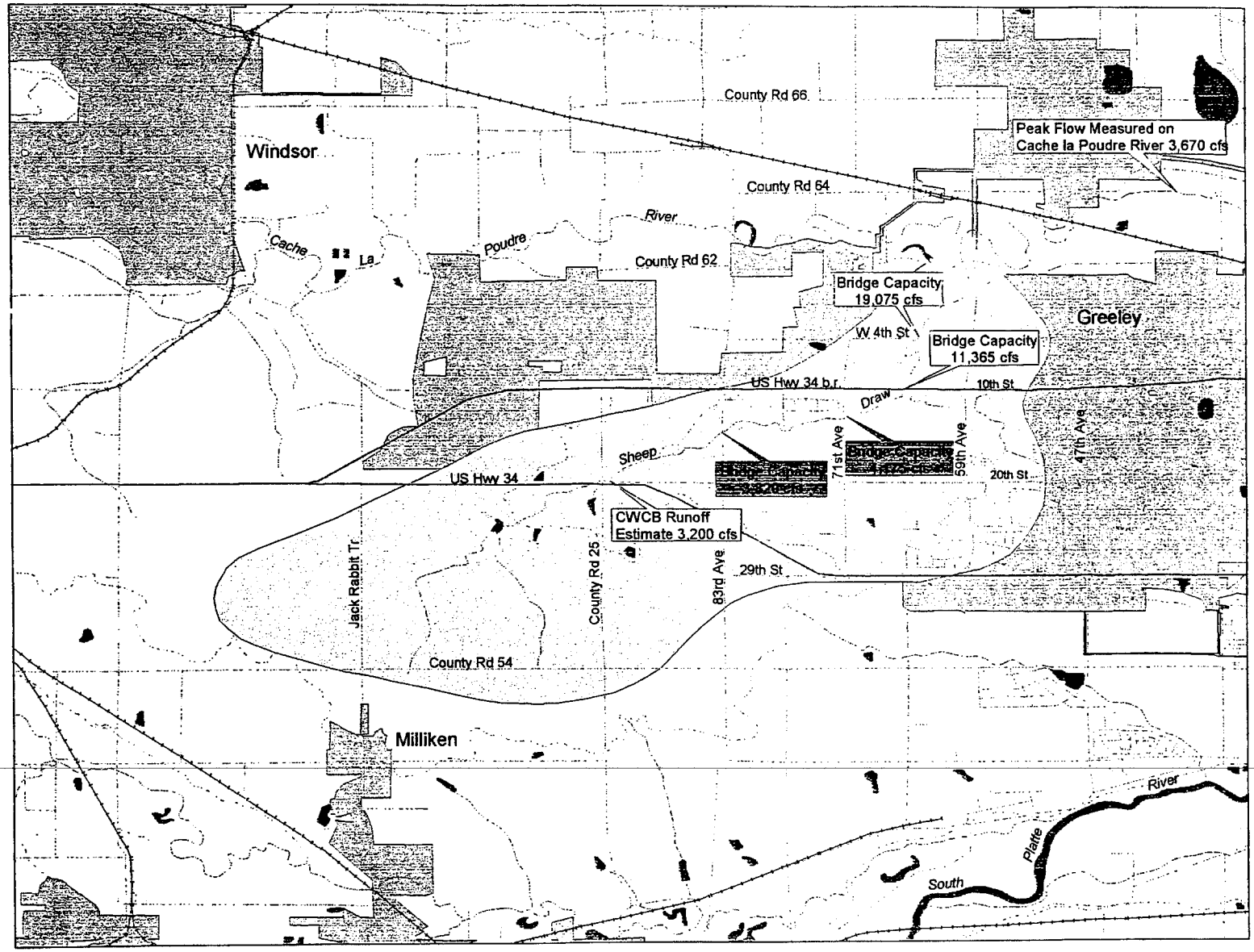

Figure 4.14-15

Weld County

Sheep Draw Basin

Estimates of Discharge for the Storm Event of June 13, 1997

N

- Rivers and Streams
- Canals and Ditches
- Interstate Highways
- Primary Roads
- Secondary Roads
- Railroads
- Lakes and Reservoirs
- Municipal Boundaries
- Sheep Draw Basin
- 100 Year Flood Boundary
- Overtopped Bridges

0.5 0 0.5 1 1.5 2 2.5

Miles

Note that the discharge capacity was exceeded at the bridge structures along 83rd Avenue and 71st Street. The discharge capacity was not exceeded at the bridge structures along 4th Street and 10th Street.

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Table 4.14-12
Chronology of Flooding in Sheep Draw
for June 13, 1997

Date/Time	Description of Event
June 13, 3:30 p.m.	Light rainfall begins west of Greeley
June 13, 5:00 p.m. to 6:30 p.m.	Period of heaviest rainfall (5.0 + inches in 1.5 hours)
June 13, 8:00 p.m. to 10:00 p.m.	Discharge peaks
June 14, 6:00 p.m. to 7:00 p.m.	Discharge approximately 25 percent of peak

Source: CWCB 1997c

An approximate hydrograph can be established for Sheep Draw by analyzing the observed discharges in the Cache la Poudre River for June 12 through June 17, 1997. The USGS measures instantaneous hourly flows along the Cache la Poudre River at several locations, including the Cache la Poudre River above Box Elder Creek near Timnath (06752280) and the Cache la Poudre River near Greeley (06752500). A water balance analysis (see the Technical Addendum for the complete calculation file) was performed for the reach between these two Cache la Poudre River gaging locations in order to estimate an approximate hydrograph for the discharge along Sheep Draw (see Technical Addendum for calculation).

There are several watersheds and irrigation canals (including Box Elder Creek and Fossil Creek) that are tributary to the Cache la Poudre River in addition to Sheep Draw between these USGS gaging locations. The assumption made for the water balance analysis is that the inflows from Box Elder and Fossil creeks (approximately 250 cfs) are minimal and that all major irrigation canals were turned off because of the amount of rain in the days before June 13 (Seivers 1998, Hoff 1998). Under these assumptions, the majority of inflow to the Cache la Poudre River is from Sheep Draw.

Physically, this assumption seems reasonable because the spatial extent of the storm event on June 13 was fairly localized to the area immediately west of Greeley, including Sheep Draw. The observed hydrographs for the two USGS gages along the Cache la Poudre River are shown in ***Figure 4.14-16***. The approximate flood hydrograph developed for Sheep Draw at the Cache la Poudre River is shown in ***Figure 4.14-17***. The peak flow experienced in the headwaters of Sheep Draw was considerably larger than the peak flow shown on ***Figure 5.14-17***. This variance is caused by the many structures along Sheep Draw that attenuate flow, as well as the fact that the flood waters were considerably dispersed into adjacent fields at the confluence of Sheep Draw and the Cache la Poudre River.

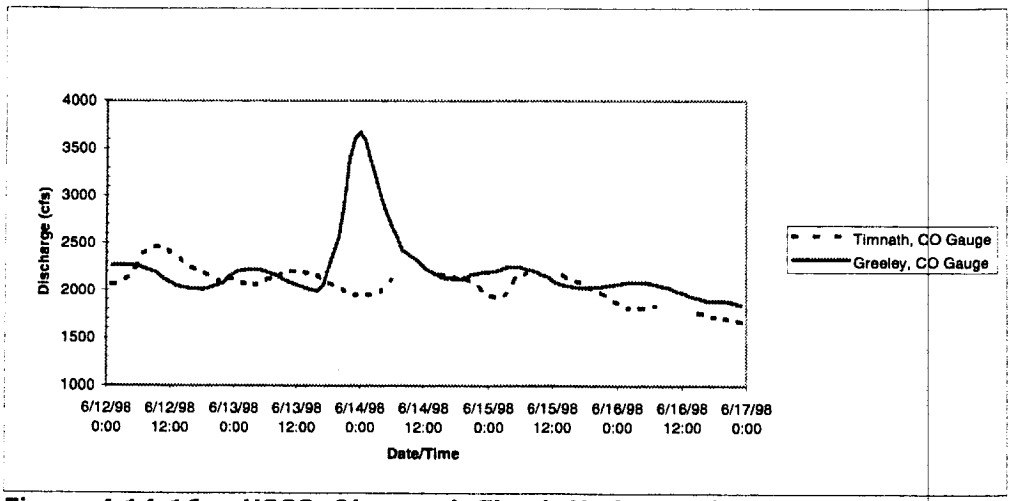

Figure 4.14-16 USGS Observed Flood Hydrographs, Cache la Poudre River, June 13, 1997

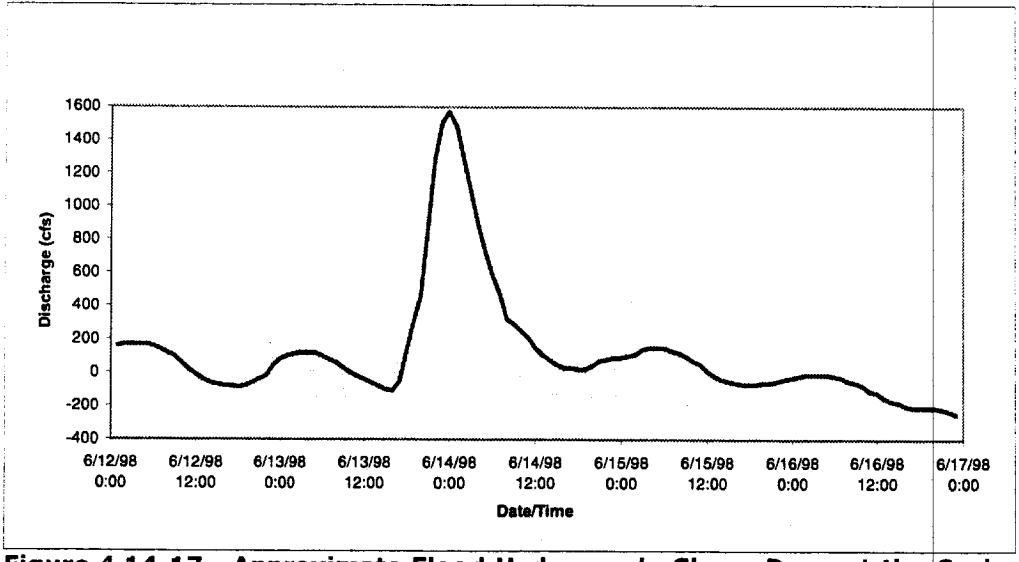

Figure 4.14-17 Approximate Flood Hydrograph, Sheep Draw at the Cache la Poudre River, June 13, 1997

July 28, 1997

On the basis of information gathered from local residents, the approximate chronology of flooding over County Road 41 at the intersection of County Road 20 associated with the storm event of July 28 is shown in ***Table 4.14-13***.

4.14.6 Specific Flooded or Inundated Areas

Specific flooded or inundated areas are documented only for the flooding resulting from the June 13 storm event west of Greeley along Sheep Draw. The City of Greeley Public Works Department sent a flood documentation team to survey flood inundation boundaries after the June 13 event. Little

information regarding specific flood inundation areas is available for the other storm events of 1997.

Table 4.14-13
Chronology of Flooding Over County Road 41 Near the Intersection With County Road 20 for July 28, 1997

Date/Time	Description of Event
July 28, 4:00 p.m.	Light rainfall begins northwest of Hudson
July 28, 10:00 p.m.	Rainfall ends
July 28, 11:00 p.m.	Discharge peaks over County Road 41; 6 to 8 inches over roadway
July 29, 1:30 a.m.	Discharge approximately 35 percent of peak; 2 to 3 inches over roadway
July 29, 3:00 a.m.	No water on roadway

Source: CWCB 1998b

Overall, flooding was extensive along the entire Sheep Draw basin as a result of the storm event on June 13. The City of Greeley Public Works Department documented the extent of flooding at each of the major bridges crossing Sheep Draw, including the F Street bridge, 4th Street bridge, 10th Street bridge, 71st Avenue bridge, and the 83rd Avenue bridge. ***Figures 4.14-18 through 4.14-22*** show the approximate extent of specific flooded areas documented by the City of Greeley Public Works Department.

4.14.7 Emergency Response Effort

Emergency actions in the event of a flood are coordinated through the Civil Defense Office in Weld County. The Denver Weather Service Forecast Office of the NWS provides general flash-flood warnings for Weld County.

Emergency response efforts associated with the storm events of June 2 and June 13, 1997, are described in this section. However, the storm events of May 24 and July 28 occurred in predominantly rural areas, and little information regarding emergency response efforts is available.

The storm events on June 2 and June 13 produced street flooding and basement flooding in local communities, but no evacuations were initiated by Weld County emergency management, Greeley City Police, Greeley Fire Authority, or the Colorado State Patrol. Emergency response efforts consisted mainly of closing state and county roads that were experiencing flooding.

June 2, 1997

Weld County road and bridge crews were dispatched to the northeast portion of the county on the evening of June 2 to close roads that were

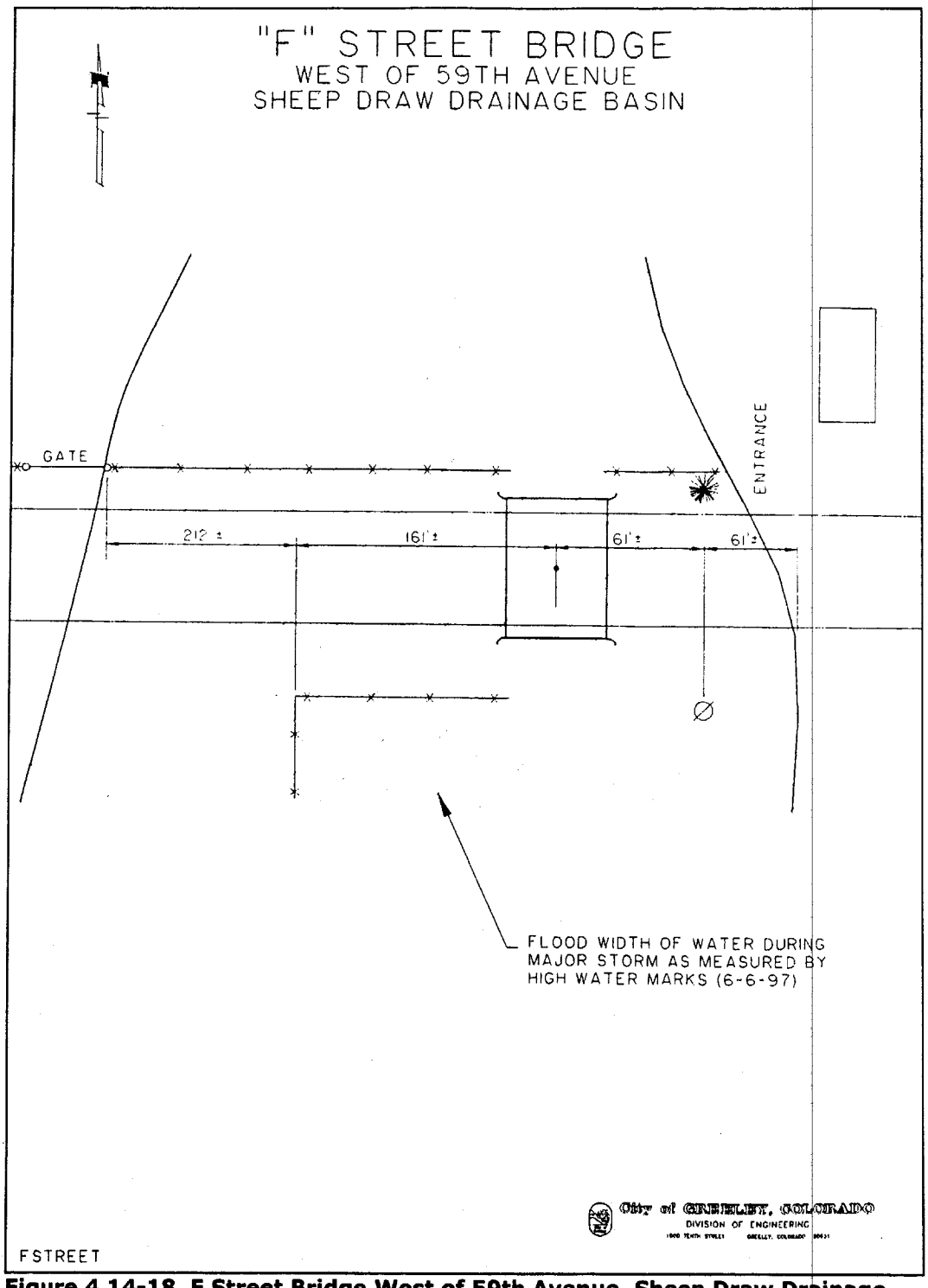

Figure 4.14-18 F Street Bridge West of 59th Avenue, Sheep Draw Drainage Basin

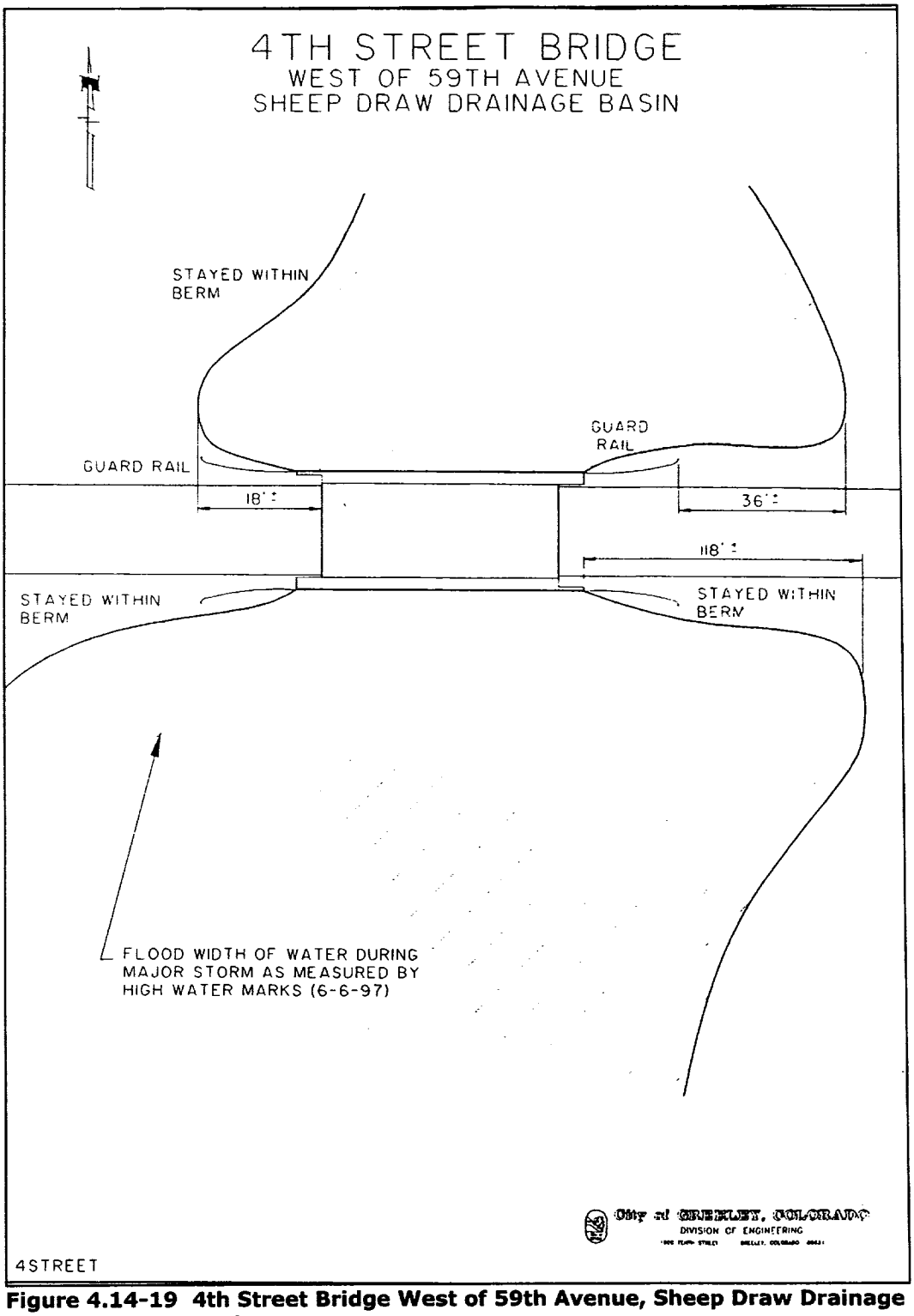

Figure 4.14-19 4th Street Bridge West of 59th Avenue, Sheep Draw Drainage Basin

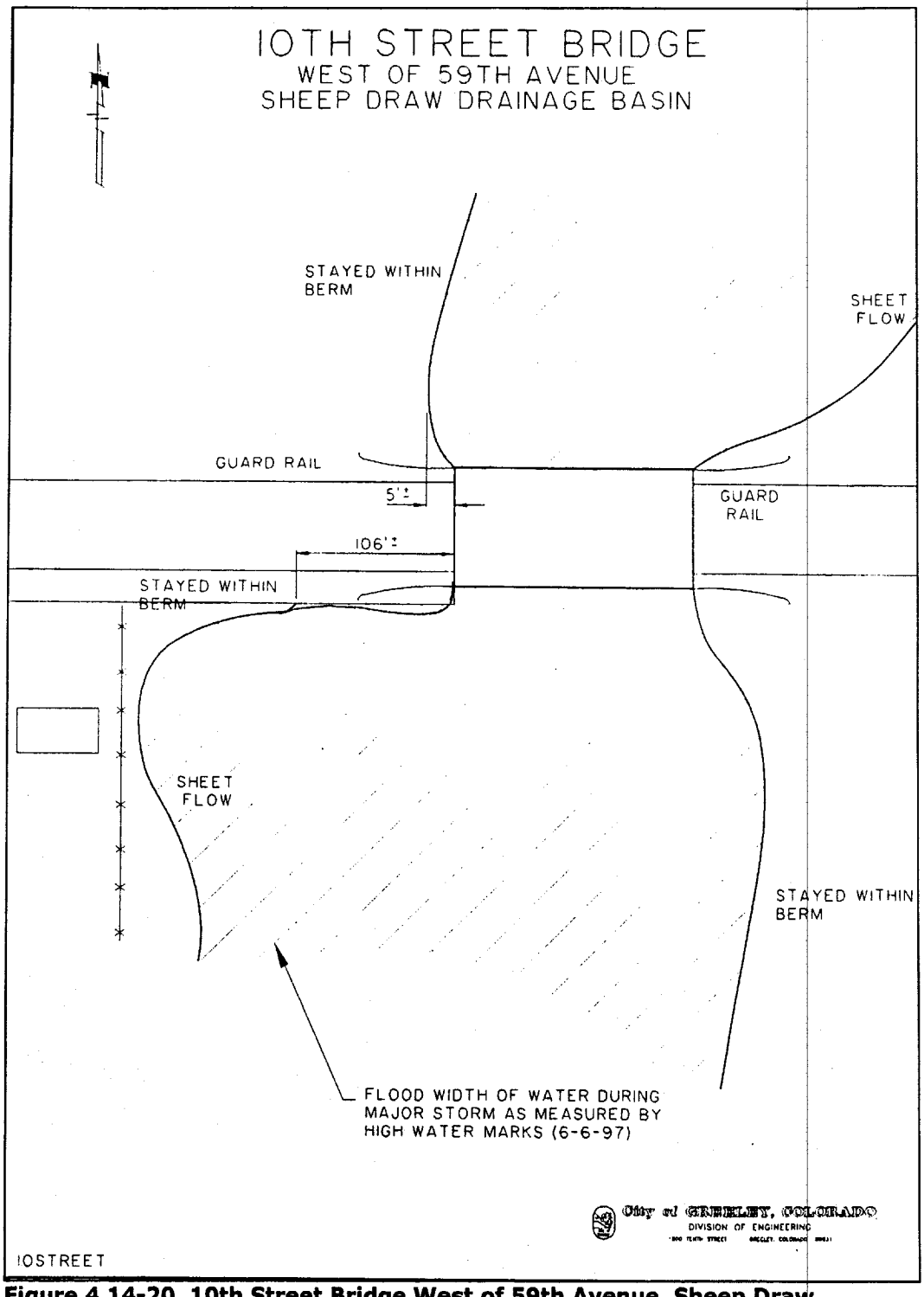

Figure 4.14-20 10th Street Bridge West of 59th Avenue, Sheep Draw Drainage Basin

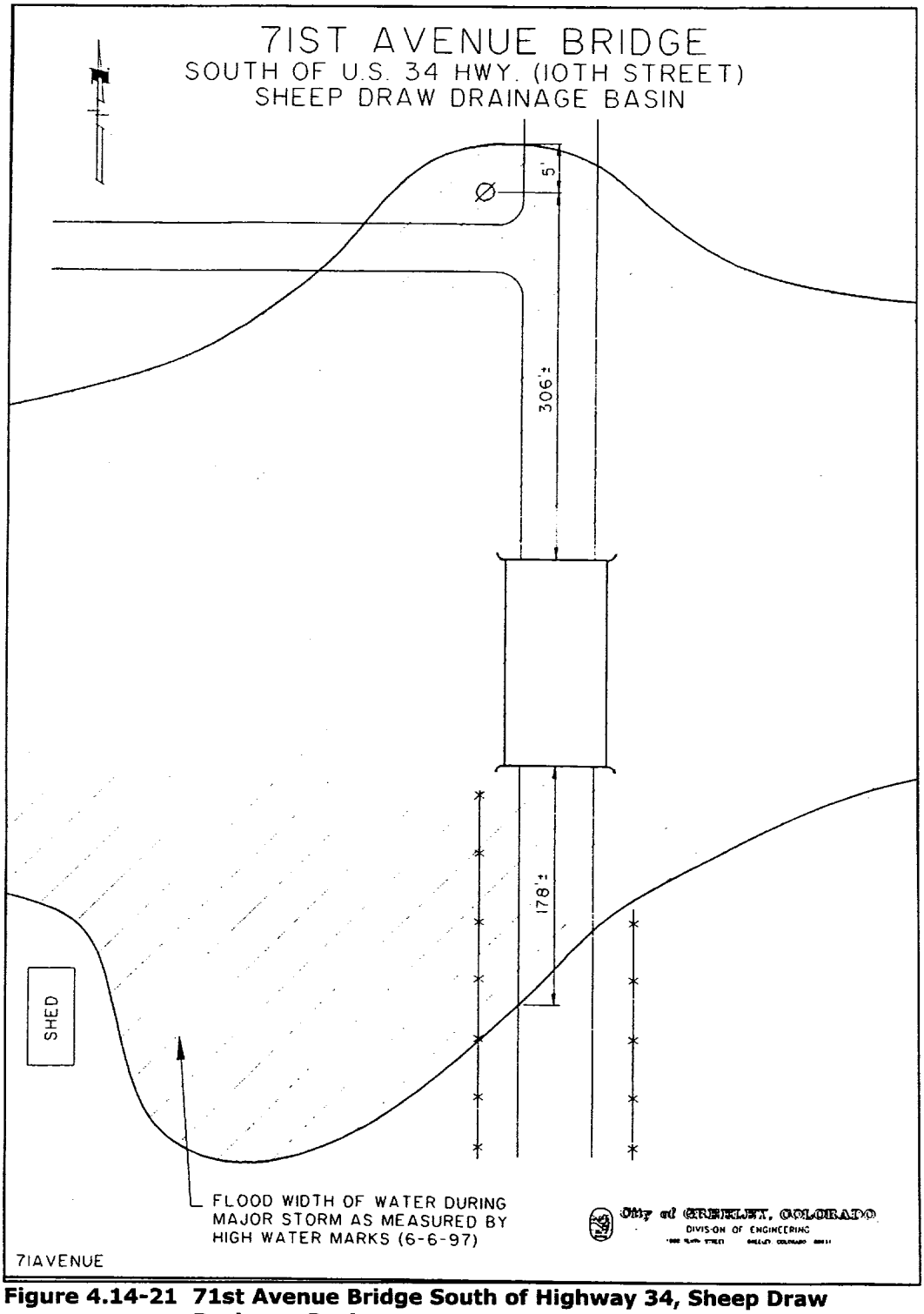

Figure 4.14-21 71st Avenue Bridge South of Highway 34, Sheep Draw Drainage Basin

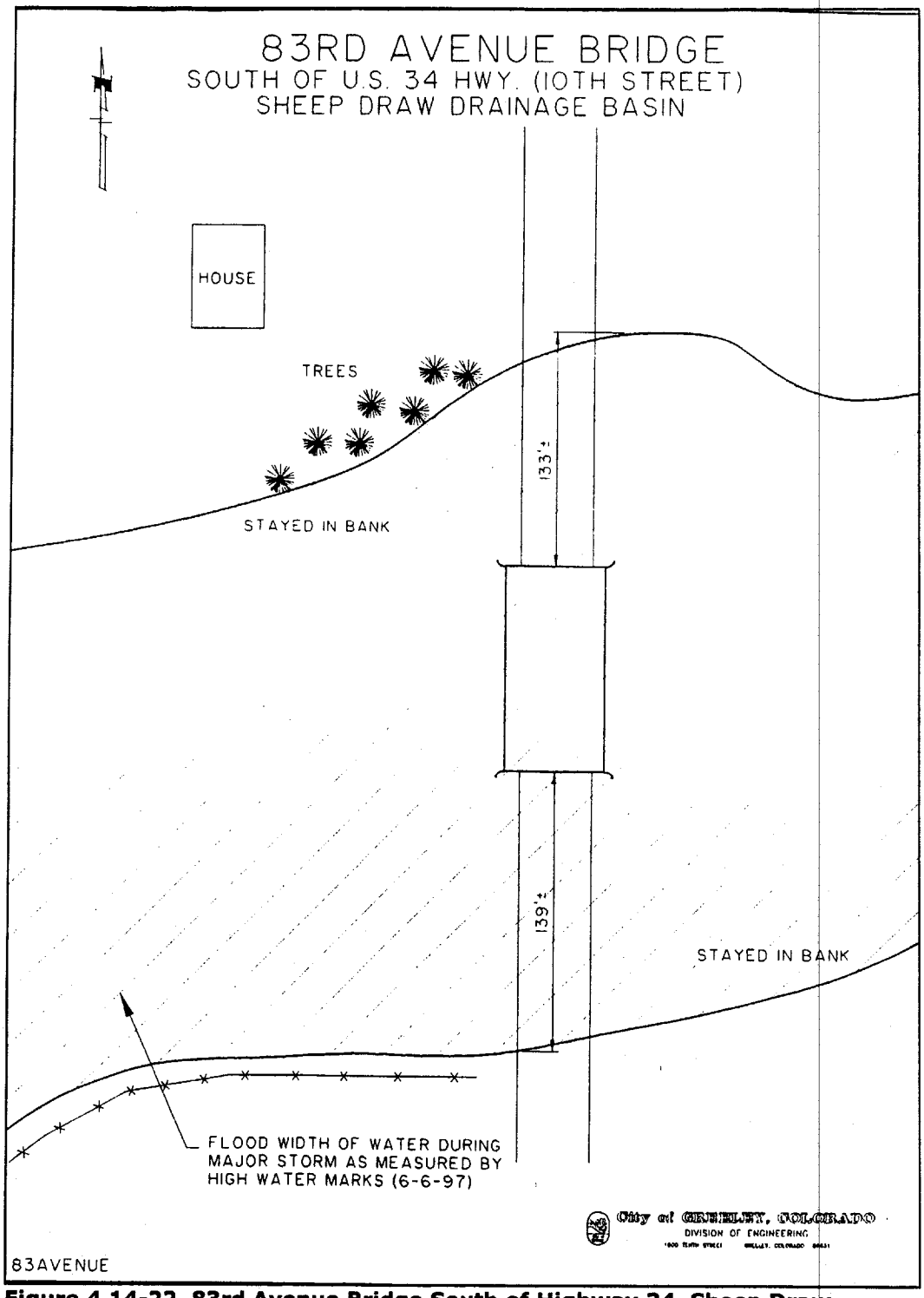

Figure 4.14-22 83rd Avenue Bridge South of Highway 34, Sheep Draw Drainage Basin

flooding. Weld County road 392 was closed at Coal Creek where more than 18 inches of water covered the roadway (*Greeley Tribune* 1997d).

In addition, the Colorado Department of Transportation closed Colorado Highway 14 shortly after 4:00 p.m. on June 2. The road was closed approximately 8 miles west of Briggsdale when water from Coal Creek began washing around the bridge (*Greeley Tribune* 1997d).

June 13, 1997

According to Greeley Police Sergeant Fred Meyer, only a single injury accident was attributed to the storm of June 13, 1997.

In Greeley, the Weld County Sheriff's Office and Weld County road and bridge officials closed the bridge near 83rd Avenue and 20th Street when flood waters from Sheep Draw caused damage to the structure (*Greeley Tribune* 1997c). In addition, Weld County road and bridge crews closed County Road 54 in the Arrowhead area, as well as the bridge on the Cache la Poudre River at 71st Avenue, which sustained damage (*Greeley Tribune* 1997e).

In Milliken, the Kilgore Supply store experienced flooding when water 18 inches deep surrounded the building. Volunteer firemen and local firefighters were dispatched to the store to help evacuate people and goods from rising flood waters (*Greeley Tribune* 1997c).

In Kersey, the local fire department responded to calls from citizens requesting help when water entered basements (*Greeley Tribune* 1997c).

In Weld County, all of the following county roads were closed because of local flooding as a result of the storms on June 2 and June 13 (*Greeley Tribune* 1997f):

- County Road 106
- County Road 96
- County Road 87
- County Road 74
- County Road 72
- County Road 65
- County Road 50

July 29 Through 30, 1997

In northeastern Weld County, many county and state roads were closed because of the extreme precipitation that fell on the Pawnee National Grassland. U.S. Highway 6, Colorado Highway 14, Colorado Highway 52,

and Colorado Highway 71 all were closed for various periods because of the floodwaters from Pawnee and Cottonwood creeks (*Greeley Tribune* 1997a).

4.14.8 1997 Flood Damage

General locations of flood damage are shown in ***Figure 4.14-23*** for the entire county during 1997.

May 24, 1997

Heavy precipitation on May 24 produced major storm runoff from several unnamed tributaries in northern Weld County along the Colorado-Nebraska border. Neither damage to Colorado county roads and bridges that traverse these drainages nor damage to residential and commercial properties was not estimated.

June and July, 1997

Heavy precipitation on June 2, June 13, and July 29 produced major storm runoff from Crow Creek, Willow Creek, Owl Creek, Lone Tree Creek, Pawnee Creek, Cottonwood Creek, Sheep Draw, and the Cache la Poudre River. Damage to county and state roads and bridges; residential and commercial properties in Greeley, Milliken, Evans, Kersey, Raymer, and Stoneham; and agricultural lands were recorded for these events. Total damage costs were estimated to be approximately $6,492,723. See ***Table 4.14-14*** for a summary of these costs.

The following properties were damaged by flood waters from the storm events on June 2 and June 13, 1997:

- Homes in the Arrowhead and Dos Rios subdivisions
- Homes along Sheep Draw in west Greeley
- Homes along Ashcroft Draw in southwestern Greeley
- Businesses, including Kilgore Supply in Milliken and Nugget International in Greeley
- Municipal building in Raymer
- Fifteen to 20 major washouts on state roads
- Three bridges (Highway 14 at Coal Creek, Highway 71 at Pawnee and Cottonwood Creeks)

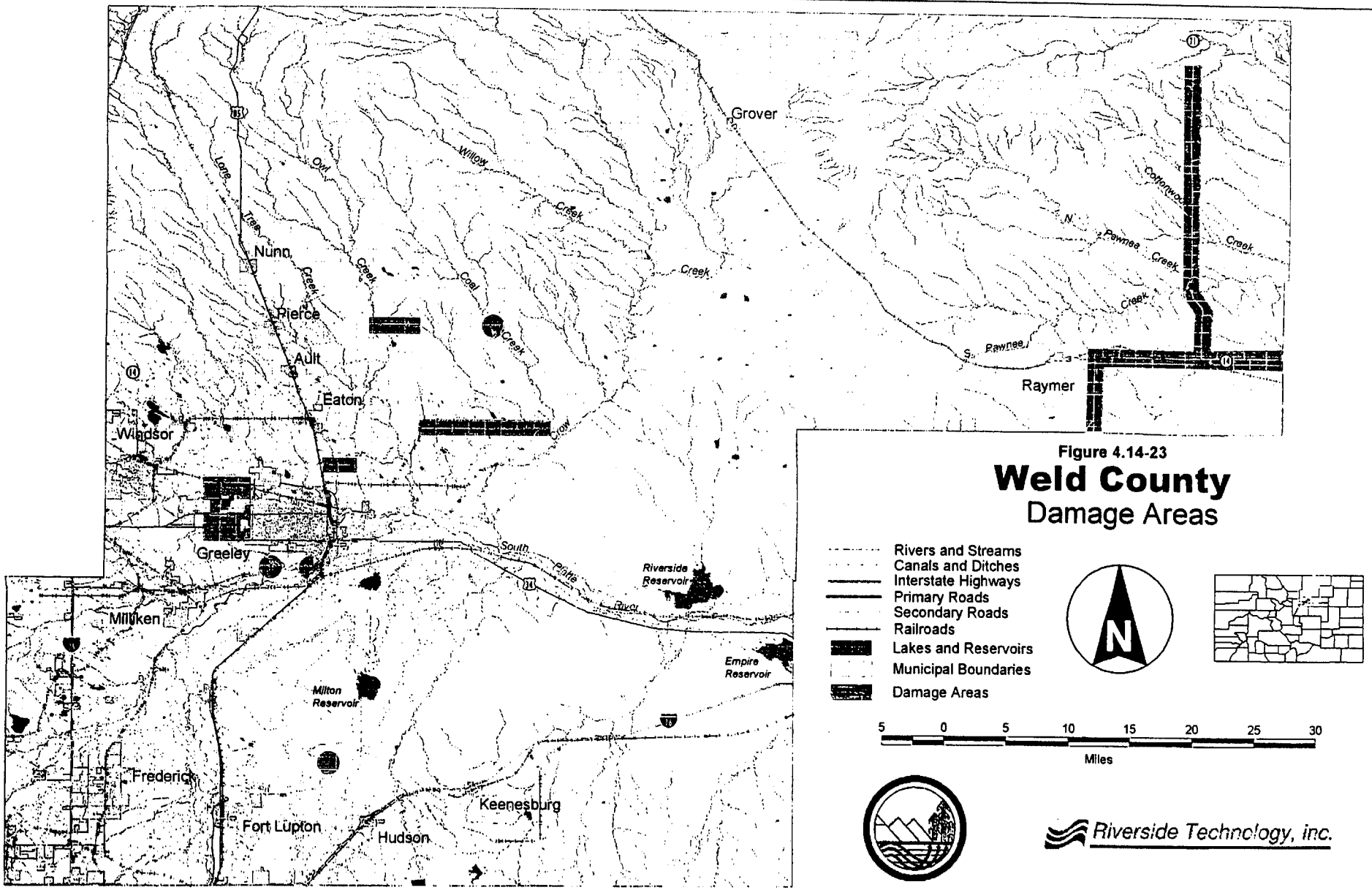

Figure 4.14-23

Weld County

Damage Areas

Table 4.14-14
Damage Estimates From the June - July 1997 Storm Events

Description	Damage Estimate	Source
County roads and bridges	$405,199[1,2] - all of June $1,103,139[1,2] - July 28 to Aug. 8	Weld County (Herring 1998)
Residential properties	[3]	Private Citizens (Sarchet 1998a)
Commercial properties	[3]	Kilgore Supply (*Greeley Tribune* 1997c)
Municipal building in Raymer	$75,000[1,2]	Weld County (*Greeley Tribune* 1997g)
State roads	$0	CDOT (Gable 1998)
State bridges on Highway 71 (one on Cottonwood Creek and another on Pawnee Creek)	$1,320,000[4]	CDOT (Gable 1998)
State bridge on Highway 14 (Coal Creek)	$4,757,524[4]	CDOT (Gable 1998)
Agriculture	No dollar cost estimated	Private citizens
FEMA - countywide	$343,567[5]	FEMA Damage Survey Reports (1998)

[1]Values are unofficial; they are best estimates at the time of the study.
[2]Estimates were gathered from various sources and may include some overlap and omissions; therefore, they are not combined for a total damage estimate for the county.
[3]Actual damage estimates were not obtained but are assumed to be on the order of several hundred thousand dollars (Browning 1998c).
[4]These damage estimates include costs for engineering design, construction (including external contractors), and maintenance. The bridge on Highway 71 was replaced with a new bridge; the damage estimate includes costs for engineering design and construction. The bridge on Highway 14 is going to be replaced. CDOT has contracted for a new bridge at an estimated cost of approximately $4.5 million. This figure includes design and construction costs.
[5]FEMA estimates are not all-inclusive, and limitations on FEMA assistance varied among counties.

- Fifty to 100 washouts on county roads
- Substantial damage to crops and fields

Although no dollar figures were determined for the damage sustained by agricultural crops, the USDA-Farm Service Agency did estimate unofficial damages that are summarized in ***Table 4.14-15***.

Table 4.14-15
Unofficial Crop Damage
Associated With the Flooding in June and July, 1997

Crop	Affected Acres	Percent Loss
Wheat	1,000	15
Corn	10,000	20
Alfalfa	3,000	4
Beans	2,200	20
Onions	3,500	20
Barley	1,800	20
Sugar beets	2,750	20

Source: Germann 1998

4.14.9 Flood Hazard Mitigation

4.14.9.1 Previous Efforts

Previous flood mitigation efforts within Weld County are fairly limited. Almost all of the reservoirs in the county are for irrigation or water supply and are not designed for flood control. The operation of most reservoirs, including Black Hollow, Kern, and Windsor Lake, result in their being nearly full in June, and there is little extra storage available during the flood season (COE 1981).

Weld County officials identified no major previous flood mitigation efforts, either structural or non-structural (Scheltinga 1998). Although specific efforts are not identified here, the City of Greeley has and does consider flood mitigation in developing its master drainage plan.

4.14.9.2 Future Needs

In 1981, the COE identified the Black Hollow Dam and Kern Dam in western Weld County as being seriously inadequate and placed the dams in the high hazard class. Colorado Highway 14 and the communities of Severance and Windsor were identified as developments subject to hazard (COE 1981).

Sheep Draw was identified by Weld County officials as a watershed potentially requiring future flood mitigation activities. This need arises primarily because of the residential development occurring in the watershed and the fact that the watershed probably will be annexed by the City of Greeley in the next 15 to 20 years (Scheltinga 1998, Bagley 1998).

The No. 3 ditch also was identified as a potential source of flooding that may require future mitigation efforts (Bagley 1998, and *Greeley Tribune* 1997h).

As a matter of regular maintenance, culverts throughout the county should be maintained and cleared of sediment and debris so that their design conveyance capacity can be achieved.

4.14.10 Special Circumstances

In general, all the tributaries in rural Weld County can experience flooding conditions along reaches where highway and railroad embankments transect the natural drainage paths. The criteria used to design these crossings were not investigated for this document.

Tributaries in urban Weld County can experience flooding conditions along reaches where structures, including box culverts, bridges, and other conduits, are inadequately designed to handle the increased volume of runoff generated as a result of local development.

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