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**DEATHS, INJURIES, AND PROPERTY DAMAGE DUE TO LIGHTNING
IN COLORADO FROM 1950 TO 1991 BASED ON *STORM DATA***

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ABSTRACT

Forty-two years of lightning casualty and damage reports in Colorado are summarized. The data are from NOAA's *Storm Data*, which is compiled monthly by the National Weather Service.

The dataset contains 103 deaths, 299 injuries, and 191 damage reports from 1950 through 1991. Time fluctuations of these lightning events are shown by classifying the data by year, month, and hour of the day. Additional information is provided on age and gender of lightning victims.

Houses were the most common objects reported as damaged by lightning. Fire was the most common source of lightning damage to structures or objects. Comparisons are made of these and other results, when possible, with previous studies of lightning in other locations around the world.

Geographical patterns of lightning incidents for the state are shown in maps of total number of casualties, and number of casualties normalized by population density for each county. Much higher casualty rates per population and area occur over the mountains and some areas of the eastern slopes than elsewhere.

Most often, people were involved in recreation or employment when they became lightning victims. Most frequent locations of lightning casualties, in order, were summits of mountains and ridges, under trees, in the open, and at lakes. Outdoor recreation casualties were most frequent in the mountains, agricultural cases over the eastern plains, and sports and domestic casualties along the Front Range urban corridor.

Year-to-year variability was high in all categories. When compared to the steady increase in the population of Colorado, there were less casualty and damage reports during the 1970s and early 1980s than before and after that period. Ranch and farm casualties decreased greatly after the early 1960s. Outdoor recreation, urban, and work cases steadily increased over the entire period in accordance with the population increase. However, sports casualties increased at a substantially larger rate than would be expected from the population increase. Statewide lightning victim counts by 5-year periods relate well with statewide summer-time temperature, but not as well with precipitation.

1. INTRODUCTION

No systematic, extensive long-term study of the impacts of lightning on people and material objects has been developed for all of Colorado to date. In this report, we summarize many of the features of the casualties and material damage that can be gleaned from the National Oceanic and Atmospheric Administration (NOAA) publication *Storm Data*. There is a broad variety of situations leading to lightning casualties and material damage. However, the most common types of events can best be identified by a review of long-term datasets such as will be described here for Colorado.

Recently, a new series of studies has begun on the medical effects of lightning on people in Australia (Andrews and Darveniza, 1992; Andrews et al., 1989, 1992) and the United States (Cherington and Vervalin, 1990; Cherington et al., 1992, 1993; Cooper, 1980, 1989). Their goals are to identify issues related to both the reporting procedures and the need for better understanding of the lightning hazard itself.

A large amount of detailed information is presented in this paper. This serves two purposes:

- This is the first extensive review of Colorado lightning casualties and damage, and these results are not found anywhere else. Publishing all results in this report records most variations that can be pursued with *Storm Data* for Colorado.
- Each reader will be interested in specific topics, whether for the county where they live or the activity they pursue. Showing

only the general results would diminish the total value that some of the data may have.

When possible, a generalized graph or diagram has been developed from the tables to make results easier to understand.

Cloud-to-ground (CG) electrical discharges cause a large number of deaths and injuries, and much material damage each year. Table 1 (after Weigel, 1976) shows the number of deaths in the United States due to different meteorological causes during the period 1940 to 1973. This is a typical summary for the earlier portion of the period to be described for Colorado in this report. The number of deaths due to lightning during this 34-year period is larger than the number caused by tornadoes, floods, and hurricanes. These statistics were based on *Storm Data* starting in 1950, and from the National Center for Health Statistics before 1950. Worldwide, lightning deaths are conservatively estimated as 1000 and injuries as 2500 per year (Mackerras, 1992).

Table 2 presents more detailed lists of deaths and injuries due to meteorological causes from annual summaries compiled by the Warning and Forecast Branch of the National Weather Service in Silver Spring, Maryland. All of these statistics were obtained from *Storm Data*. Lightning is consistently one of the top three causes of deaths during each year. Flash floods, winter weather, and extreme temperatures exchange places from year to year. Also in Table 2, lightning is one of the most consistent causes of injuries.

TABLE 1. Deaths over the United States due to weather causes from 1940 to 1973 (after Weigel, 1976).

Deaths	Lightning	Tornado	Flood	Hurricane
Total	6928	4474	3075	1825
Annual average	204	132	90	54

TABLE 2. Summary of 1990, 1991, and 1992 weather casualties, and 1963-1992 average deaths per year.

Weather type	Deaths				Injuries		
	1990	1991	1992	1963-92	1990	1991	1992
Flash flood	109	45	55	} 139	60	13	41
River flood	33	16	7		51	43	207
Lightning	74	73	41	93	247	429	266
Tornado	53	39	39	82	1150	854	1300
Hurricane	0	13	27	28	0	208	298
Winter weather	48	45	64		499	427	379
Extreme temperatures	45	49	22		75	247	79
Thunderstorm wind	39	32	13		571	522	282
Other high wind	32	32	15		93	90	44
Fog	17	17	14		116	69	173
Other	11	30	11		94	362	170

Additional lightning cases are known to have also occurred during this period. Mogil et al. (1977) examined the issue of underreporting in databases of lightning strikes to people, and recommended that renewed efforts be conducted on this topic. A new study by López et al. (1993) covering 12 years in Colorado showed that *Storm Data* underestimated lightning deaths by at least 28%, and underestimated lightning injuries requiring hospitalization by at least 42%.

Storm Data has also undergone other changes in reporting weather that could influence these numbers. There has been an increased awareness of casualties from winter weather during recent years, as Table 2 shows. In the last few years, more efforts have gone into identifying direct rather than indirect causes of weather casualties, which could

increase or decrease the numbers in Table 2 for different types of casualties.

Nevertheless, in terms of longevity and large geographic coverage, *Storm Data* holds a great potential for documenting the lightning threat. Specific warnings are not provided for lightning, so people are personally responsible for being aware of, and taking action in response to their lightning situation. It is expected that a better understanding of what occurred in past lightning events will help identify typical, recurring situations. Identifying such casualty patterns should lead to better education of the public about the magnitude of the lightning threat, and about particularly vulnerable scenarios to avoid. Hopefully, improved education will lead to a reduction of the rather large number of cases involving lightning deaths, injuries, and material damage.

2. LIGHTNING INCIDENT REPORTS IN STORM DATA

All data used in this report are based exclusively on reports from *Storm Data*, a monthly NOAA publication that describes damaging and severe weather during the year. These reports include deaths and injuries, and material damage reports from such phenomena as tornadoes, hurricanes, strong straight-line winds, flash and river floods, hail, heavy rain, and heat and cold waves.

The name *Storm Data* is used to describe two separate publications, as follows:

- From 1950 through 1958, information was given in approximately the same form as in the more recent years, in the sections "Severe Local Storms" or "Storm Data and Unusual Weather Phenomena" in monthly issues of the *Climatological Data National Summary* of the U.S. Weather Bureau. These earlier issues appear to be more abbreviated in their reports concerning lightning events than during the more recent years.
- From 1959 to the present, *Storm Data* has been published in Asheville, North Carolina. Presently, *Storm Data* is available by subscription from NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) in Asheville.

With regard to lightning, López et al. (1993) emphasized that *Storm Data* is compiled primarily from newspaper reports provided to the NWS by contracted clipping services that attempt to cover all counties of the state by reviewing newspapers. The newspaper clippings are provided to one or two NWS stations per state - for Colorado it is

Denver. In a few cases, the Denver NWS office may obtain reliable reports from the electronic media of lightning events that are not found in the papers. The information compiled by the Denver NWS office is sent to the National Climatic Data Center (NCDC), where it is published, together with similar information from other states, in *Storm Data*.

Reports of lightning-related events used for this Colorado study usually contain the following data:

- Day, month, year
- Time of day in Mountain Standard Time, often to the nearest 15 minutes
- Location in terms of state and county, and usually the closest city
- Type of casualty or damage
- Age and gender of the victims
- Verbal description of the event. For people, this often indicates the activity, location, or occupation of the victims. For material damage, the description briefly identifies the type of property or other object that was impacted. The information that is provided by *Storm Data* is generally accurate.

It should be emphasized, however, that a number of lightning incidents were not entered into the NWS database, mainly because of its primary reliance on newspaper reports. The extent of this underreporting is the subject of the study by López et al. (1993) for the last 12 years in Colorado, concentrating on the nature of newspaper coverage and comparing *Storm Data* reports with externally-provided medical records of lightning casualties.

3. TIME AND SPACE VARIATIONS OF LIGHTNING EVENTS

A. Year-to-year Variations

Table 3 summarizes the individual yearly entries of lightning victims and material damage events found for *Storm Data* in Colorado for each year from 1950 through 1991. Deaths were reported in Colorado every year except during six years, and as many as six

deaths occurred in three different years. Injuries have ranged from none to 25 during one year, and damage has varied from none to 28 events in a single year. There were 103 people killed, 299 injured, and 331 material damage entries from 1950 to 1991.

TABLE 3. Annual variation of number of deaths, injuries, and material damage events due to lightning in Colorado from 1950 through 1991, based on *Storm Data* from NOAA.

Year	Deaths	Injuries	Material damage	Year	Deaths	Injuries	Material damage
1950	0	0	0	1970	1	2	2
1951	4	3	0	1971	0	0	0
1952	2	2	1	1972	3	4	3
1953	3	9	6	1973	0	2	4
1954	1	2	8	1974	1	4	2
1955	1	2	8	1975	1	4	3
1956	3	4	8	1976	2	3	17
1957	4	19	13	1977	3	6	10
1958	0	2	6	1978	5	6	3
1959	2	17	13	1979	0	8	3
1960	6	5	19	1980	1	5	7
1961	6	9	7	1981	5	15	12
1962	3	7	8	1982	6	9	14
1963	2	5	10	1983	1	5	8
1964	3	14	6	1984	4	2	7
1965	3	2	7	1985	1	2	4
1966	0	0	1	1986	1	5	4
1967	3	4	7	1987	3	22	20
1968	2	5	2	1988	5	25	19
1969	4	4	3	1989	4	18	28
1990	2	13	20	1991	2	24	8
Total					103	299	331
Annual average					2.5	7.1	7.9

B. Monthly Variations

Table 4 lists the number of lightning casualties and damage reports by month; Figures 1 and 2 show the data in histogram form. Casualties have occurred in Colorado almost entirely between May and August, with only a few cases outside of these months. Material damage, however, is somewhat more spread through the months before and especially after the mid-summer months of high recreational activity and outdoor employment. The difference could be due to

lesser activity of people during the cooler months in Colorado when there is still some lightning activity. The concentration of events in the summer is common, such as in Australia (Prentice, 1973 and Coates et al., 1993); in England and Wales (Elsom, 1993); and in Singapore (Pakiam et al., 1981). However, Colorado has a shorter peak season than in some warmer locations such as Florida and Arizona where the thunderstorm season is longer.

TABLE 4. Monthly numbers and percentages of annual deaths, injuries, and material damage due to lightning in Colorado from 1950 through 1991, based on *Storm Data*.

Month	Deaths		Injuries		Material damage	
	Cases	%	Cases	%	Cases	%
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	4	1
April	3	3	8	3	6	2
May	10	10	34	11	39	12
June	22	21	99	33	68	21
July	41	40	88	29	102	31
August	23	22	63	21	77	23
September	3	3	7	2	28	8
October	1	1	0	0	5	2
November	0	0	0	0	2	1
December	0	0	0	0	0	0
Total	103		299		331	

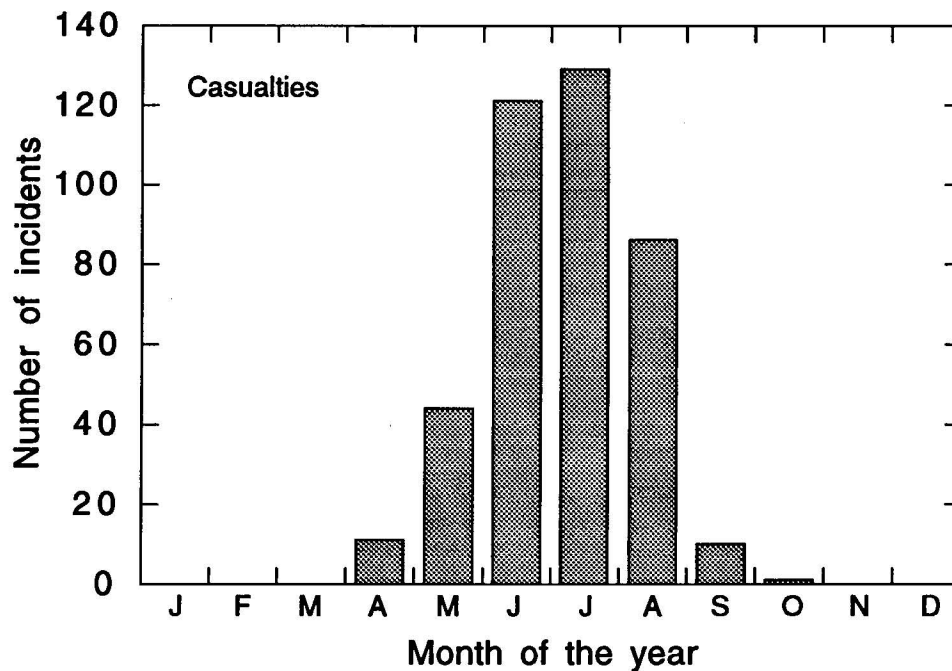


FIGURE 1. Monthly variation of lightning casualties (deaths and injuries) in Colorado from 1950 through 1991.

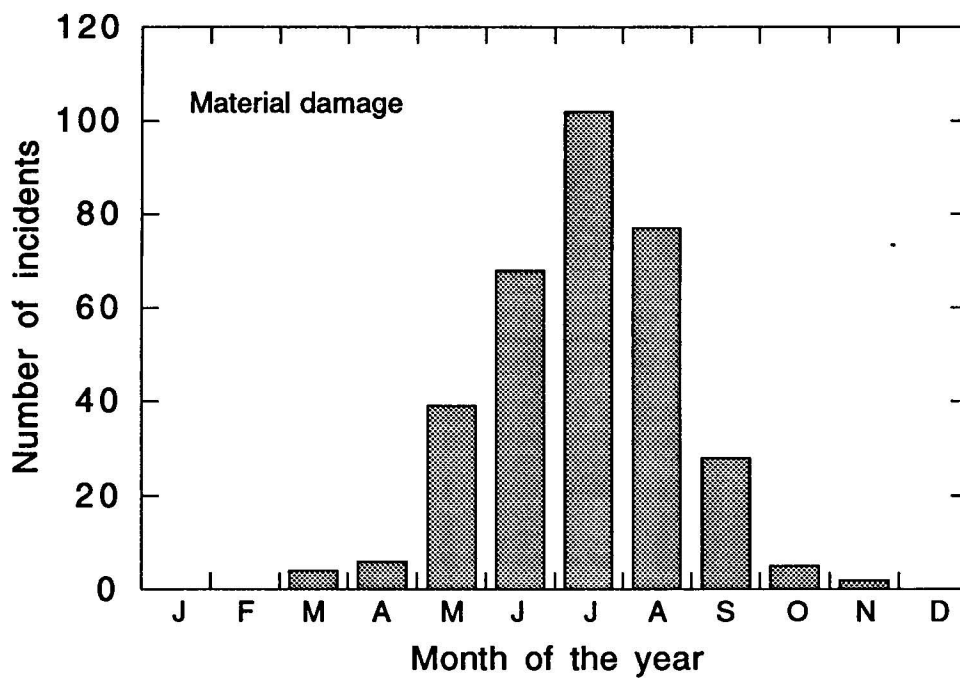


FIGURE 2. Monthly variation of reports of lightning damage in Colorado from 1950 through 1991.

C. Time of Day Variations

Table 5 lists the number of lightning casualties and damage reports by time of day; Figures 3 and 4 show the data in histogram form. More lightning cases of all types occurred during the afternoon than during any other 6-hour period. During the morning hours (6 a.m. to noon), there was a higher percentage of casualties than cases of material damage, but more damage reports than casualties during the evening and night. Such differences may result from greater exposure to lightning of people outdoors during regular daylight working hours (before 6 p.m.) compared to immobile property

being struck at night when significant lightning activity sometimes occurs (López and Holle, 1986). Note that time is given in Mountain Standard Time (MST), while the state observes Mountain Daylight Time (MDT) during the summer; add one hour to this table for MDT.

The dominance of casualties from noon to 6 p.m. is found worldwide (Zegel, 1967; Prentice, 1973; Coates et al. 1993). Holle et al. (1993) found that 27% of material damage cases in central Florida took place outside the hours of 6 a.m. to 6 p.m., while 40% did in this Colorado dataset.

TABLE 5. Time of day variation of number and percentage of deaths, injuries, and material damage due to lightning in Colorado from 1950 through 1991, based on *Storm Data* from NOAA. MST is Mountain Standard Time.

	<u>Deaths</u>		<u>Injuries</u>		<u>Material damage</u>	
	Cases	%	Cases	%	Cases	%
Morning 6 a.m. - Noon MST	9	9	23	8	10	3
Afternoon Noon - 6 p.m. MST	59	57	193	65	157	47
Evening 6 p.m. - Midnight MST	25	24	60	20	130	39
Night Midnight - 6 a.m. MST	0	0	1	0	4	1
Time unknown	10	10	22	7	30	9
Total	103		299		331	

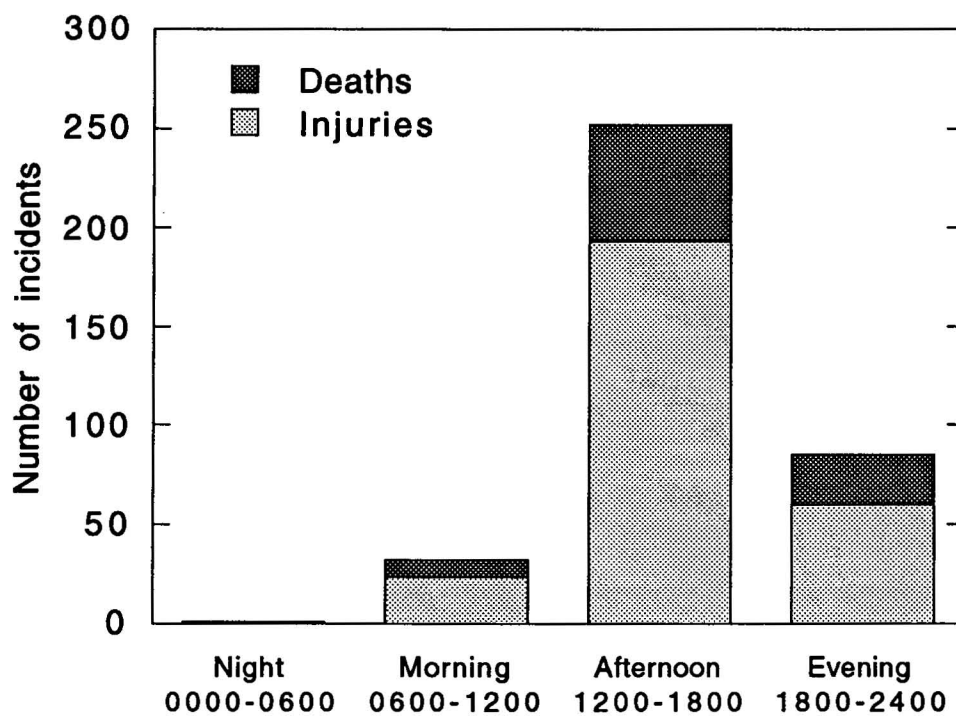


FIGURE 3. Time-of-day variation of lightning casualties, divided by deaths and injuries, in Colorado from 1950 through 1991.

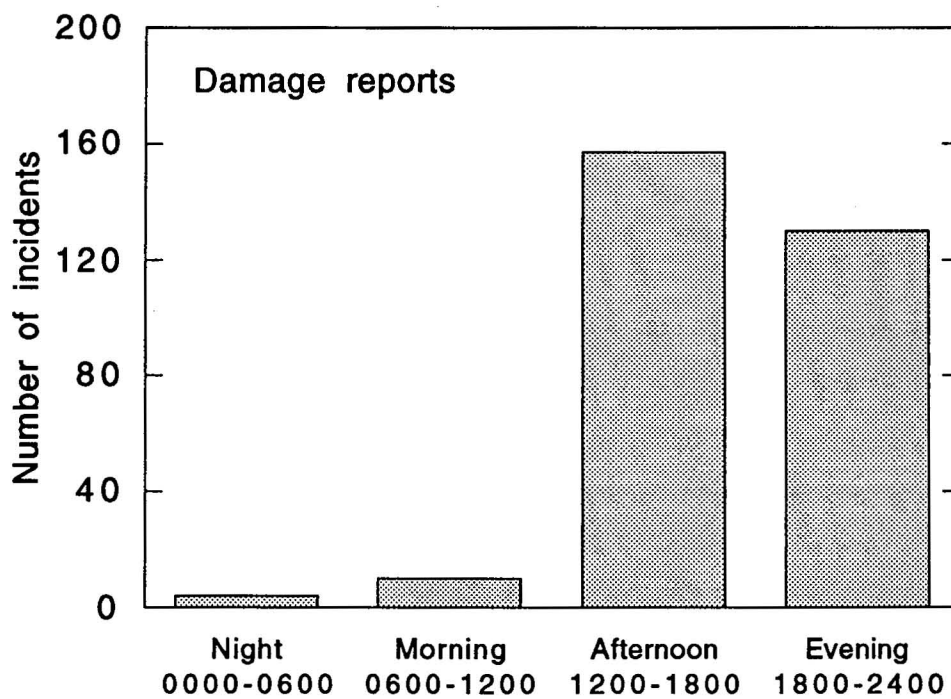


FIGURE 4. Time-of-day variation of lightning damage reports in Colorado from 1950 through 1991.

D. Variability by County

A few counties contributed the great majority of cases of lightning-related events in *Storm Data*, as shown in Table 6. If they are ranked in terms of lightning casualties, the top 10% of the counties reported 60% of all deaths and injuries, and 20% reported 77% of the casualties (Table 7). On the other hand, 48% of the counties reported one or no casualties.

Figure 5 shows a map of the counties with the highest numbers of casualties. Note the following groupings:

- Denver Metropolitan area: Denver, Adams, Arapahoe, Jefferson, and Boulder counties all have a high incidence of lightning casualties. These counties include the cities of Denver, Arvada, Aurora, Boulder, Westminster, Wheat Ridge, and many smaller

communities, as well as the heavily-populated unincorporated portions.

- El Paso and Larimer counties also suffered large numbers of victims. These include the cities, respectively, of Colorado Springs and Fort Collins.

All of these top 7 counties, which comprise 65% of the casualties, lie to the east of the Front Range and include the largest population centers of the state. In fact, most of the top 25% of the counties (Figure 5) lie to the east of the Front Range. Is this spatial distribution of lightning casualties the result of the high population density of the region, or is it also the result of occupational and meteorological factors? These questions are explored in subsequent sections.

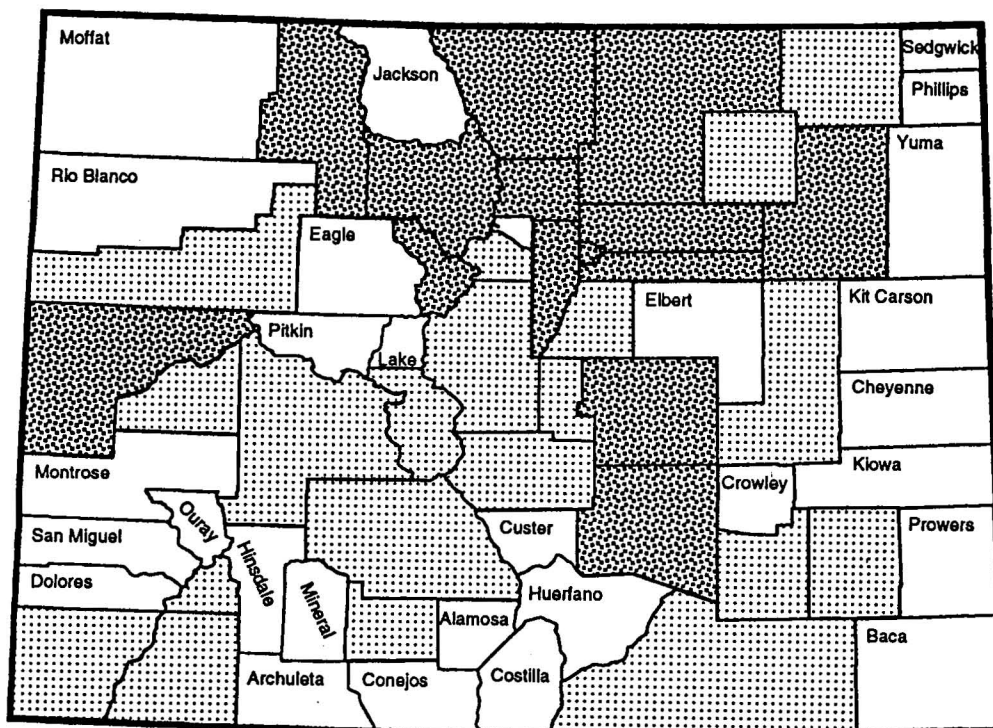


FIGURE 5. Map of counties with highest numbers of lightning-related casualties from 1950 to 1991. Darker shading for counties with top 25% casualty numbers per county; lighter shading for other counties with above-average casualty numbers.

Table 8 lists the population- and area-weighted yearly lightning casualties for each county. The average population was computed from decennial census data from 1950 to 1990. The state-wide average is 0.1 casualties per year per million people per 10,000 square kilometers. Figure 6 is a map showing the counties with the highest normalized casualty rates. The top 25% and 25%-50% of the counties are indicated by shading. Comparison with Figure 5 shows a dramatic change in the distribution of casualties. The first quartile of counties with a high normalized number of casualties are mostly located over mountainous terrain and a few areas on the eastern high plains. The second quartile is mostly along the eastern slopes of the Front Range and the Palmer Lake Divide (also called the Palmer Ridge) that juts eastward from the Front Range in the middle of the state.

The region of high normalized casualties over the mountains probably corresponds to a high level of exposure to lightning during recreational activities (Chapter 4), while

regions over the plains have a high level of exposure associated with agriculture. The distribution of second-quartile counties east of the mountains matches the area of high cloud-to-ground lightning flash density found by López and Holle (1986) for northeastern Colorado. Their study showed a band of high lightning density along the eastern side of the Continental Divide and over the northern slope of the Palmer Ridge. The flash densities along the band appeared higher than over regions to the west and east. Also, the study showed more lightning on slopes of mountains than at the summit. However, the vulnerability of people in mountainous areas and over the eastern plains appears to be more important than the high number of flashes along the eastern slopes and the Palmer Ridge, although many normalized casualties occur there also. It should be emphasized that a definitive, detailed cloud-to-ground lightning climatology for all of Colorado is yet to be developed.

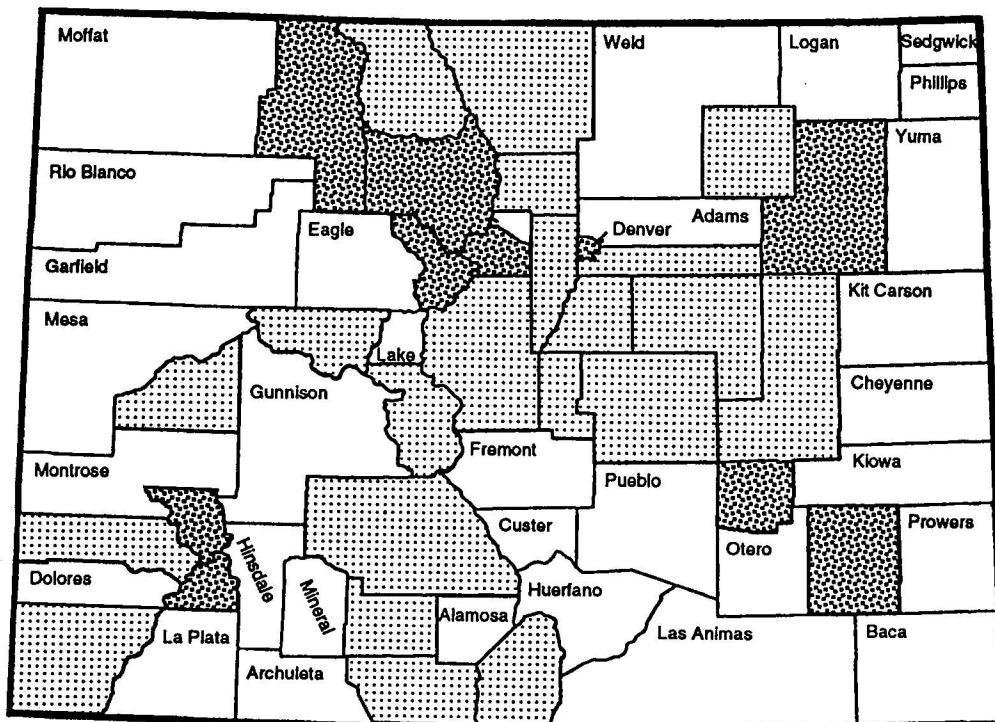


FIGURE 6. Map of highest rates of lightning-related casualties per million people per 10,000 square kilometers by county from 1950 to 1991. Darker shading for counties with top 25% casualty rates per county; lighter shading for other counties with above-average casualty rates.

TABLE 6. Distribution by county of number of deaths, injuries, and material damage events due to lightning in Colorado from 1950 through 1991, based on *Storm Data*.

County	No. of deaths	No. of injuries	Material damage	County	No. of deaths	No. of injuries	Material damage
Adams	3	13	4	Lake	0	0	0
Alamosa	0	0	0	La Plata	0	3	2
Arapahoe	4	20	14	Larimer	7	20	16
Archuleta	0	0	1	Las Animas	2	0	1
Baca	0	0	0	Lincoln	1	2	2
Bent	0	5	1	Logan	1	1	10
Boulder	5	24	22	Mesa	3	3	7
Chaffee	1	3	4	Mineral	0	0	1
Cheyenne	0	0	0	Moffat	1	0	0
Clear Creek	0	4	1	Montezuma	3	2	2
Conejos	1	0	1	Montrose	0	1	4
Costilla	0	1	1	Morgan	0	3	13
Crowley	0	1	4	Otero	0	2	2
Custer	0	0	0	Ouray	0	1	0
Delta	2	3	3	Park	3	1	1
Denver	10	42	42	Phillips	0	0	3
Dolores	0	0	1	Pitkin	1	0	1
Douglas	3	2	13	Prowers	0	0	3
Eagle	0	0	1	Pueblo	1	7	11
Elbert	1	0	2	Rio Blanco	1	0	1
El Paso	12	61	53	Rio Grande	4	1	1
Fremont	1	2	4	Routt	4	4	1
Garfield	1	1	3	Saguache	1	4	2
Gilpin	0	0	3	San Juan	1	1	0
Grand	2	4	0	San Miguel	0	1	0
Gunnison	0	2	2	Sedgwick	0	0	2
Hinsdale	0	0	0	Summit	2	7	1
Huerfano	1	0	1	Teller	1	2	1
Jackson	1	0	0	Washington	0	6	2
Jefferson	10	20	19	Weld	5	8	23
Kiowa	0	0	0	Yuma	0	1	6
Kit Carson	0	1	1	Unknown	3	9	11
Total					103	299	331

TABLE 7. The top 20% of the counties with the most lightning deaths and injuries in Colorado from 1950 through 1991, based on *Storm Data*.

County	Deaths	Injuries	Total casualties
El Paso	12	61	73
Denver	10	42	52
Jefferson	10	20	30
Boulder	5	24	29
Larimer	7	20	27
Arapahoe	4	20	24
Adams	3	13	16
Weld	5	8	13
Summit	2	7	9
Pueblo	1	7	8
Routt	4	4	8
Grand	2	4	6
Mesa	3	3	6
Washington	0	6	6

TABLE 8. Frequency of lightning casualties (deaths and injuries combined) weighted by population and area by Colorado county from 1950-1991, based on *Storm Data*.

County	Average population	Area		Casualties	Annual casualties per million people	
		miles ²	km ²		per 10,000 mi ²	per 10,000 km ²
Adams	171,460	1235	3198	16	18	7
Alamosa	11,473	719	1863	0	0	0
Arapahoe	202,565	800	2072	24	35	14
Archuleta	3,480	1353	3503	0	0	0
Baca	5,984	2554	6614	0	0	0
Bent	6,736	1517	3930	5	117	45
Boulder	133,880	742	1923	29	70	27
Chaffee	10,307	1008	2610	4	92	35
Cheyenne	2,637	1783	4617	0	0	0
Clear Creek	5,165	397	1027	4	464	180
Conejos	8,338	1285	3327	1	22	9
Costilla	3,927	1227	3178	1	49	19
Crowley	3,655	790	2045	1	82	32
Custer	1,568	740	1917	0	0	0
Delta	18,091	1141	2956	5	58	22
Denver	476,865	111	287	52	234	90
Dolores	1,793	1064	2756	0	0	0
Douglas	20,450	841	2178	5	69	27
Eagle	10,382	1690	4376	0	0	0
Elbert	5,716	1851	4795	1	23	9

TABLE 8, continued.

County	Average population	Area		Casual- ties	Annual casualties	
		miles ²	km ²		per million people per 10,000 mi ²	per 10,000 km ²
El Paso	232,135	2129	5514	73	35	14
Fremont	24,290	1538	3983	3	19	7
Garfield	18,190	2952	7645	2	9	3
Gilpin	1,663	149	387	0	0	0
Grand	5,413	1854	4802	6	142	55
Gunnison	7,946	3238	8386	2	19	7
Hinsdale	309	1115	2889	0	0	0
Huerfano	7,491	1583	4101	1	20	8
Jackson	1,802	1615	4182	1	82	32
Jefferson	245,751	768	1989	30	38	15
Kiowa	2,216	1758	4554	0	0	0
Kit Carson	7,565	2160	5595	1	15	6
La Plata	22,602	1692	4382	3	19	7
Lake	7,274	379	982	0	0	0
Larimer	104,423	2604	6745	27	24	9
Las Animas	18,058	4771	12,356	2	6	2
Lincoln	5,049	2586	6698	3	55	21
Logan	18,741	1819	4710	2	14	5
Mesa	63,747	3309	8571	6	7	3
Mineral	654	877	2272	1	415	160
Moffat	8,804	4732	12,255	1	6	2
Montezuma	14,429	2038	5279	5	40	14
Montrose	20,129	2240	5802	1	5	2
Morgan	20,764	1276	3306	3	27	10
Otero	23,135	1247	3229	2	17	6
Ouray	1,894	542	1403	1	232	9
Park	3,676	2192	5678	4	118	46
Phillips	4,445	688	1782	0	0	0
Pitkin	6,642	968	2508	1	37	14
Prowers	13,561	1629	4219	0	0	0
Pueblo	115,231	2377	6157	8	7	3
Rio Blanco	5,387	3222	8345	1	14	5
Rio Grande	11,153	913	2365	5	117	45
Routt	9,784	2367	6130	8	82	32
Saguache	4,503	3167	8203	5	83	32
San Juan	945	388	1004	2	1298	501
San Miguel	2,886	1287	3333	1	64	25
Sedgwick	3,739	540	1398	0	0	0
Summit	5,520	607	1573	9	639	247
Teller	5,813	559	1447	3	220	85
Washington	5,962	2520	6527	6	95	37
Weld	96,880	3990	10,335	13	8	3
Yuma	9,383	2365	6125	1	11	4
Colorado	3,294,394	103,595	268,311	390	0.3	0.1

4. ACTIVITIES AND PLACES OF LIGHTNING VICTIMS

A. Activities

Table 9 shows what people in Colorado were doing when they became victims of lightning during the 42 years. The activity categories come from descriptions in *Storm Data*. Together with descriptions of the location of the victims in the next section, they provide a characterization of the casualty situation.

Table 9 shows activities ranked according to number of casualties (first column). The first five activities of working, golfing, mountain climbing, farming, and standing are much more common than any of the others. This set of five activities comprises 57% of all known cases.

TABLE 9. Activities at the time of lightning deaths, injuries, and incidents in Colorado from 1950 through 1991, based on *Storm Data* from NOAA. Total number of incidents may be less than sum of two incident columns when both deaths and injuries occurred at same event.

Activity	Total		Deaths		Injuries	
	Casualties	Incidents	Deaths	Incidents	Injuries	Incidents
Working	32	17	7	6	25	12
Golfing	29	15	5	4	24	12
Mountain climbing	29	12	9	8	20	10
Farming	25	19	14	14	11	7
Standing	23	11	8	7	15	7
Camping	13	6	4	3	9	5
Picnicking	10	2	2	1	8	2
Fishing	9	7	3	3	6	6
Bicycling	7	3	2	2	5	2
Walking	6	5	3	3	3	3
Riding	6	5	1	1	5	4
Playing	6	4	3	2	3	2
Horseback riding	5	3	3	3	2	1
Playing football	5	1	-	-	5	1
Gardening	4	4	2	2	2	2
Sitting	4	3	-	-	4	3
Boating	4	2	-	-	4	2
Wedding rehearsal	4	1	1	1	3	1
Rock climbing	4	1	-	-	4	1
Watching thunderstorm	3	1	1	1	2	1
Using telephone	3	2	-	-	3	2
Hiding from rain	2	2	1	1	1	1
Housework	2	2	-	-	2	2
Hunting	2	1	1	1	1	1
Playing baseball	2	1	1	1	1	1
Hiking	2	1	-	-	2	1
Filling oil tank	1	1	-	-	1	1
Ride at amusement park	1	1	-	-	1	1
Sightseeing	1	1	-	-	1	1
Unknown	158	90	32	28	126	75
Total	402	224	103	92	299	169

Table 10 and Figure 7 summarize Table 9 into a few general categories of activities. More people were casualties during recreation (52%) than during employment (25%) or other activities (23%). In contrast, the employment

component in central Florida was 38% and recreation was 32% of the casualties (Holle et al., 1993), and in Australia employment was 63% and recreation was 20% of the fatalities (Coates et al., 1993).

TABLE 10. Summary of people's activities at the time of lightning casualties and incidents in Colorado from 1950 through 1991, based on entries in Table 9. Unknown cases not in sample.

Activity	Casualties		Incidents	
	People	%	Cases	%
Recreation	128	52	64	48
Employment	60	25	39	29
Other	56	23	31	23
Total	244		134	

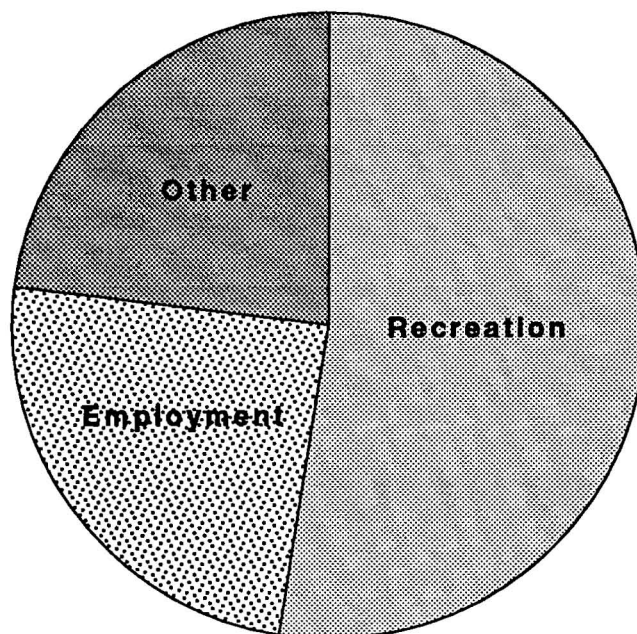


FIGURE 7. Pie graph representation of the most common activities at the time of lightning casualties in Colorado, from Tables 9 and 10.

B. Places

Table 11 shows where people in Colorado were located when they were victims of lightning during the 42-year period. The table shows the locations ranked by number of casualties. The most common places for lightning victims were at the summit of a mountain or ridge. Next most often was under a tree, followed by in the open, then on a lake. All of these have one common element - being the highest object, or in close proximity to the highest object, such as a tree.

A significant group of incidents also occurred at houses (either inside or in the yard) and ranches, presumably because of the large amount of time spent there by people. The category of telephone, presumably corded, in Table 11 has been noted as a continual problem by Zegel (1967), Mogil (1979), and Andrews et al. (1992).

Table 12 and Figure 8 summarize Table 11 into broader categories. More people in Colorado were lightning victims near mountains (18%) and the vicinity of trees (16%), followed by around a residence, in the open, around transportation vehicles, and water proximity.

For the United States from 1959 to 1985, Vigansky (1985) found the most frequent places for fatalities were open fields (27%), trees (16%), and water proximity (13%). In central Florida, Holle et al. (1993) found that being close to water was the most common location (25%), followed by trees (22%) and transportation (10%). In Colorado, the presence of people at or near mountain tops is especially important, whereas Florida has a higher frequency near its abundant ocean, beaches, lakes, and other waterways.

TABLE 11. Locations where lightning deaths, injuries, and incidents occurred in Colorado from 1950 through 1991, based on *Storm Data*. Total number of incidents may be less than sum of two incident columns when both deaths and injuries occur at same event.

Location	Total		Deaths		Injuries	
	Casualties	Incidents	Deaths	Incidents	Injuries	Incidents
Summit of mountain/ridge	45	21	12	10	33	16
Under tree	40	18	15	11	25	14
Open	31	16	7	7	24	10
Lake	20	11	6	6	14	10
Yard	10	6	2	2	8	4
In house	9	5	-	-	9	5
Ranch	8	7	7	7	1	1
On tractor	6	5	3	3	3	3
Park	6	3	2	2	4	3
Near plane	6	3	-	-	6	3
Construction camp	6	1	-	-	6	1
On horse	5	3	3	3	2	1
Fairground	5	1	-	-	5	1
Scaffolding	5	1	-	-	5	1
Near wall	4	4	1	1	3	3
Foot of mountain	4	1	1	1	3	1
Telephone	4	3	-	-	4	3
Near car	3	3	2	2	1	1
At work	3	3	-	-	3	3
On bicycle	3	2	2	2	1	1
Clothesline	3	2	2	1	1	1
On ground	3	2	1	1	2	2
In truck	3	2	-	-	3	2
Near monument	3	1	2	1	1	1
Near river/creek	2	2	1	1	-	-
Near truck	2	2	-	-	2	2
In wagon	2	2	-	-	2	2
Playground	2	1	2	1	-	-
Beneath powerline	1	1	1	1	-	-
On motorcycle	1	1	1	1	-	-
Telephone pole	1	1	1	1	-	-
Amusement park ride	1	1	-	-	1	1
Country club	1	1	-	-	1	1
In car	1	1	-	-	1	1
Inside tent	1	1	-	-	1	1
Near tank	1	1	-	-	1	1
On porch	1	1	-	-	1	1
On roof	1	1	-	-	1	1
Trailer	1	1	-	-	1	1
Unknown	148	82	29	27	119	65
Total	402	224	103	92	299	169

TABLE 12. Major categories of locations where lightning deaths and injuries occurred in Colorado from 1950 through 1991, based on *Storm Data*. Unknown cases not in sample.

Activity	Casualties		Incidents	
	People	%	Cases	%
Mountains	45	18	21	15
Trees	40	16	18	13
Residence	32	13	22	15
Open	31	12	16	11
Transportation	27	11	21	15
Water	22	9	13	9
Other	57	22	31	22
Total	254		142	

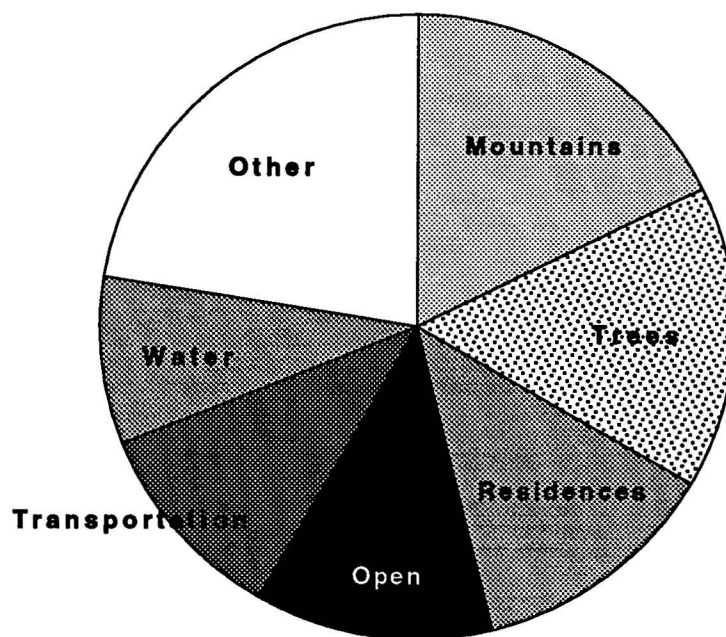


FIGURE 8. Pie graph representation of the most common locations at the time of lightning casualties in Colorado, from Tables 9 and 10.

C. Regional Distributions of Casualty Situations

The situations when people became victims of lightning were classified into six broad categories according to both activity and place. Table 13 shows this classification using both what people were doing and where they were located when they became lightning victims. For example, an event showing a camping activity and/or a place near a river would be classified as outdoor recreation. By using both activity and place, events were included that were ambiguous in one of these two items.

The map in Figure 9 shows the counties with the highest numbers of "outdoor recreation" casualties normalized per million people per 10,000 square kilometers from 1950 to 1991. Shaded counties represent the 25% having the highest number of normalized casualties (first quartile). The majority of counties having large numbers of normalized casualties due to outdoor situations is concentrated over the mountainous and forested regions. This distribution corresponds very closely to the first quartile of normalized casualties due to all types of situations in Figure 6.

On the other hand, Figure 10 shows the distribution of high rates of "farming" events on ranches and other agricultural facilities. The majority of counties with high numbers of

normalized casualties due to farming and ranching are concentrated over the eastern high plains. These counties are mostly to the east of the highly populated metropolitan areas.

Figure 11 corresponds to "sports" situations. Here, the majority of counties with the largest numbers of normalized casualties are over the large metropolitan areas east of the Front Range, between the mountains and the plains. Similarly, Figure 12 indicates the majority of counties with high "urban/domestic" normalized casualties to be located in a wide band just east of the mountains, including the larger urban areas from Fort Collins to the north to Pueblo in the south. "Work" events (Figure 13), which do not include farming or ranching, and "others" (Figure 14) do not show clear patterns.

In summary, there is a well defined geographical pattern of lightning casualty situations. Outdoor recreation casualties are prevalent over the mountains; farming and ranching casualties are prevalent over the eastern high plains; and sports and urban/domestic casualties dominate the urban areas between the two. Outdoor recreation in the mountain and forested regions accounted for the highest numbers of normalized casualties in Colorado during the 42-year period.

TABLE 13. Classification of events by activity and place of lightning casualties.

	Activity	Place
Farming	Farming	Ranch
		On tractor
		In wagon
Sports	Golf	Park
	Bicycling	Fairground
	Playing	On bicycle
	Playing football	Playground
	Playing baseball	On motorcycle
	Ride at amusement park	Amusement park ride
		Country club
Outdoor Recreation	Mountain climbing	Summit of mountain/ridge
	Camping	Open
	Picnicking	Lake
	Fishing	On horse
	Riding	Foot of mountain
	Horseback riding	Near river/creek
	Boating	Inside tent
	Rock climbing	
	Hunting	
	Hiking	
	Sightseeing	
Urban/Domestic	Gardening	Yard
	Using telephone	In house
	Housework	Near wall
		Telephone
		Clothesline
		Telephone pole
		On porch
Work (non-farm)	Working	Near plane
	Filling oil tank	Construction camp
		Scaffolding
		At work
		In/near truck
		Near tank
		On roof
		Trailer
Others	Standing	Under tree
	Walking	Near car
	Sitting	On ground
	Wedding rehearsal	Near monument
	Watching thunderstorm	Beneath power line
	Hiding from rain	In car
	Unknown	Unknown

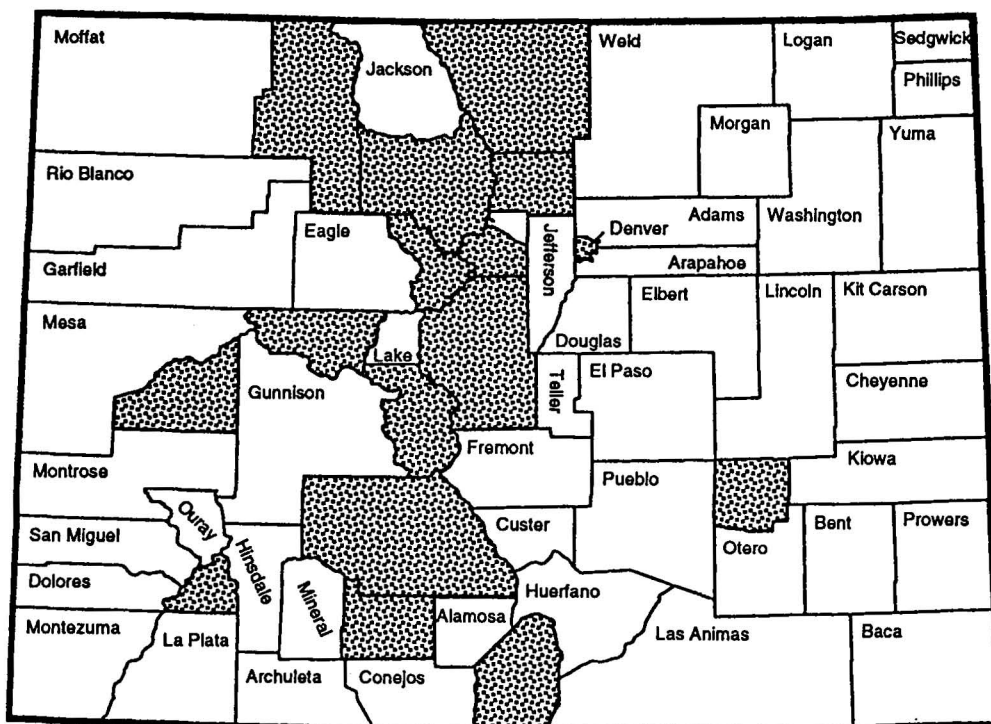


FIGURE 9. Map showing top 25% counties (shaded) with lightning-related casualties in outdoor recreation situations per million people per 10,000 square kilometers from 1950 to 1991.

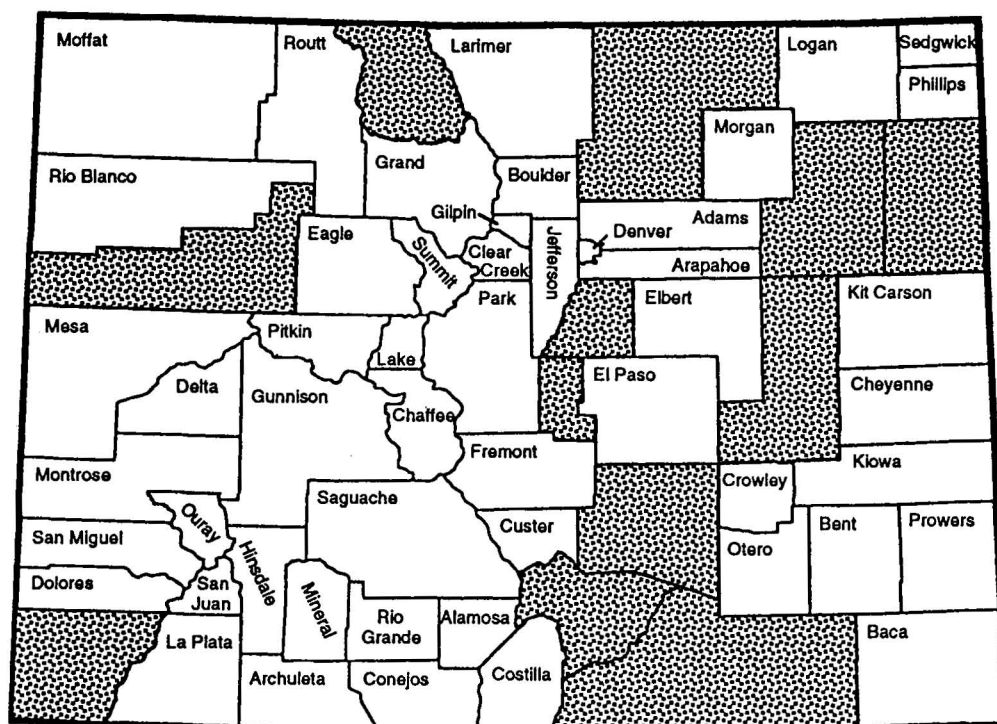


FIGURE 10. Same as Figure 9 for farming.

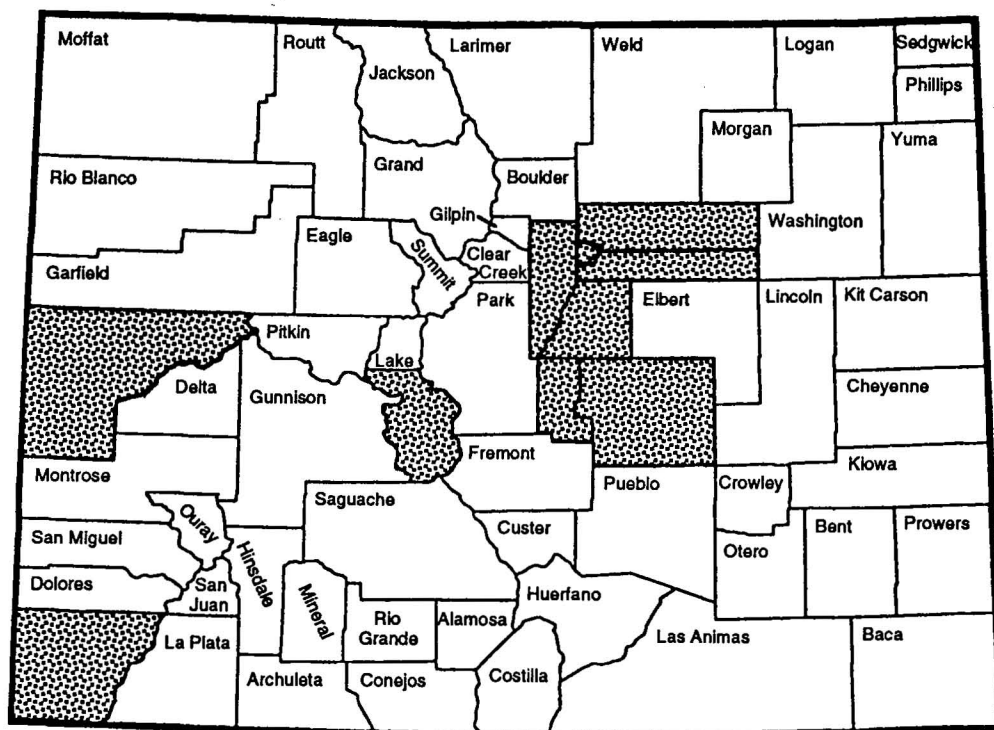


FIGURE 11. Same as Figure 9 for sports.

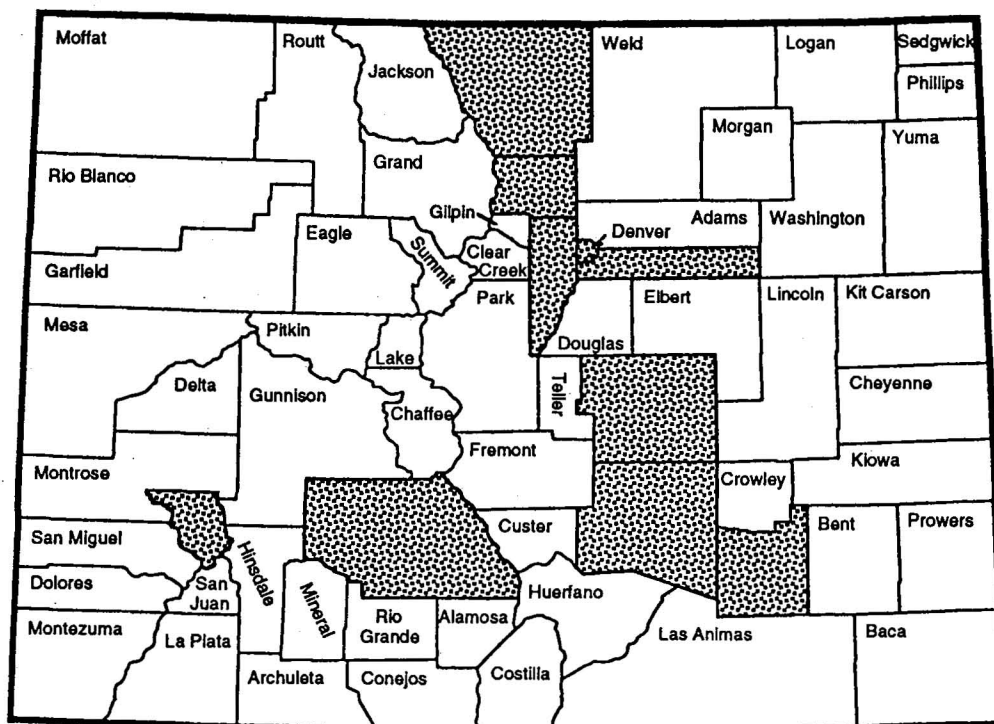


FIGURE 12. Same as Figure 9 for urban and domestic situations.

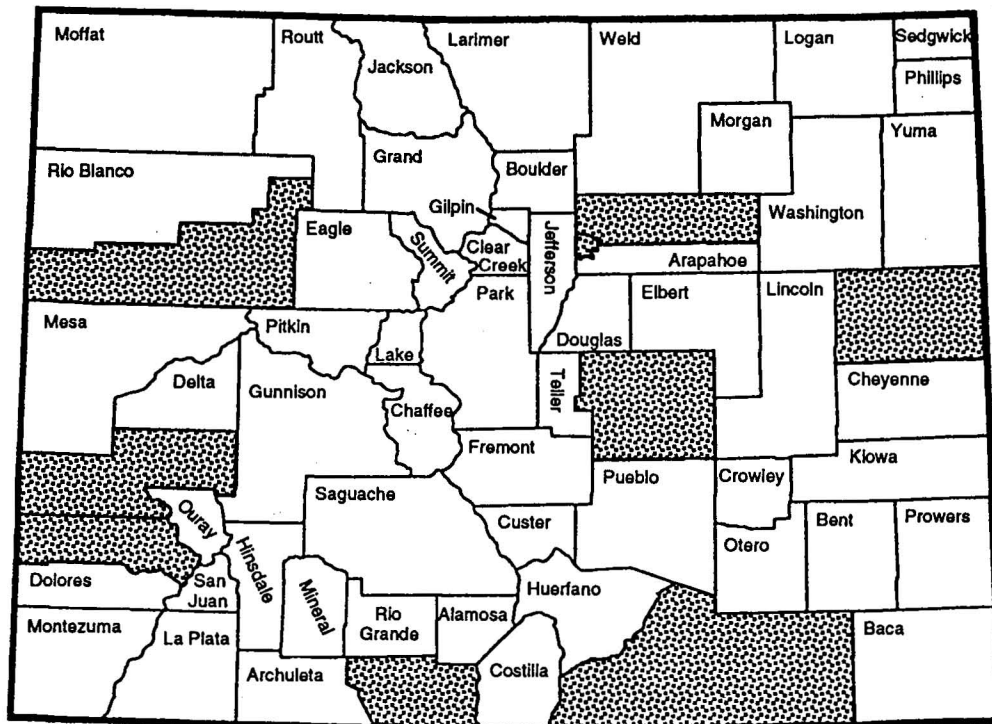


FIGURE 13. Same as Figure 9 for work situations (except farming).

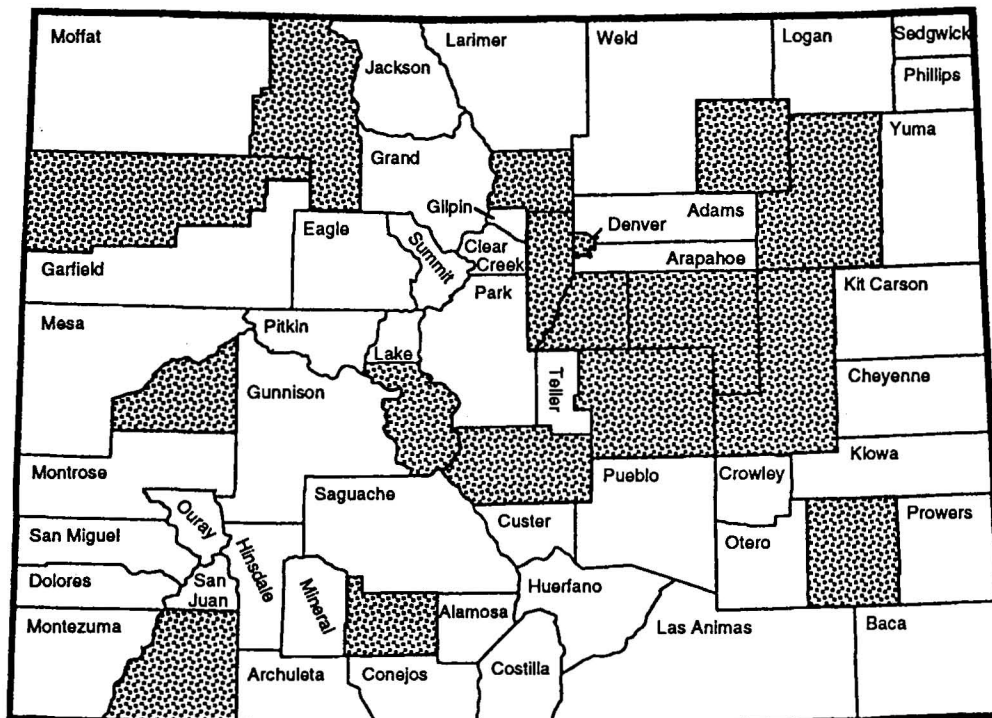


FIGURE 14. Same as Figure 9 for miscellaneous situations.

5. ADDITIONAL CASUALTY INFORMATION

Table 14 shows the age and sex distribution of lightning casualties in Colorado. Of the 402 casualties in the record, 203 were identified as males, 59 as females, and for 123 there was no gender information available. That gives a ratio of 2.5 male casualties for every female one. This result has been found worldwide in previous studies (Zegel, 1967; Prentice, 1973; Pakiam et al., 1981; Holle et al., 1993; Coates et al., 1993; Elsom, 1993).

The highest number of victims was younger than 16 years and between 26 and 35 years old; 76% of all casualties were younger than 35 years. Both male and female victims had the same age spread. The age information for lightning casualties is much more meager than

that of sex. In general, Colorado lightning victims are predominantly younger males below 35 years of age.

Prentice (1973), Pakiam et al. (1981), and Coates et al. (1993) also found a peak in deaths when people were in their teens and twenties, and a secondary peak in their forties and fifties. The NWS (1992) survey for the United States in 1990, however, found more people killed by lightning in their thirties than twenties. Holle et al. (1993) for central Florida found seven deaths or injuries up to 15 years of age, seven more from 16 to 25 years old, ten from 26 to 35, seven from 36 to 45, and seven again from 46 years old and over.

TABLE 14. Age and sex distributions of lightning victims in Colorado from 1950 through 1991, based on *Storm Data*.

Age	Male	Female	Gender not available	All entries
Under 16	13	7	-	20
16-25	13	2	-	15
26-35	13	5	-	18
36-45	7	3	-	10
46-55	4	0	-	4
Over 55	3	0	-	3
Age not available	150	59	123	332
Total	203	76	123	402

In Table 15, the casualties have been stratified by time of day, and by the victims' type of situation at the time of the incident. All types basically show the same time distribution. The largest number of casualties occur in the afternoon from noon to 6 p.m.; the second largest number is during the evening from

6 p.m. to midnight. There were very few casualties from midnight to midmorning, except that outdoor situations have a slightly higher number in the morning than other situations. Urban casualties are more evenly distributed from noon to midnight than in the other types.

TABLE 15. Time of day of lightning casualties according to activity in Colorado from 1950 through 1991, based on *Storm Data*.

Time	Farm	Sports	Outdoors	Urban	Work	Other	All
Morning							
6 a.m. - Noon MST	1	0	9	0	1	21	32
Afternoon							
Noon - 6 p.m. MST	16	52	74	12	20	78	252
Evening							
6 p.m. - Midnight MST	9	8	12	12	7	37	85
Night							
Midnight - 6 a.m. MST	0	0	0	0	0	1	1
Time unknown	2	1	14	3	1	11	32
Total	28	61	109	27	29	148	402

The number of victims per lightning incident is shown in Table 16 and Figure 15. The last column shows that 66% of the incidents had only one casualty (either a death or a non-fatal injury). The maximum number of casualties in an incident was 12. In the case of injuries, 69% of the incidents had only one victim, and 16% had two. Deaths tended to occur singly a larger percentage of the time, with 89% of the incidents having only one death and the rest (11%) having two or three. Zegel (1967) also indicated 70% of lightning fatalities to occur singly, and 15% in groups of two.

This result is important in terms of the lightning threat, since only one person is typically involved. Usually, no specific warnings are available for the exact time and location of a lightning casualty. Therefore, each person must take personal responsibility for awareness of the lightning situation. Also, he or she must take responsibility for personal action based on what is seen and heard in the immediate surroundings concerning thunderstorm development, movement, and dissipation.

TABLE 16. Distribution of the number of victims per lightning incident in Colorado from 1950 through 1991, based on *Storm Data*.

Number of victims per incident	Deaths		Injuries		Casualties	
	Cases	%	Cases	%	Cases	%
One	82	89	118	69	150	66
Two	9	10	28	16	42	18
Three	1	1	10	6	15	7
Four	0	0	4	2	10	4
Five or more	0	0	12	7	12	5
Total	92		172		229	

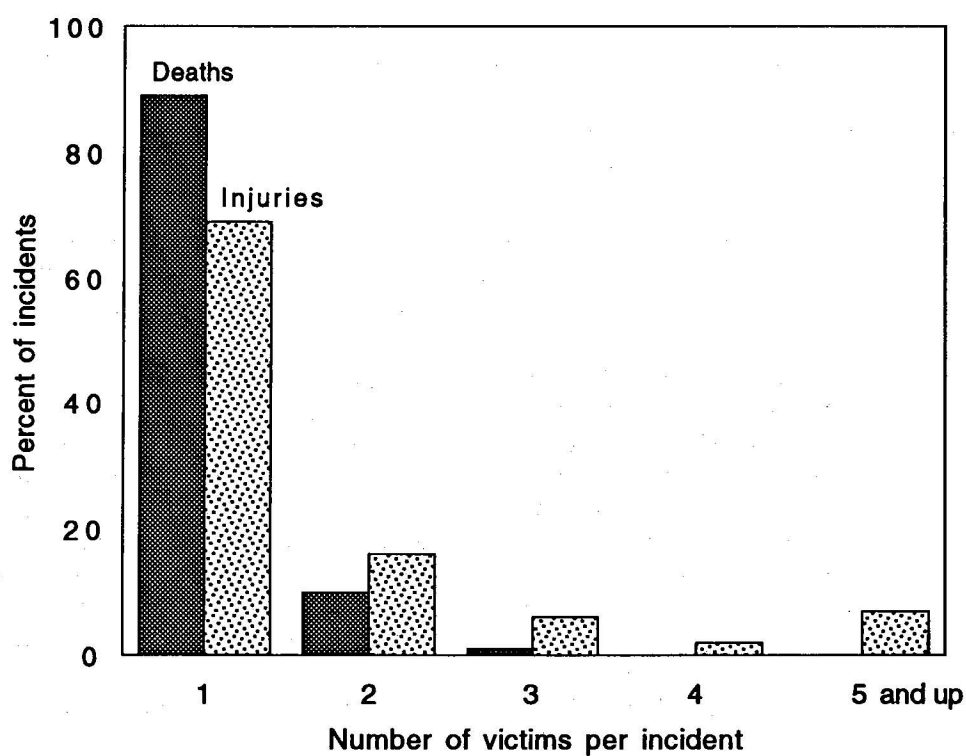


FIGURE 15. Bar graphs of number of lightning deaths and injuries per lightning incident in Colorado, from Table 16.

6. MATERIAL DAMAGE REPORTS

Table 17 shows how often different types of structures and objects were damaged by lightning in Colorado, according to the 331 material damage reports contained in *Storm Data* from 1950 to 1991.

Houses were by far the most frequently reported type of structure damaged by lightning; they were in 132 reports, which is 40% of all damage cases. Of the house reports, 79 were of one house or occupied cabin damaged, 10 reports had two houses damaged, and 13 had more than two dwellings damaged. In addition, there were 13 reports of a house or cabin that was destroyed by lightning (10% of total).

There were 168 buildings of all types damaged during the period, including houses, churches, warehouses, barns, sheds, schools, and nursing homes; they accounted for 51% of all reports. On the other hand, power line and telephone poles, power lines, electrical equipment, communications antennas, power transformers, power plants, and telephone installations totalled 77 reports, or 23% of all cases. There were 50 reports of animals, trees, and stacks of hay affected, for 15% of all reports. Finally, there were 6 storage tanks struck by lightning as well as one large pile of tires, one truck, one bridge, and one sign, making up the remaining known 3% of the cases.

TABLE 17. Structures and objects damaged by lightning in Colorado from 1950 through 1991, based on *Storm Data*.

Material damaged	Incidents	Material damaged	Incidents
Houses	132	Barns	5
Animals	26	Fields	4
Power line/Telephone poles	21	Warehouses	3
Power lines	19	Weeds	3
Buildings	19	Sheds	2
Trees	18	Telephone installations	2
Electrical equipment	12	Tires	1
Antennas (communications)	9	Trucks	1
Power transformers	9	Schools	1
Hay	6	Nursing homes	1
Storage tanks	6	Bridges	1
Churches	5	Signs	1
Power plants	5	Structure type unknown	19

Table 18 lists the types of lightning damage suffered by structures or objects in Table 17. Damage due to fire was the most frequent occurrence (36% of all cases). Damage due to concussive or explosive effects was second; 95 incidents or 28% of all occurrences. Next were electrical problems with 76 cases (22%). Killing or injuring of animals occurred in 28 cases (8%). Holes (8 cases) were probably caused by melting or burning due to the intense heat produced by the lightning branch affecting the structure.

Damage categories of the reports are in Table 19. Two coding methods were used:

- *Storm Data* often provides a category of dollar amount for the lightning damage.
- When not explicitly provided, the degree of damage was qualitatively divided into light, medium or severe.

No attempts were made in this analysis to account for the effects of inflation during the period of record. The damage classes, however, are broad enough to mask some of the fluctuations in the value of the dollar. In a total of 86 cases (26%) damage was between \$5,000 and \$50,000, and in another 72 (22%) were between \$500 and \$5,000. Only one case was above half a million dollars. Fairly high

and fairly small damage categories were represented about equally with 4% each. No cases under \$50 were reported. In the qualitative categories, light damage dominates with 48 cases, medium damage has

10 cases and severe damage has one case. It is difficult to assign a value to these categories, but most of the light damage was probably below \$1,000.

TABLE 18. Types of lightning damage reported in Colorado from 1950 through 1991, based on *Storm Data*.

Material damaged	Incidents	%
Fires	122	36
Shattered/broken/damaged	95	28
Electrical problems	76	22
Animals killed or injured	28	8
Holes	8	2
Unknown	13	4

TABLE 19. Categories of material damage of reports in Colorado from 1951 through 1987, based on *Storm Data*.

Damage category	Incidents	%
Less than \$50	0	0
\$50 to \$500	12	4
\$500 to \$5,000	72	22
\$5,000 to \$50,000	86	26
\$50,000 to \$500,000	13	4
Greater than \$500,000	1	0.3
Light	48	14
Medium	10	3
Severe	1	0.3
Unknown	88	27

7. YEARLY FLUCTUATIONS IN CASUALTIES AND DAMAGE

A. Year-to-year Variability

The number of deaths, injuries, total casualties, and material damage reports due to lightning in Colorado from 1950 to 1991 are portrayed in Figures 16 to 19. This information was also presented in Table 3. In all of these figures, a large year-to-year (interannual) variability can be observed. Years with large numbers of incidents are often followed by years with few incidents and vice versa. This variability is typical of weather and climate phenomena. The frequency distribution of annual deaths and injuries is presented by histograms in Figures 20 and 21. There are more years with small numbers of deaths and injuries than with high numbers. These distributions are typical of meteorological phenomena, especially of thunderstorm activity.

In addition to the large interannual variability, the time series of Figures 16 to 19 show some overall trends in the number of

casualties and material damage. The decade of 1955 to 1965 tended to have larger annual numbers of incidents than from 1965 to 1975. In general, very low numbers are found in this last decade, with no casualties or damage reports at all during 1971. After 1975, reports of both casualties and material damage increase considerably to the end of the period, although a few years with low values are found around 1985. It is important to understand the reasons for these apparent trends. Are they the result of population changes or occupational shifts in Colorado? Or are they due to climatic fluctuations affecting lightning activity in the region? Another possibility is that they correspond to changes in the procedure used by NOAA to report lightning casualties and incidents of material damage in *Storm Data*. In the next few sections, these possibilities are explored.

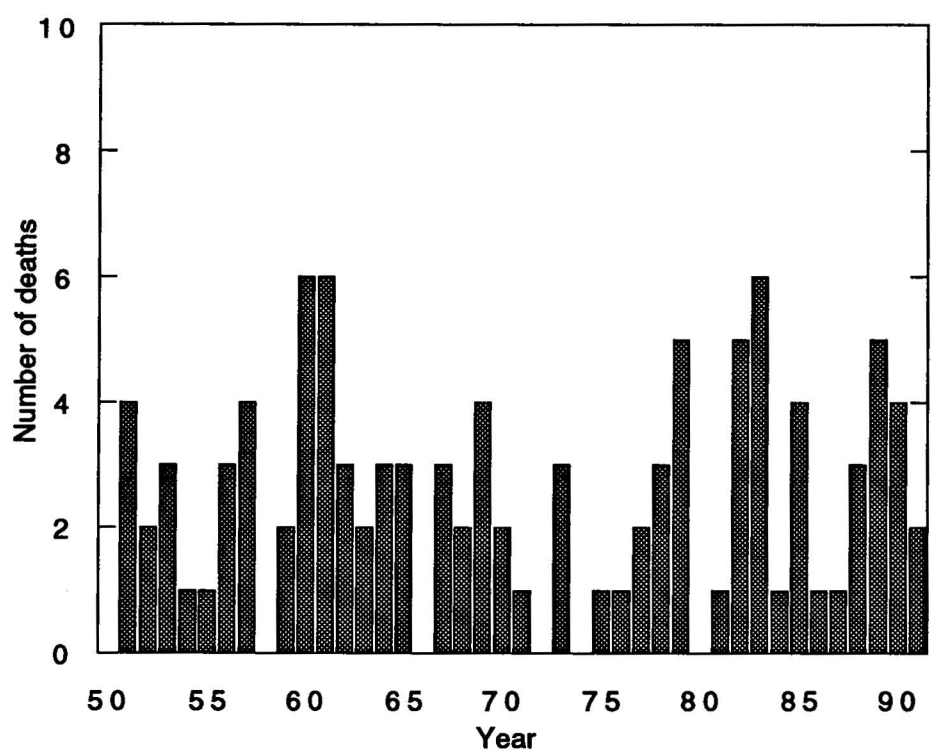


FIGURE 16. Time series from 1950 to 1991 of the annual number of Colorado deaths due to lightning.

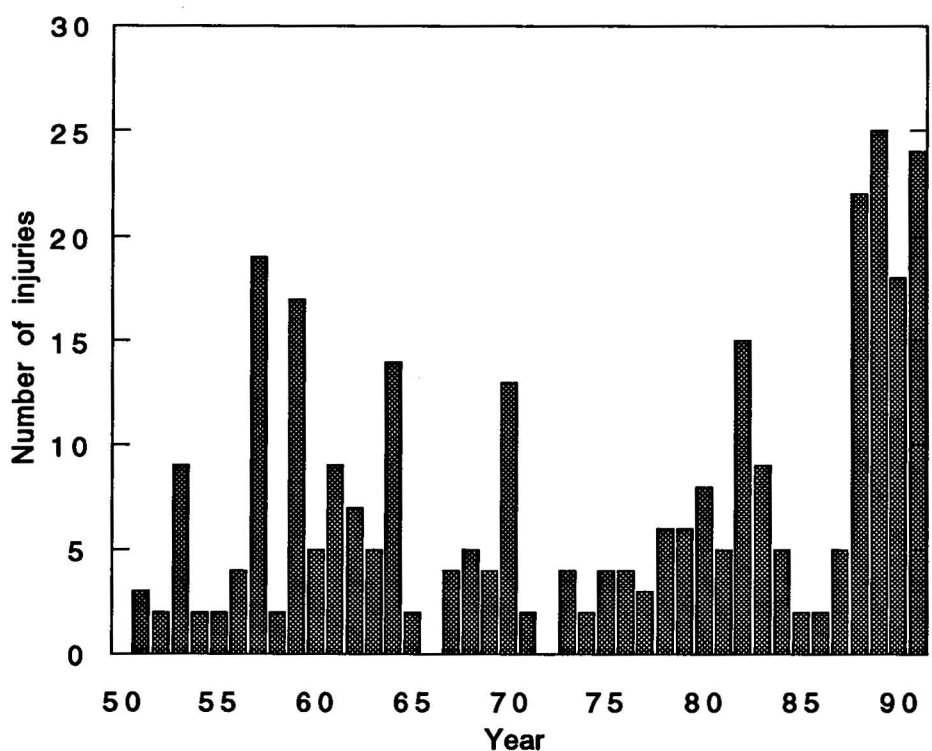


FIGURE 17. Time series from 1950 to 1991 of the annual number of Colorado injuries due to lightning.

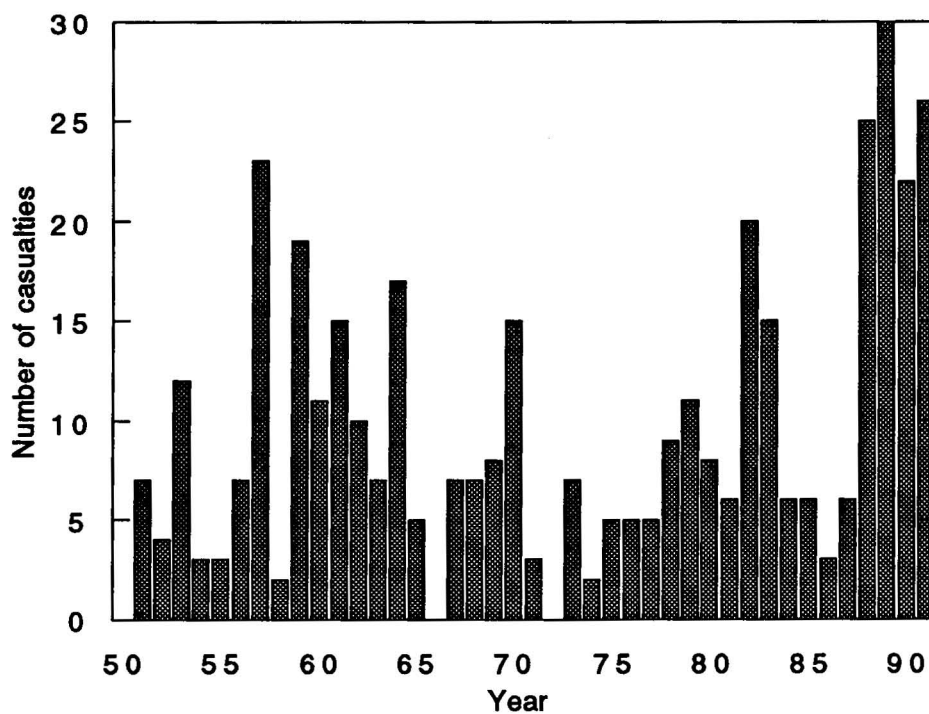


FIGURE 18. Time series from 1950 to 1991 of the annual number of Colorado casualties due to lightning.

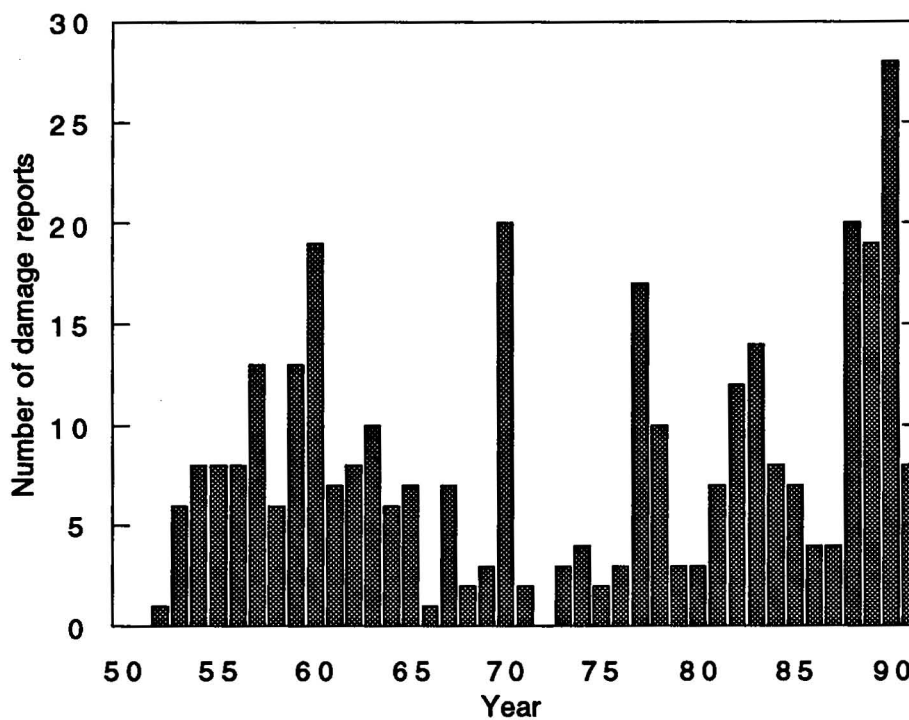


FIGURE 19. Time series from 1950 to 1991 of the annual number of material damage reports in Colorado due to lightning.

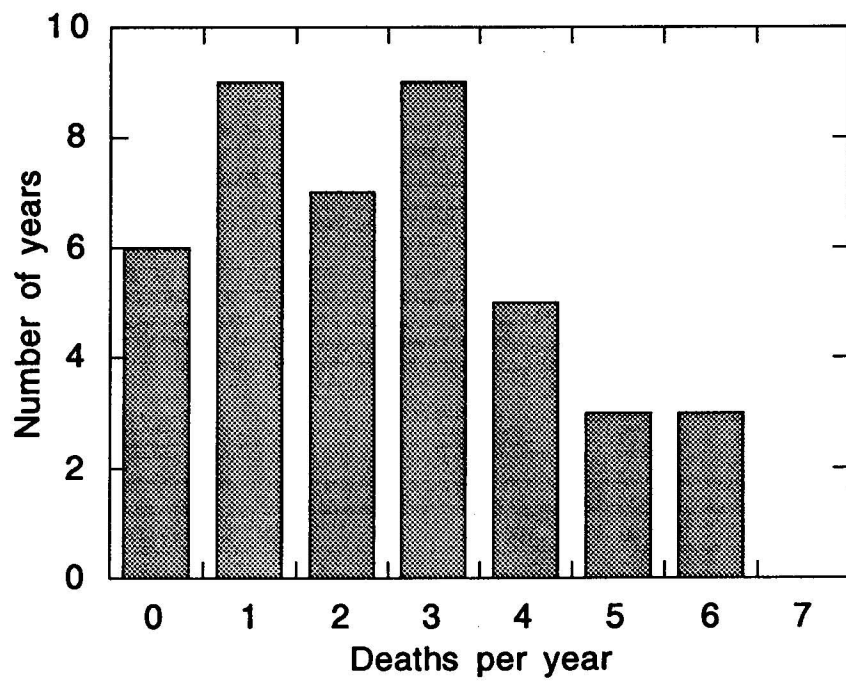


FIGURE 20. Frequency distribution of the annual number of lightning deaths per year in Colorado from 1950 to 1991.

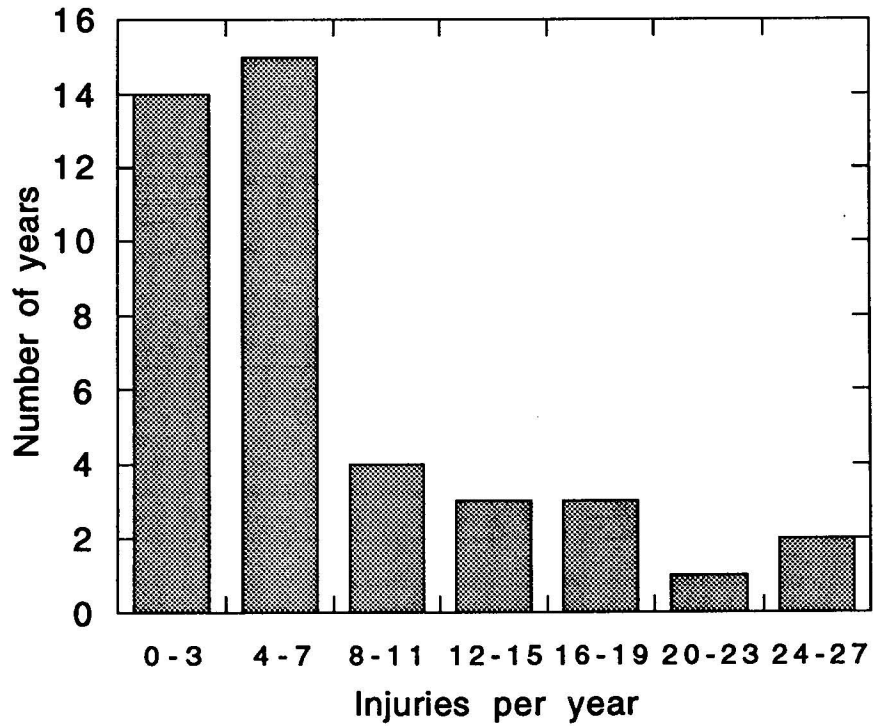


FIGURE 21. Frequency distribution of the annual number of lightning injuries per year in Colorado from 1950 to 1991.

B. Population Trends

The trend of the population of Colorado from 1950 to 1990 is portrayed in Figures 22 and 23. The values plotted are the 5 decennial census figures included in the period of study. Superimposed are the total number of casualties (Figure 22) and damage reports (Figure 23) for each 5-year interval (pentad) during the same period. The graphs show that the population of Colorado increased almost linearly since 1950. This mainly linear increase is reflected in the overall trends of the number

of casualties and damage reports. Superimposed on these trends, however, are long term fluctuations with five-year periods with much higher or lower numbers than those that would correspond to the overall trend paralleling the population increase. These long term fluctuations were apparent in the time series of yearly values discussed in the previous section, but become clearer after grouping the data in 5-year periods. In this way, much of the year-to-year variability is filtered out of the sample.

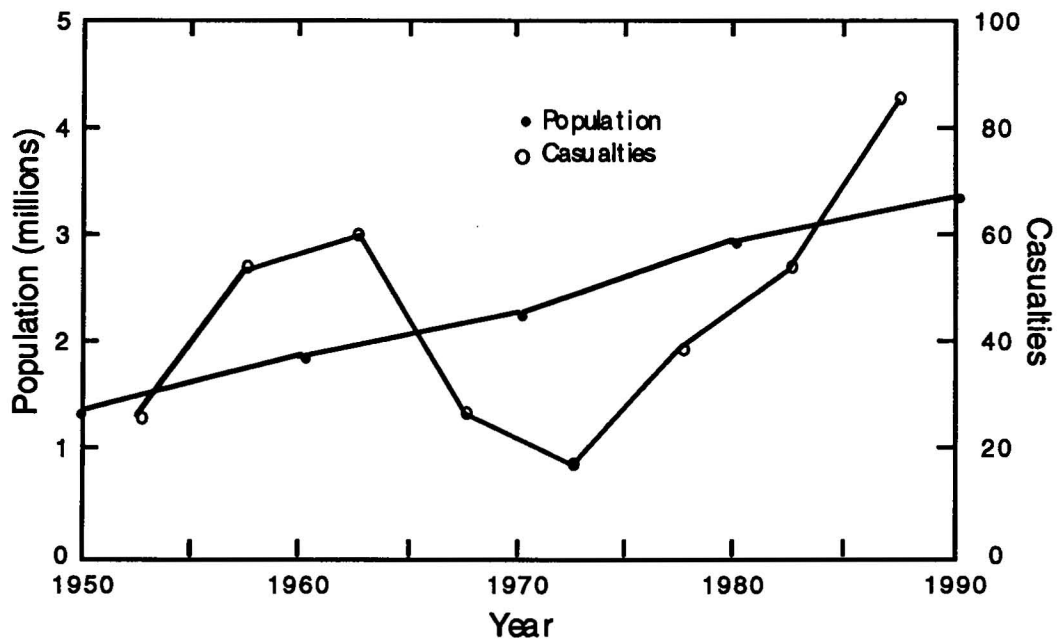


FIGURE 22. Population of Colorado by decade, and number of lightning casualties per 5-year intervals from 1950 to 1990.

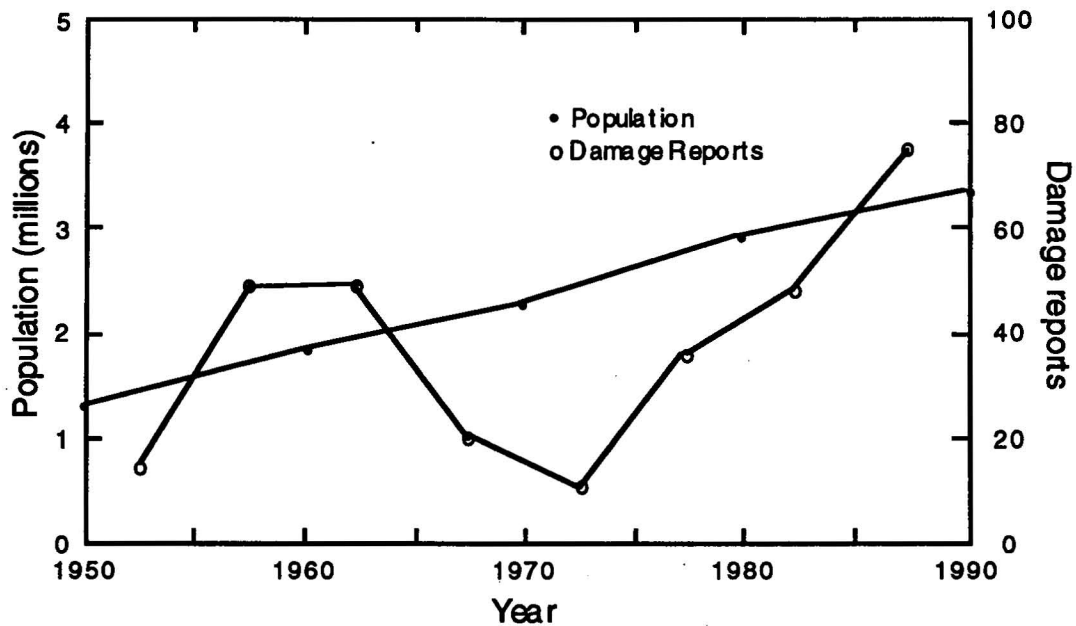


FIGURE 23. Population of Colorado by decade, and number of damage reports due to lightning per 5-year intervals from 1950 to 1990.

C. Long-term Changes in Places and Locations of Casualties

Figures 24 to 28 show the changes with time in the number of lightning casualties due to each type of situation discussed in Section 4C. For clarity, the numbers plotted are for 5-year periods (pentads). For reference, population for Colorado is also in each figure. All graphs show the same general fluctuations as the overall casualty curve of Figure 22. This general pattern has a maximum around the sixties, a minimum in the seventies, and an increase in later years. The amplitudes and timing of those fluctuations, however, are different for each type of casualty situation and illustrate changes in socioeconomic patterns in Colorado.

Casualties resulting from farming are shown in Figure 24. During the decade of 1955 to 1965, farming casualties were at a maximum and accounted for nearly 20% of all lightning casualties (Table 9). After 1965, the number dropped dramatically and was zero in the pentad starting in 1970. During the last few pentads, farming-related lightning casualties have not increased commensurate with the population or the overall pattern of casualty fluctuations. So, after allowing for the population increase, lightning casualties due to farming still have decreased considerably during the four decades.

Outdoor recreation casualties (Figure 25) were most frequent in the 1960s when they accounted for more than 30% of all casualties. They also experienced low values in the 1970s, and have since increased at a long-term rate commensurate with population. During the overall minimum in casualties of the seventies, however, the number of outdoor recreation casualties did not drop as much as other groups, and therefore contributed 47% of all casualties during the pentad starting in 1970.

Casualties due to sports (Figure 26) also had a minimum during the 1970 pentad, but have since increased considerably. The overall

rate of increase during the four decades of record has been substantially higher than for population.

Casualties due to urban and non-farming work situations (Figures 27 and 28) were more prevalent during the first two decades of record as was the farm situation. They also experienced minima during the seventies as farm casualties. But, they rebounded later to similar trends to those of Colorado population and outdoor casualties.

In summary, lightning casualties in farming situations decreased during the four decades of record, compared to casualties associated with the other major categories. Outdoor recreation, urban, and non-farming work situations have increased over the long run in accordance with the overall population increase. Sports-associated casualties, however, had a substantial increase during the period that is larger than that of the population. These trends probably represent a decrease in the number of people engaged in farming, as well as a significant growth in participation of recreational outdoor sports in Colorado. A trend away from outdoor worker casualties to recreation has also been noted by Prentice (1973) and Coates et al. (1993) for Australia, and Golde and Lee (1976) for England and Wales.

The Colorado data also show that recreation casualties have been generally high during the entire period, and outdoor recreation activities have been the number one hazard. In the latest decade, however, the number of sports-related casualties has equalled or exceeded outdoor recreation casualties. In the pentad from 1985 to 1990, casualties due to recreation activities accounted for 21% of all casualties, sports and urban situations each accounted for about 12%, work-related for 15%, and farming was 0%. The rest were distributed fairly uniformly in a variety of situations.

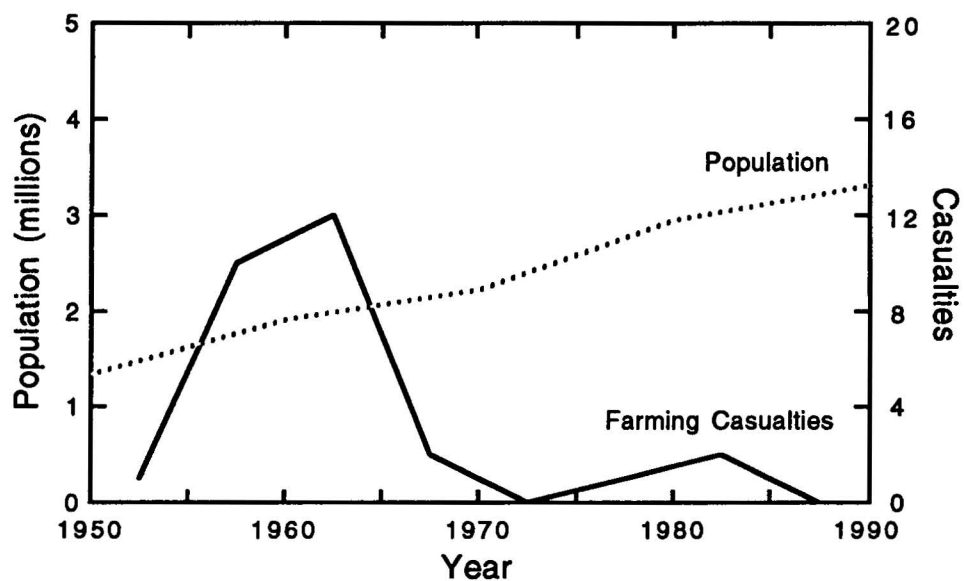


FIGURE 24. Change with time of number of lightning casualties in farming situations per 5-year periods (solid line). Dotted line represents population of Colorado.

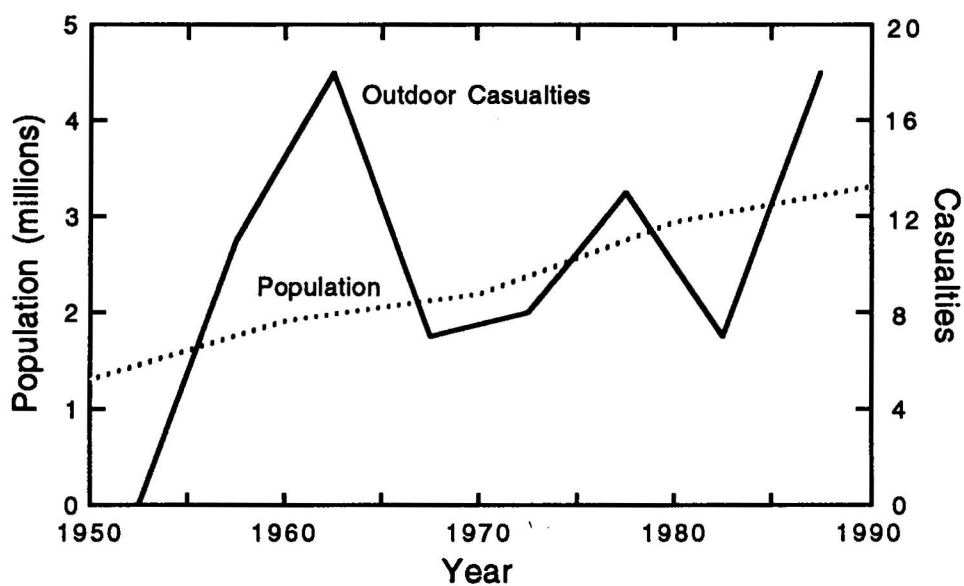


FIGURE 25. Same as Figure 24 but for outdoor recreation.

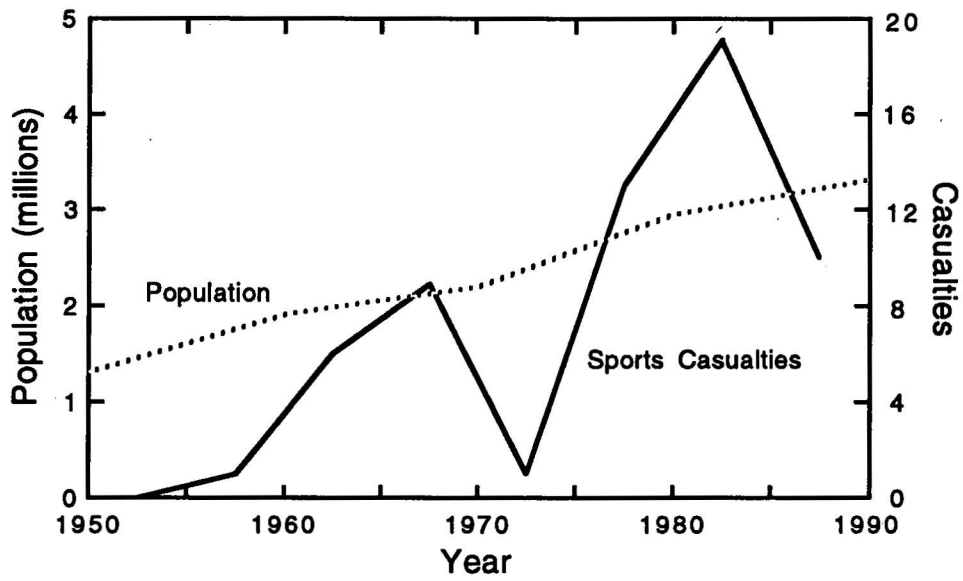


FIGURE 26. Same as Figure 24 but for sports.

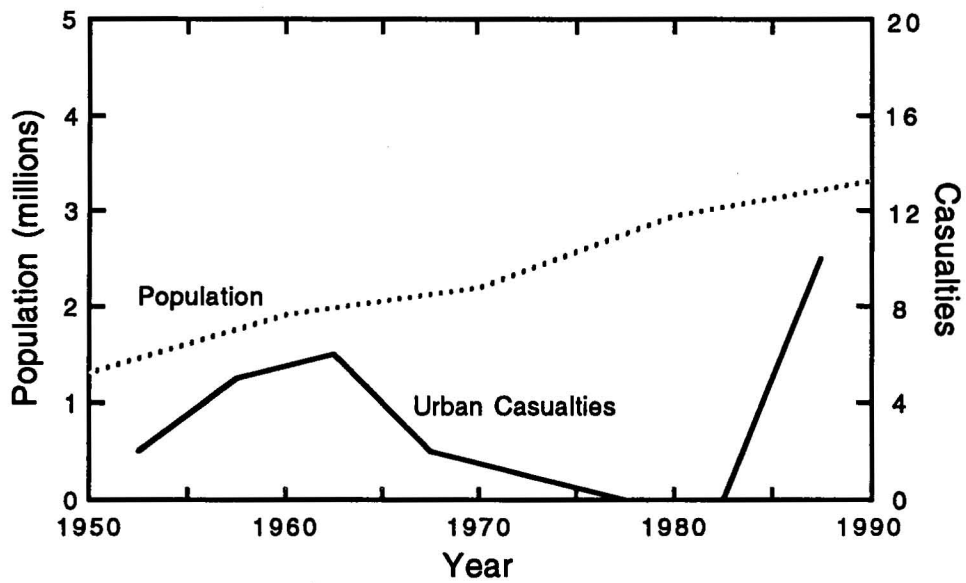


FIGURE 27. Same as Figure 24 but for urban situations.

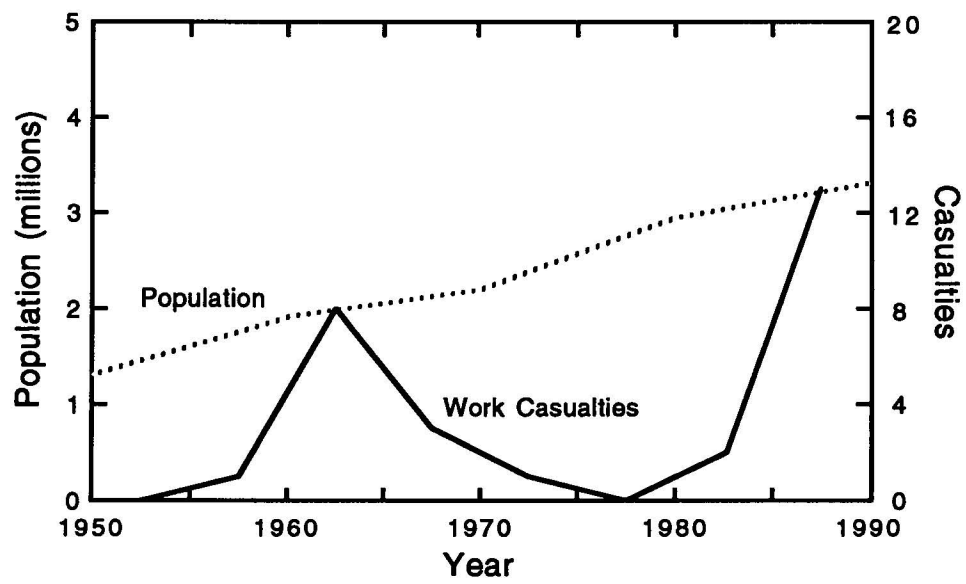


FIGURE 28. Same as Figure 24 but for work (non-farming) situations.

D. Long-term Fluctuations of Climatic Conditions

Another explanation for long-term fluctuations in lightning casualties in Colorado could be climatic fluctuations over the region including Colorado. These changes could affect the degree of convective activity during the summer, and thus the number of cloud-to-ground flashes. Alternatively, climatic fluctuations could affect outdoor recreation, sports, and employment patterns, and thus the number of lightning casualties. Testing such connections, however, is very involved and outside the scope of this paper. A few comments and some evidence, however, will underscore the possibility of such an explanation.

Ideally, it would be desirable to have a long-term series of yearly lightning frequencies. Unfortunately, such a series does not exist for the period of record, and series of conventional climatological variables such as temperature and precipitation must be considered. Figures 29 and 30 portray the average surface temperatures and precipitation from May through September for each 5-year period from 1950 to 1990. Superimposed on both figures is the lightning casualty curve for the same interval. The temperature and precipitation values correspond to the average of all values reported by climatological stations in

Colorado. During the period of study, 90 to 150 stations have reported temperature and 130 to 200 for precipitation. The months from May to September cover most casualties (Figure 1).

Figure 29 for temperature shows a remarkable similarity between the fluctuations of lightning casualties and the statewide temperature of Colorado. The period of low casualties in the decade of 1965 to 1975 matches very well with a period of low May-to-September temperatures. On the other hand, the higher numbers of casualties before and after this decade match with higher Colorado temperatures. The statewide precipitation time series of Figure 27 does not match as well with the casualty series. However, there is a tendency for fewer casualties during periods of high precipitation, and vice versa.

In summary, there is some evidence for a climatic correlation with lightning casualty and property damage time series from 1950 to 1990. A more detailed investigation of this issue should consider a careful characterization of the Colorado climate, more quantitative comparisons between lightning casualties and climatic variables, and comparisons with lightning casualty data from neighboring states.

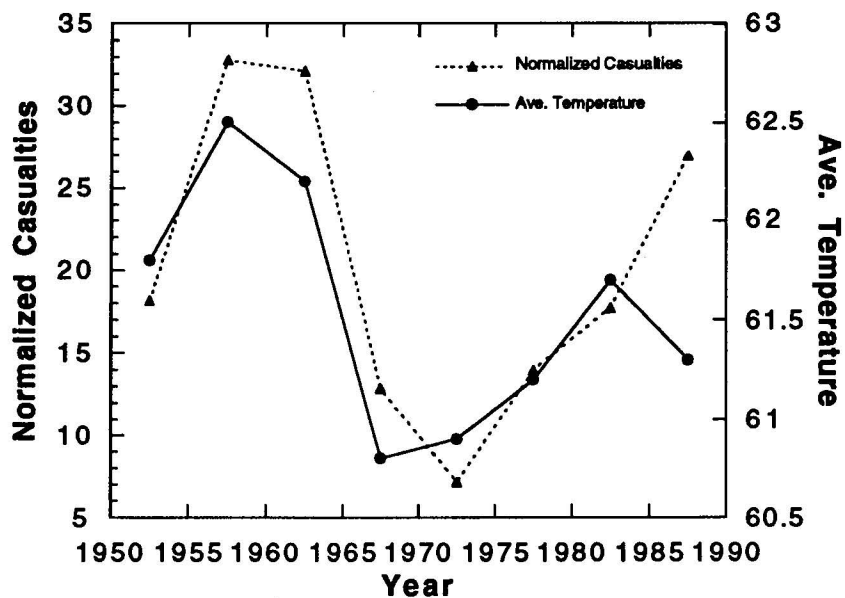


FIGURE 29. Average temperature (°F) in Colorado from 1950 to 1990 (solid line), and number of normalized casualties due to lightning per 5-year interval in same period (dotted line).

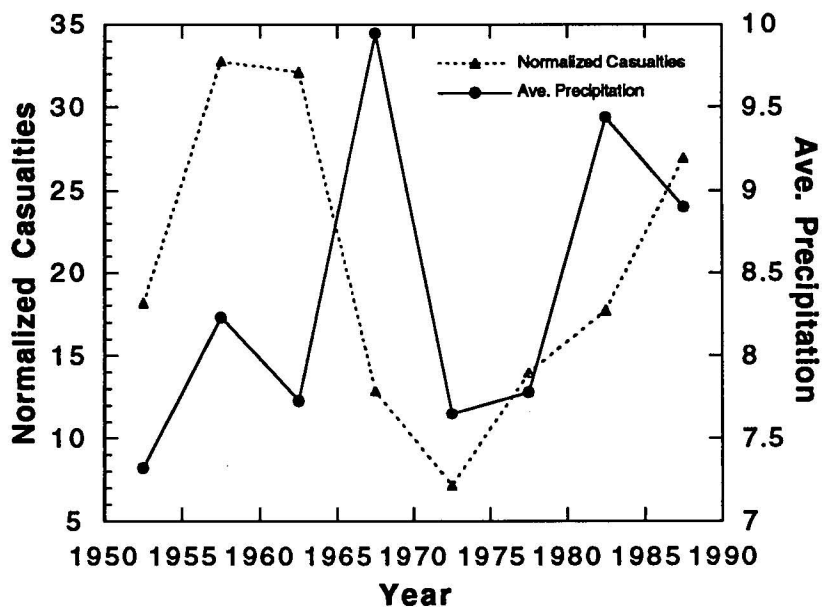


FIGURE 30. Same as Figure 29, except average precipitation (inches) shown by solid line.

E. Long-term Changes in *Storm Data* Compilation Procedures

There is also the possibility that long-term fluctuations in the number of casualties in Colorado are due to changes in the way that NOAA compiled *Storm Data*. If this were true, and NWS reporting procedures were uniform throughout the nation, the same basic fluctuations would be found in lightning casualty time series from all states. If the procedures were not uniform but varied from state to state or from region to region, a haphazard variation would be expected in patterns of time series. Time series of lightning casualties for all 48 states show that neither scenario is true.

The following two basic patterns of changes in yearly lightning casualties emerge:

- The Colorado type: Very few casualties during the 1970s. Colorado time series in Figures 22, 29, and 30 are also in Figure 31.
- The opposite type: A peak in lightning casualties during the 1970s. The time series for Florida is portrayed in Figure 32.

Across the continental United States, the Colorado type is found in the following two regions:

- A continuous region of western states, including California, Arizona, New Mexico, Utah, Colorado, Wyoming, and South Dakota.
- A few states along the east coast.

The rest of the country, including most northwestern, central, midwestern, and southern states, is characterized by the opposite, or Florida pattern. Therefore, in view of the quasi-longitudinal division of two opposite long-term patterns, and a good correlation with the temperature time series, it is difficult to attribute long-term fluctuations in lightning casualties observed in Colorado principally to changes in the reporting procedures of lightning casualties that have been used by the NWS.

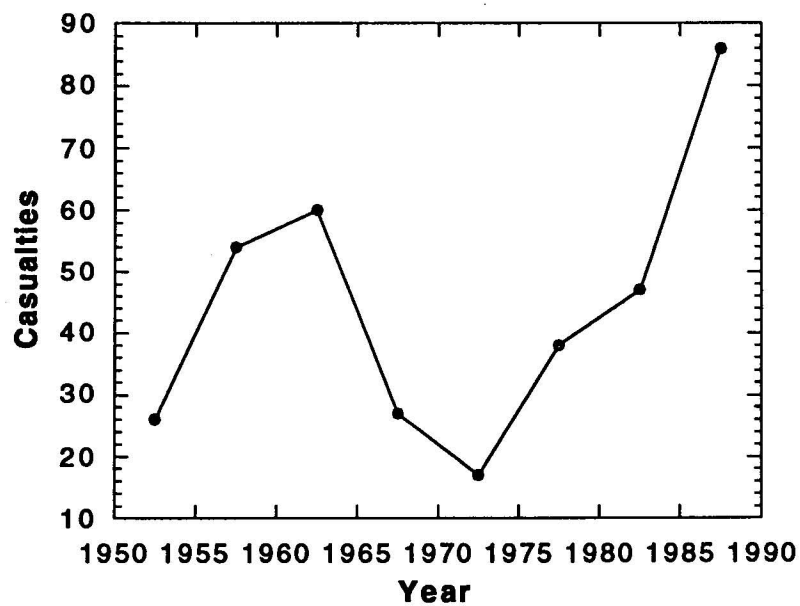


FIGURE 31. Lightning casualties in Colorado from 1950 to 1990 during 5-year intervals.

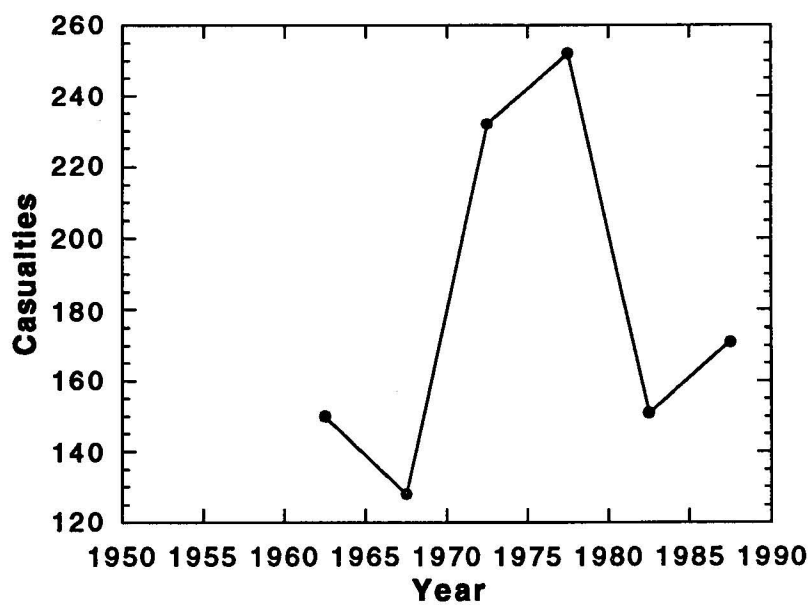


FIGURE 32. Same as Figure 31 for Florida.

8. SUMMARY AND CONCLUSIONS

This study of Colorado casualties and material damage is the most extensive long-term review to date of the impacts of lightning on people and material objects for all of Colorado. It used the NOAA/National Weather Service Publication *Storm Data*.

General results were as follows:

- 1) An average of 2.5 deaths, 7.1 injuries, and 7.9 material damage entries were reported in *Storm Data* per year across Colorado from 1950 through 1991.
- 2) Almost all casualties and damage reports occurred during the months of May through August.
- 3) More than half of the deaths and injuries were during the afternoon from noon to 6 p.m., and another quarter were from 6 p.m. to midnight. A higher percentage of material damage occurred during the evening than casualties.
- 4) Houses were the most common object reported damaged, and fires the most common damage.

According to county in Colorado:

- 1) The largest number of victims were in the counties with the largest population.
- 2) Much higher casualty rates per population and area occurred over the mountains and some areas of the eastern slopes than elsewhere.
- 3) Outdoor recreation casualties were most frequent in the mountains.
- 4) Farm and ranch cases occurred at the highest rate over the eastern plains.
- 5) Sports and domestic casualties were most common per population and area along the Front Range urban corridor.

For people who were killed or injured:

- 1) More than half of the deaths and injuries occurred during recreational activities, which is a higher ratio than has been found in many other locations.
- 2) The number of people killed and injured by lightning were nearly identical for golf and mountain climbing.
- 3) More people were victims at or near mountain tops than any other location, followed by being in the direct vicinity of trees, at residences, in the open, transportation, and in the vicinity of water.
- 4) Lightning casualties were typically younger males, as has been found in many other locations around the world.

Compared to the population trend:

- 1) There were fewer lightning casualties and damage reports in the 1970s and early 1980s than in other time periods.
- 2) Ranch and farm casualties decreased after being significant during the early 1960s, and are now very infrequent.
- 3) Outdoor recreation, urban, and work cases have increased with population growth.
- 4) Sports casualties had a substantially higher rate of increase than the population growth would indicate.

Statewide, the fluctuation in lightning victims relates well with statewide summer-time temperature changes, but not as well with precipitation. Long-term changes in casualties and damage reports in surrounding states are similar to those in Colorado.

ACKNOWLEDGMENTS

Mr. William Ramsey first generated the idea for this project while a student at Metropolitan State College in Denver, Colorado. Without his efforts in the laborious initial task of reducing the 40-year dataset into a coded form, this study may well have not been completed. We also thank Mr. Robert

Ortiz of NSSL in Norman, who helped find and enter a number of missing events from *Storm Data*. Members of the Lightning Data Center at St. Anthony Hospital Central in Denver, especially Dr. Michael Cherington, were important in giving constant encouragement to complete this report.

BIBLIOGRAPHY

- Andrews, C.J., and M. Darveniza, 1992: Telephone-mediated lightning injury: An Australian Survey. *Journal of Trauma*, 29, 665-671.
- , —, and D. Mackerras, 1989: Lightning injury—A review of clinical aspects, pathophysiology, and treatment. *Advanced Trauma*, 4, Year Book Medical Publishers, Inc., 241-288.
- , M.A. Cooper, M. Darveniza, and D. Mackerras, 1992: *Lightning injuries: Electrical, medical, and legal aspects*. CRC Press, Boca Raton, Florida, 195 pp.
- Cherington, M., and C. Vervalin, 1990: Lightning injuries—Who is at greatest risk? *The Physician and Sportsmedicine*, 18, 58-61.
- , P. Yarnell, and D. Lammereste, 1992: Lightning strikes: Nature of neurological damage in patients evaluated in hospital emergency departments. *Annals of Emergency Medicine*, 21, 133-136.
- , —, and D. Hallmark, 1993: MRI in lightning encephalopathy. *Neurology*, 43.
- Coates, L., R. Blong, and F. Siciliano, 1993: Lightning fatalities in Australia, 1824-1991. *Natural Hazards* [submitted].
- Cooper, M.A., 1980: Lightning injuries: Prognostic signs for death. *Annals of Emergency Medicine*, 9, 134.
- , 1989: Lightning injuries. *The Management of Wilderness and Environmental Injuries*, Second Edition, Chapter 7, Auerbach and Geehr, Mosby, St. Louis, 173-193.
- Darveniza, 1992: Prolongation of the QT interval in lightning strike, with implications for the 'Cessation of Metabolism' hypothesis. *Journal of Wilderness Medicine*.
- Elsom, D.M., 1993: Deaths caused by lightning in England and Wales, 1852-1990. *Weather*, 48, 83-90.
- Golde, R.H., and W.R. Lee, 1976: Death by lightning. *Proceedings of the Institute of Electrical Engineers*, 123, 1163-1180.
- Holle, R.L., R.E. López, R. Ortiz, C.H. Paxton, D.M. Decker, and D.L. Smith, 1993: The local meteorological environment of lightning casualties in central Florida. Preprints, 17th Conference on Severe Local Storms and Conference on Atmospheric Electricity, October 4-8, St. Louis, MO, American Meteorological Society, Boston, 779-784.
- López, R.E., and R.L. Holle, 1986: Diurnal and spatial variability of lightning activity in northeastern Colorado and central Florida during the summer. *Monthly Weather Review*, 114, 1288-1312.
- , —, T.A. Heitkamp, M. Boyson, M. Cherington, and K. Langford, 1993: The underreporting of lightning injuries and deaths in Colorado. *Bulletin of the American Meteorological Society*, 74, 2171-2178.
- Mackerras, D., 1992: Occurrence of lightning death and injury. Chapter 4 in *Lightning injuries: Electrical, medical, and legal aspects* by Andrews, C.J., M.A. Cooper, M. Darveniza, and D. Mackerras, CRC Press, Boca Raton, Florida, 195 pp.
- Mogil, H.M., 1979: Lightning in 1978: Refuting the misconceptions. *Weatherwise*, 32, 17-20.
- , M. Rush, and M. Kutka, 1977: Lightning—An update. Preprints, 10th Conference on Severe Local Storms, October 18-21, Omaha, NE, American Meteorological Society, Boston, 226-230.
- Pakiam, J.E., T.C. Chao, and J. Chia, 1981: Lightning fatalities in Singapore. *Meteorological Magazine*, 110, 175-187.
- Prentice, S.A., 1973: Death by lightning. *Medical Journal of Australia*, 2, 252.
- Vigansky, H.N., 1985: General summary of lightning, 1985. *Storm Data*, 27, No. 12, 37-44.
- Weigel, E.P., 1976: Lightning: The underrated killer. *NOAA*, 6, 4-11.
- Zegel, F.H., 1967: Lightning deaths in the United States: A seven-year survey from 1959 to 1965. *Weatherwise*, 20, 169-173, 179.

ACRONYMS

Casualty	Death or injury from lightning.
MST	Mountain Standard Time (UTC minus 7 hours).
NCDC	National Climatic Data Center of NESDIS.
NESDIS	National Environmental Satellite, Data, and Information Service of NOAA.
NOAA	National Oceanic and Atmospheric Administration.
NSSL	National Severe Storms Laboratory of NOAA.
NWS	National Weather Service of NOAA.

NATIONAL SEVERE STORMS LABORATORY

The NSSL Technical Memoranda, beginning at No. 28, continue the sequence established by the U.S. Weather Bureau National Severe Storms Project, Kansas City, Missouri. Numbers 1-22 were designated NSSL Reports. Numbers 23-27 were NSSL Reports, and 24-27 appeared as subseries of Weather Bureau Technical Notes. These reports are available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151, a microfiche version for \$4.00 or a hard copy, cost depending upon the number of pages. NTIS numbers are given below in parenthesis.

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