Colorado Department of Public Health and Environment
Radioactive Materials License 1102-01
Renewal Application

Volume 7 of 7

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Crow, L. W. 1987. *Analysis of Pertinent Weather Factors Related to the Permit Application for Proposed Highway 36 Waste Management Facility*. Prepared for Morrison Knudsen Engineers, Inc., Denver, CO

McCulley, Frick and Gilman, Inc. 1997; *Highway 36 Facility Groundwater Protection Program Design and Rationale;* Prepared for the Highway 36 Land Development Company, Deer Trail, Colorado.

Cameron-Cole, 2004; *2003 Annual Groundwater Protection Monitoring Report;* Prepared for Clean Harbors Deer Trail, LLC.

Clean Harbors Deer Trail, LLC, 2004; *Waste Filling Plan and Drawings for Secure Cell Number 2, Revision 1.*

May, 2010

Clean Harbors Deer Trail, LLC
108555 East Highway 36
Deer Trail, CO 80105-9611

CleanHarbors®
ENVIRONMENTAL SERVICES, INC.

RADIOACTIVE MATERIALS LICENSE APPLICATION

CLEAN HARBORS DEER TRAIL, LLC. HAZARDOUS WASTE TREATMENT, STORAGE, DISPOSAL FACILITY

PREPARED BY

CLEAN HARBORS DEER TRAIL, LLC.
108555 EAST US HIGHWAY 36
DEER TRAIL, COLORADO 80105-9611

JANUARY 2005

VOLUME 6 OF 6

Radioactive Materials License Application
for

Clean Harbors Deer Trail, LLC.,
108555 East US Highway 36
Deer Trail, Colorado 80105-9611

Volume 6 – Contents

ANALYSIS OF PERTINENT WEATHER FACTORS RELATED TO THE PERMIT APPLICATION FOR PROPOSED HIGHWAY 36 WASTE MANAGEMENT FACILITY

prepared for

MORRISON-KNUDSEN ENGINEERS, INC.

by

LOREN W. CROW

Certified Consulting Meteorologist

LWC #310 June 1987

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I. SUMMARY

The following comments are intended to summarize my most significant findings of the analysis of pertinent weather factors related to the Highway 36 Hazardous Waste Management Facility area and a 55-mile radius area surrounding the proposed facility:

- The heaviest rainfall at the Project Site will be delivered by large thunderstorms normally occuring in June, July, and August;

- The duration of a heavy thunderstorm will be less than six hours and a high fraction of the rain will fall within the first two hours;

- The development of comparative precipitation data from 23 stations within 55 miles of the Project Site furnished a data base which has been useful in conducting a statistical-type analysis;

- By performing a statistical analysis of that data base, the peak 24-hr precipitation amounts for 100, 200, 500, 1,000 and 10,000 year return periods have been estimated as shown in Figure 12. The estimated amount of peak 24-hr precipitation for each of these return periods is as follows:

Return Period (yrs)	Peak 24-Hour Amount (inches)
100	5
200	5.9
500	7.0
1000	7.9
10000	11.0

- The validity of the Site Rainfall Intensity-Duration-Frequency curve for a 100-year storm, developed based on NOAA Atlas 2 Vol III, Colorado 1973 data and procedures and presented in Attachment LF-3 to the CDH Permit, has been confirmed by comparing it with information from the USGS Small Plot Studies;

- Some of the CDH technical requirements are technically inconsistent. In such cases, standard meteorological procedures were utilized to obtain the desired end results;

- Differences in terrain elevation are of some importance. The annual peak 24-hr rainfall amounts are expected to be greater along the higher terrain running nearly west-to-east several miles south of the Project than at the Project Site;

- The Figure 12 precipitation estimates for various recurrance interval events were conservatively derived because a disproportionately higher number of the precipitation measurements used as data points came from sample stations located at higher elevations which experience more total and larger precipitation events than at the Project Site;

- In my opinion, using data from sample stations which more correctly reflect the Project Site conditions, the peak 24-hr rainfall amount at the 1/100 level (100-year recurrance interval) at the Project Site is estimated to be 4.40 inches. This estimate is lower than the 5.0 inch estimate shown in Figure 12 because Figure 12 is based on the 23 station composite data set which includes the higher elevation data previously mentioned. Use of a value of 4.75 inches should be considered conservative and 5.00 inches could be considered to be very conservative.

- The estimates for the 100- and 200-year return periods may be considered quite reliable. The degree of uncertainty increases for the 500- and 1,000-year return period estimates. Great uncertainty must be assigned to this, and any other, estimate for the 10,000-year return period, no matter what source or technique is utilized, because of the limited length of record available compared to the return period.

Loren W. Crow

Loren W. Crow
Certified Consulting Meteorologist
Certification Number 7

II. INTRODUCTION

This report summarizes the results of an analysis of pertinent weather factors related to the permit application for the proposed Highway 36 Hazardous Waste Management Facility (H36HWMF) located near the southeast corner of Adams County, Colorado. Most specific attention has been given to addressing the requirments of the Colorado Department of Health (CDH) as listed in Part II, Section E.1.a, of the Highway 36 Land Development Company Hazardous Waste Permit. These requirements are as follows:

vii. The permittee shall revise the runoff drainage system design for the active facility life to control the peak and total runoff resulting from the 24-hour, 500-year rainstorm or twice the 100-year rainstorm, whichever is less, in conjunction with the largest recorded regional hail fall, according to the following procedures (264.31, 264.301 (c, d, g, and e).

aa. The permittee shall survey hail and rainfall records from all National Weather Service recording stations within 55 air miles from the facility site. Intensity-duration versus one- to one-hundred-year recurrence interval curves shall be prepared for each station where the one-hundred-year rainfall may exceed 4.4 inches. The permittee shall also determine the years of record for each station and maximum amount of hail recorded at each station.

bb. The permittee shall estimate the Probable Maximum Precipitation (PMP) for the site in accordance with National Weather Service Hydrometeorological Report No. 55. The PMP is defined as the 10,000-year storm for the purposes of this permit.

cc. The permittee shall estimate the 24-hour, 500- and 1,000-year rainfalls by analytically fitting a curve to the largest 100-year (and associated 1- and 10-year) storm estimate. Alternate procedures for determining the 1,000-year storm may be proposed by the permittee.

dd. The permittee shall obtain a statement from a Certified Consulting Meteorologist registered by the American Meteorological Society regarding the validity of the 100-year and 10,000-year storm predictions, and of the methods proposed for estimating the 1,000-year storm. The statement shall address any geographic factors or known weather patterns which may cause actual precipitation at the site to be greater or less than the estimates obtained as specified in sections as., bb., and cc.

Some of the CDH requirements are technically inconsistent. In such cases, I complied with the intent of the requirements utilizing standard meteorological procedures to obtain the desired end results.

The site of the H36HWMF is located in the southeast corner of Township 3 South and Range 57 West, Adams County, Colorado. The facility is located on a knoll and local drainage is away from rather than toward the site.

The regional area surrounding the site is a part of the eastern plains of Colorado. There is a gradual slope downward toward the north, as well as a gradual slope downward toward the east. Dry land type of farming is the rule rather than the use of irrigation. Two prominent terrain features are worth mentioning, as they relate to precipitation. The higher terrain extending toward the east and northeast from the Palmer Lake Divide plays an important part in "triggering" heavy summer thunderstorms. The comparatively higher precipitation is further confirmed by the sustained tree growth along the crest of the Palmer Ridge. A second area of important terrain features is the tongue of higher terrain that extends northward in Washington County to the vicinity of Akron. Convective cloud development will tend to begin above this comparatively higher terrain before it can begin over the surrounding lower elevations. Once formed, the convective cloud formations tend to be fed by inflowing air from over the lower areas.

The annual sequence of precipitation in northeastern Colorado tends to follow the amount of the available moisture within the total column of air from the surface to near the tropopause (somewhere within the 30,000- to 40,000-foot msl range). The lowest amounts of atmospheric moisture available occur in the winter months of December through February. July generally has the greatest amounts of atmospheric moisture.

An excerpt from the recently published **"Colorado Average Annual Precipitation 1951-1980"** map is presented as Figure 1. The Project Site is identified as

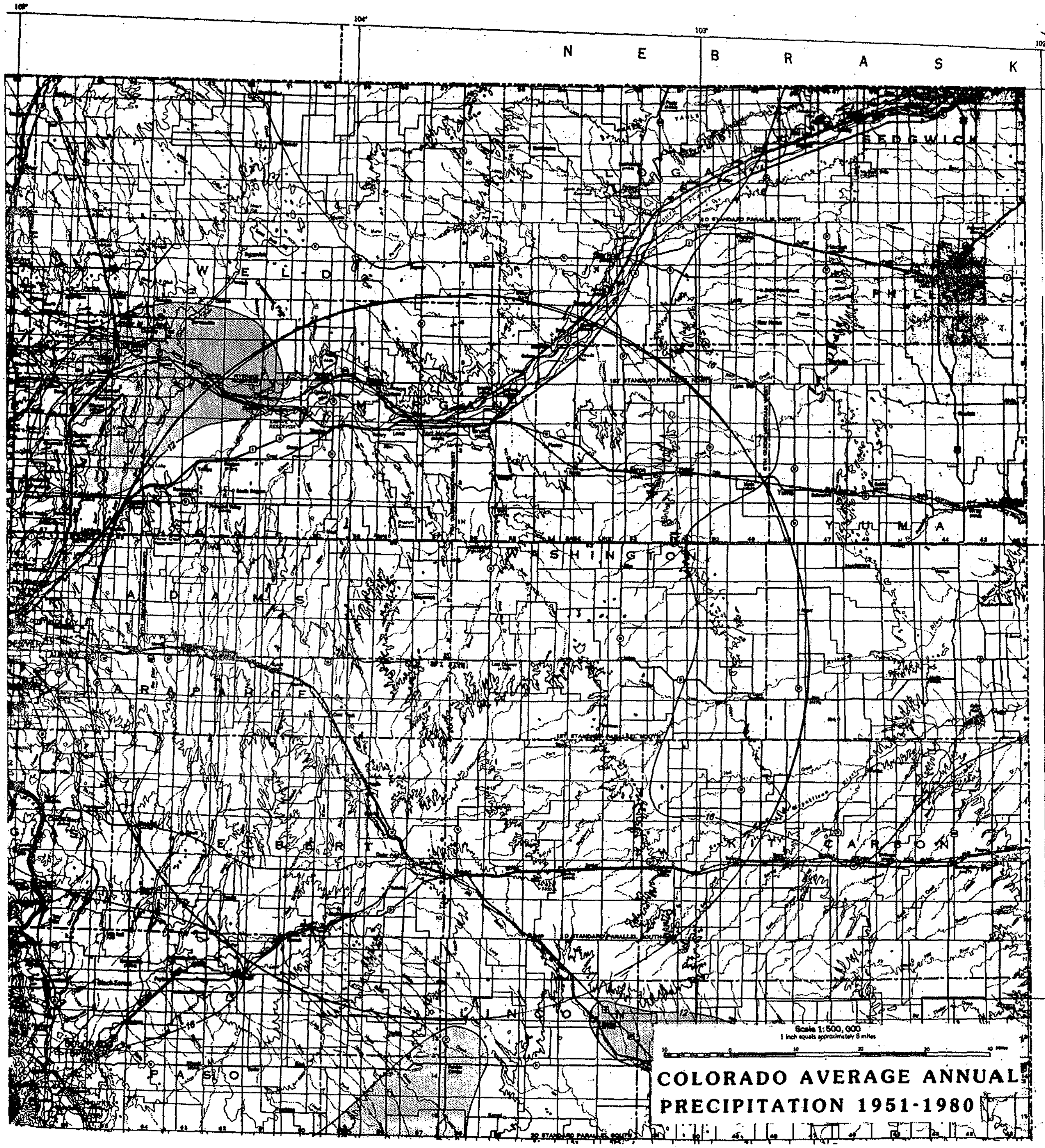

Figure 1. **Annual precipitation pattern in northeastern Colorado**

Source **Colorado Climate Center**
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado

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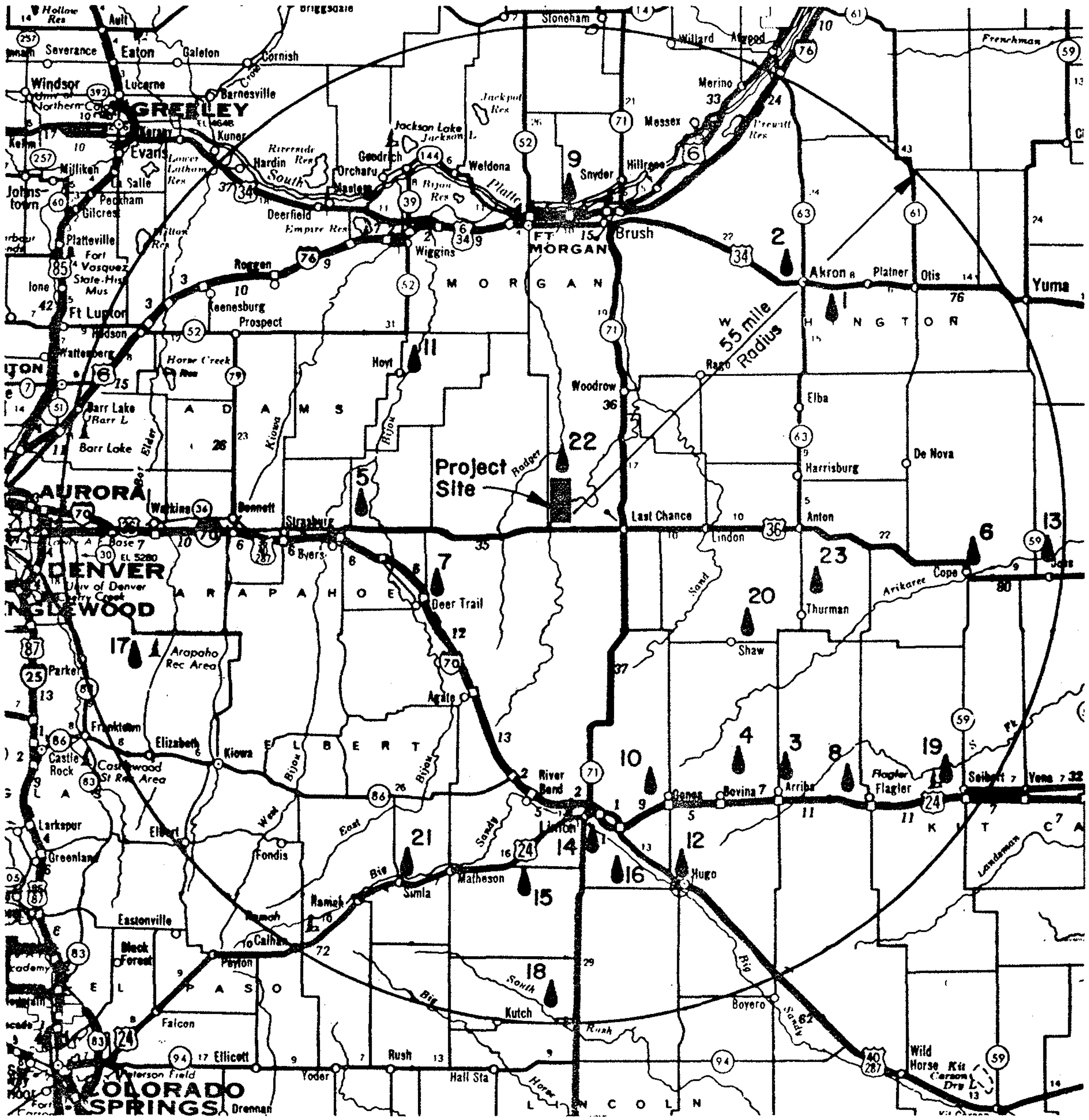
the BFI site near the center of the map segment presented. A circle has been drawn to include the area within 55 miles from the site. The mean annual precipitation at the site is approximately 14 inches. Note that the 12-inch lines and the 16-inch lines fall some distance from the site. Most of the precipitation falls within the six months from April through September.

III. STATION SURVEY WITHIN 55-MILE RADIUS

The same geographic area covered in Figure 1 is also covered in Figure 2. Within this geographic area there have been 23 separate station locations that have recorded precipitation for periods of two or more years. These 23 stations are listed in alphabetical order in the upper right portion of Figure 2. Although the elevation height lines have not been included in Figure 2, the drainage patterns are clearly portrayed by the various creeks and rivers. Note the paths of drainage away from the comparatively higher ground along Highway 24 to the northeast and eastward from Colorado Springs. This ridge contains some 11 of the 23 places where precipitation has been measured for two years or more within the period from 1914 through 1986. The greater density of stations in this area could be explained by the fact that dry land type farming may have its best chances of success in this area, and thus, there is a somewhat greater concern for measuring the amounts of precipitation.

Although Figure 1 does not cover enough area to show it, the average annual precipitation tends to increase as one moves east from the facility site. This increase is a general trend and ignores local factors. The increase is caused by higher available atmospheric moisture due to two factors. First, the total volume of air available to hold moisture increases because the vertical height differential between the surface and the tropopause increases as the terrain elevation becomes lower. Second, as the distance to a main major source of air moisture, namely the Gulf of Mexico, decreases, the chances of encountering air containing more moisture increases. These two factors produce a notably higher susceptability to heavy summer thunderstorms the further east from the site you go. Subsequent data from the rainfalls at Cope, Joes, and Siebert will confirm this observation.

All the published <u>daily</u> records from stations within a 55-mile radius of the Project Site were reviewed for the period 1914 through 1986. The data reviewed indicated that most of the high precipitation events occured during the period of May through September. The review concentrated on precipitation records for the months of June, July, and August. Only the highest daily amount per summer season was included within the data set for each station. However, in a few instances, the highest 24-hour amounts have occured in



1 Akron 4 E.
2 Akron FAA AP
3 Arriba
4 Bovina 3 N.E.
5 Byers 5 E.N.E.
6 Cope
7 Deer Trail
8 Flagler 2 N.W.
9 Fort Morgan
10 Genoa 1 W.
11 Hoyt
12 Hugo
13 Joes
14 Limon
15 Limon 10 S.S.W.
16 Limon WSMO
17 Parker 6 E.
18 Peverly Ranch
19 Seibert
20 Shaw 2 E.
21 Simla
22 Simpson
23 Thurman 3 E.N.E.

Figure 2
Locations of 23 precipitation measuring stations within 55 miles of the Project Site.

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either May or September. When this happened, the hourly amounts were notably lower than during the peak summer thunderstorms. Also, the peak 24-hour amounts that occurred in May were primarily near the foothills to the west, where upslope motion toward higher terrain is a factor.

A total of 718 station years of record were analyzed and tabulated. Arrays of the annual peak 24-hour precipitation amounts for all stations are presented in Table I. At each station, the set of historical peak 24-hour amounts is arrayed from lowest to highest as one progresses from the bottom of the column toward the top. For example, at Akron 4E, one summer had a 24-hour peak amount of only .18 inch. The highest 24-hour amount at this station was 4.00 inches.

Beginning in 1948 and 1949, recording rainfall gages were added at several locations. One of the primary purposes for adding the recording gages was to determine rates of fall within comparatively short periods of time. As time progressed, some of these stations used both the cumulative once-per-day type rain gage, along with the new recording gage. At other stations, only the recording gage was used after it was installed. In this current study, both the so-called daily gage readings and the hourly amounts totaled through midnight from the recording gages were checked when a station continued to use both type gages. The higher of the two values was used. Thus, the data sets presented in Table I include the annual peak 24-hour values each year whether the values came from the so-called daily gage or from the recording gage. Only the one highest amount for each of the years with complete data during the summer months was used.

The data presented in Table I includes a few recordings greater than 4.40 inches. For example, the Akron FAA Airport station recorded one high value of 4.55 inches and another high value of 5.50 inches. The highest value at Arriba was 5.10 inches. A rather unusual array of data shows up at Cope. With only 18 years of valid data available, the highest value was reported as 7.00 inches, followed by the second highest 24-hour amount of 2.24 inches. The two middle values in this set of 18 were 1.35 and 1.36 inches respectively. The "neat" rounding off of the highest amount at Cope to exactly 7.00 inches leaves room for doubt that the value may have been an estimate rather than an actual measurement.

TABLE I ARRAYS OF THE MEASURED HIGHEST 24-HOUR RAINFALL AMOUNTS PER YEAR DURING THE MONTHS OF JUNE, JULY, AND AUGUST* WITHIN THE HISTORICAL PERIOD, 1914 THROUGH 1986, AT ALL STATIONS WITHIN 55 MILES OF THE PROPOSED HIGHWAY 36 WASTE MANAGEMENT FACILITY

AMOUNT INTERVALS	AKRON 4E.	AKRON FAA AP	ARRIBA	BOVINA 3 N.E.	BYERS 5 E.N.E.	COPE	DEER TRAIL	FLAGLER 2 N.W.	FORT MORGAN	GENOA 1 W.
6.00 and up						7.00				
5.50-5.99		5.50								
5.00-5.49			5.10							
4.50-4.99		4.55							4.60	
4.00-4.49	4.00		4.00		4.00, 4.10, 4.40		4.00, 4.12			
3.50-3.99	3.74							3.65		
3.00-3.49		3.14, 3.19			3.00, 3.24, 3.25		3.11	2.77, 3.45	3.05, 3.15	
2.90-2.99				2.95						
2.80-2.89	2.80	2.85					2.85			
2.70-2.79	2.71, 2.73							2.72		
2.60-2.69	2.62, 2.65									
2.50-2.59		2.59								2.50
2.40-2.49	2.42	2.40, 2.49			2.40, 2.41			2.42, 2.46		2.40
2.30-2.39		2.30	2.32				2.30	2.30, 2.39		2.37
2.20-2.29	2.20					2.24		2.23	2.25	2.27
2.10-2.19				2.10	2.08			2.15		2.12
2.00-2.09		2.04	2.00, 2.05			2.08		2.03	2.00, 2.00, 2.13	
1.90-1.99	1.90, 1.90, 1.94 1.97	1.94	1.90				1.91			
1.80-1.89	1.83, 1.86, 1.87	1.80, 1.81, 1.83 1.85, 1.85, 1.86	1.85, 1.88		1.80, 1.80, 1.81 1.87		1.80, 1.85	1.82, 1.83, 1.83	1.84, 1.88	1.88
1.70-1.79		1.71, 1.72	1.70		1.70, 1.71, 1.73		1.71, 1.72	1.75, 1.76	1.73	1.70, 1.72, 1.74
1.60-1.69		1.60, 1.63, 1.66	1.60		1.65	1.64, 1.65, 1.68		1.67	1.63	
1.50-1.59	1.50, 1.58	1.50, 1.50, 1.55 1.58	1.51	1.58, 1.51, 1.51	1.50, 1.55, 1.58	1.51	1.51	1.55	1.55, 1.55, 1.58	1.53, 1.53
1.40-1.49	1.42	1.49	1.45	1.40, 1.41	1.45, 1.48	1.45	1.41, 1.41, 1.46 1.47, 1.48	1.44, 1.46, 1.49	1.41, 1.46	1.44, 1.45
1.30-1.39	1.32, 1.35, 1.36	1.31, 1.33, 1.33	1.35	1.33	1.34, 1.35	1.30, 1.35, 1.36	1.31	1.30, 1.34	1.30, 1.30	1.34, 1.35, 1.37
1.20-1.29	1.20, 1.24, 1.25 1.26	1.22, 1.26, 1.29	1.22, 1.26	1.26	1.20, 1.21, 1.23 1.25	1.22	1.20, 1.21	1.21, 1.23, 1.23 1.29	1.20, 1.20, 1.20 1.20, 1.22, 1.22 1.23, 1.23, 1.26 1.28	1.23, 1.24
1.10-1.19	1.13, 1.14, 1.17	1.10, 1.11, 1.15	1.10, 1.10, 1.13 1.14, 1.18	1.12	1.11, 1.15, 1.16	1.10, 1.15	1.12, 1.13, 1.19	1.10, 1.12, 1.12	1.10, 1.10, 1.10 1.11, 1.12, 1.13 1.15, 1.16	1.15
1.00-1.09	1.09	1.00, 1.02, 1.03 1.06	1.07, 1.09		1.02, 1.02, 1.02 1.05, 1.08	1.01	1.01, 1.05	1.04, 1.05	1.02, 1.02, 1.03 1.04, 1.05	1.00, 1.00, 1.03 1.03
.90-.99	.91, .93	.91, .93, .95, .98 .98	.90, .90, .99	.91	.90, .94, .94, .96 .96, .99	.99	.95, .97, .98	.93	.90, .90, .92, .94 .95, .95, .98, .99	.92, .93, .95
.80-.89		.82, .86	.80	.85	.80, .81, .85, .85 .85, .86, .87		.86	.87	.80, .80, .81, .81 .81, .82, .85	.85, .86, .86, .89
.70-.79	.70, .75, .77		.70, .71, .77	.75, .77		.78	.75	.71, .73, .77	.70, .72, .75, .76 .78, .79	.72, .75, .79
.60-.69	.60, .62	.61	.63, .65, .69		.60, .66, .68, .69		.60		.64, .67, .68	.63, .64
.50-.59					.50, .55	.55	.52, .53			.50
.40-.49			.44		.42				.40, .45	
.30-.39		.34			.35, .35				.36	
.20-.29										
.10-.19	.18								.17	
YEARS OF RECORD	30	49	33	14	58	18	32	37	69	36

* A LIMITED NUMBER OF PEAK 24-HOUR RAINFALL AMOUNTS HAVE BEEN RECORDED IN MAY AND SEPTEMBER, BUT THE RATES OF FALL PER HOUR ARE NOTABLE LOWER THAN DURING INTENSE SUMMER THUNDERSTOMS.

AMOUNT INTERVALS	HOYT	HUGO	JOES	LIMON - ALL	PARKER 6 E.	PEVERLY RANCH	SEIBERT	SHAW 2 E. & THURMAN 3 E.N.E.	SINIA	SIMPSON
6.00 AND UP										
5.50-5.99										
5.00-5.49	5.33		5.30							
4.50-4.99							4.84			
4.00-4.49										
3.50-3.99	3.86			3.50, 3.60, 3.72	3.60		3.53, 3.85		3.84	
3.00-3.49			3.05, 3.27		3.20			3.19		
2.90-2.99										
2.80-2.89	2.80			2.80, 2.82	2.80	2.80			2.87	
2.70-2.79				2.70			2.73, 2.78	2.75		
2.60-2.69	2.63		2.66, 2.67						2.64	
2.50-2.59	2.58		2.50, 2.57							
2.40-2.49		2.42		2.43						
2.30-2.39	2.30	2.39		2.33					2.34	
2.20-2.29		2.23		2.27	2.20		2.29			
2.10-2.19		2.10, 2.10, 2.10	2.11, 2.12	2.13, 2.13, 2.18						2.18
2.00-2.09			2.04	2.00			2.00	2.00	2.05	2.00
1.90-1.99		1.90, 1.98		1.97, 1.99	1.90			1.95	1.93, 1.98	
1.80-1.89	1.80, 1.83		1.86	1.82, 1.82, 1.83 1.83, 1.83, 1.84 1.85	1.88, .189				1.88	
1.70-1.79		1.70, 1.76	1.70	1.70, 1.70, 1.75 1.78	1.75, 1.75, 1.78	1.71		1.70, 1.70, 1.70 1.72, 1.75, 1.77		
1.60-1.69	1.68	1.60	1.60	1.60, 1.65, 1.65 1.65, 1.67, 1.67	1.65, 1.67, 1.67		1.60, 1.60			
1.50-1.59	1.55	1.50, 1.50, 1.55	1.53, 1.54, 1.58	1.50, 1.55	1.50		1.50, 1.59		1.50, 1.50	1.50, 1.50
1.40-1.49	1.43, 1.46	1.44, 1.49	1.40, 1.44, 1.47	1.44, 1.44, 1.45 1.47, 1.48		1.45	1.40, 1.40, 1.40 1.40	1.43, 1.45	1.40, 1.41, 1.48	
1.30-1.39	1.33	1.37	1.38	1.30, 1.35, 1.38	1.35		1.30, 1.30, 1.34	1.35, 1.39	1.30, 1.31	1.35
1.20-1.29	1.20, 1.22	1.23, 1.23, 1.25 1.27	1.20, 1.20, 1.28 1.29	1.20, 1.24, 1.26 1.29	1.20, 1.24, 1.25 1.25, 1.26		1.20, 1.21, 1.24	1.22,	1.24, 1.26	1.25, 1.29
1.10-1.19	1.15, 1.16, 1.18 1.18	1.13, 1.19	1.01, 1.05, 1.07 1.07, 1.08	1.12, 1.14, 1.15 1.19	1.13	1.10, 1.11, 1.17	1.10	1.17, 1.17, 1.18 1.18	1.17, 1.17, 1.18	1.15
1.00-1.09	1.00, 1.00, 1.07	1.00, 1.01, 1.03 1.04, 1.04		1.00, 1.02, 1.03 1.05, 1.09	1.00, 1.03	1.03, 1.04, 1.08	1.00, 1.07	1.02	1.00, 1.04, 1.06	1.00, 1.05
.90-.99	.93	.91		.90, .91, .91, .93 .93, .94, .94, .96 .98, .99, .99	.90, .90, .92	.90, .99	.95, .95	.90	.97	
.80-.89	.81, .81	.86, .88, .89	.83	.80, .80, .83, .84 .85, .86, .87, .88	.80, .85, .86		.83	.82	.86	
.70-.79	.70, .78	.70, .74	.70	.70, .71, .71, .74 .78	.72, .75, .76, .77			.75	.70, .74, .77	.70
.60-.69	.64, .67, .69	.65		.65	.64, .65, .67	.63	.60	.68	.63, .65	
.50-.59	.50, .58		.59	.51, .52, .54					.56	
.40-.49	.40		.44	.42				.45	.44	
.30-.39	.37, .38	.39	.35							
.20-.29							.20			
.10-.19										
YEARS OF RECORD	35	36	34	84	36	12	29	25	32	11

The second page of Table I shows three values above 4.40 inches. The highest amount at Hoyt was 5.33 inches; at Joes it was 5.30 inches; and at Seibert it was 4.84 inches.

Since there were only two summers with valid measurements of precipitation at Thurman 3 ENE, and since it is comparatively near to the station at Shaw 2 E the data from the two sites were combined to present an array of some 25 values.

IV. RATES OF FALL DERIVED FROM HOURLY PRECIPITATION RECORDS

The more detailed records furnished by the recording rain gages permit the examination of rates of fall. An initial request was made to the Colorado Climate Center in Fort Collins for the detailed hourly records for all days during June, July, or August when the 24 hours ending at midnight equaled or exceeded 2.00 inches. The response to that request is presented in the two pages of tabular data found in APPENDIX A. Note that whenever an amount is directly followed by the letter A, that amount has been accumulated over a period of two hours or more. When the letter I follows the 24 hour total amount there has been some period of the day when the record is less than complete (incomplete).

The sets of data presented in Table II have been extracted from the more complete data in APPENDIX A. Within Table II only the two-hour periods that produced a combined total of 2.00 inches or more have been included. The resultant total from those two peak hours is easily compared with the full total for all 24 hours ending at midnight in the two columns near the right edge of Table II. In nearly all instances the peak two-hour amounts contribute a very high fraction of the full 24-hour amount. On July 19, 1973 the data from the stations at Joes and Seibert show the existence of a broad general storm area within which comparatively heavy thunderstorms were imbedded. Note that most of the two-hour periods that produced two or more inches of precipitation occurred during the afternoon and evening hours.

To illustrate the precipitation intensity patterns of these more intense summer thunderstorms, copies of the original recording charts for 9 different

TABLE II

SUMMARY OF PRECIPITATION EVENTS WHERE 2-HOUR RAINFALL EQUALED OR EXCEEDED 2 INCHES

	06	07	08	09	10	11	NOON 12	13	14	15	16	17	18	19	20	21	22	23	MIDNIGHT 24	HIGHEST 2-HOURS	24-HOUR TOTAL
AKRON 4 E																					
7/26/55														2.19	.05					2.24	2.65
7/26/57											1.05	1.30								2.35	2.62
7/20/80																		2.07	.61	2.68	2.68
7/17/81																		2.83	.71	3.54	3.54
BYERS 5 ENE																					
6/30/62								1.18	.88											2.06	2.21
7/21/74														2.10	.10					2.20	2.40
DEER TRAIL																					
7/31/61													2.10	.15						2.05	2.30
6/15/65													.60	1.44						2.04	2.64
HUGO																					
7/16/58												.50	1.82							2.32	2.63
6/09/60											1.34	.85								2.19	2.23
7/23/65																.97	1.35			2.32	2.39
JOES																					
6/14/55																2.21	.49			2.70	3.05
7/19/73			1.17	.85																2.02	5.27
SIEBERT																					
6/17/58													1.51	1.23						2.74	2.78
8/03/63													1.85	.45						2.10	3.53
7/19/73	.38	1.90			1.87	.17													(4 hrs)	4.32	4.84
7/20/77																		1.70	.30	2.00	2.00
SHAW 2 E																					
8/19/53										2.35	.55									2.90	3.19
SIMLA																					
7/09/57										.97	2.81									3.78	3.84
7/15/59									1.96	.04										2.00	2.05
7/20/77														.15	1.99					2.14	2.64

days at five stations were obtained from the National Climatic Data Center in Asheville, North Carolina. Copies of all nine chart are presented in APPENDIX B. The chart from Akron 4 E for July 20-21 has been used as an example and is shown in Figure 3.

The record of heavy rainfall shown in Figure 3 shows over two inches of rainfall during the last 30 minutes of the hour ending at 11 P.M. MST. The chart was using Daylight Saving Time at that time. There was a much slower rate of fall for the entire hour ending at midnight, (1 A.M. MDT). Similar patterns are shown in each of the several charts included in APPENDIX B. There were two cases when the total fall within four sequential 15-minute periods reached approximately three inches. One of these occurred at Akron 4 E on July 17, 1981. The other occurred at Simla on July 9, 1957.

V. PRECIPITATION DATA FROM UNITED STATES GEOLOGICAL SURVEY SMALL PLOT STUDIES

Within the period from 1972 through 1984 the USGS has conducted, both on their own and in cooperation with other governmental agencies, several field study projects to gain additional information on rainfall-runoff relationships in eastern Colorado. The data sets used in this report have been checked for validity by the project scientists involved, but summary reports have not yet been published by the USGS. Segments of two separate studies have been included in APPENDIX C:

RAINFALL-RUNOFF DATA FROM SMALL WATERSHEDS IN COLORADO
by COCHRAN, MINGES, JARRET, & VEENHUIS

USE OF RAINFALL-SIMULATOR DATA IN PRECIPITATION-RUNOFF MODELING STUDIES
by LUSBY & LICHTY

The results from those two separate studies have been reviewed as a part of this study. Primary concern was given to those instances in which the peak 5-minute rainfall accumulation was greater than .20 inch. As an example, the results of the highest case are presented in Table III. The location of this

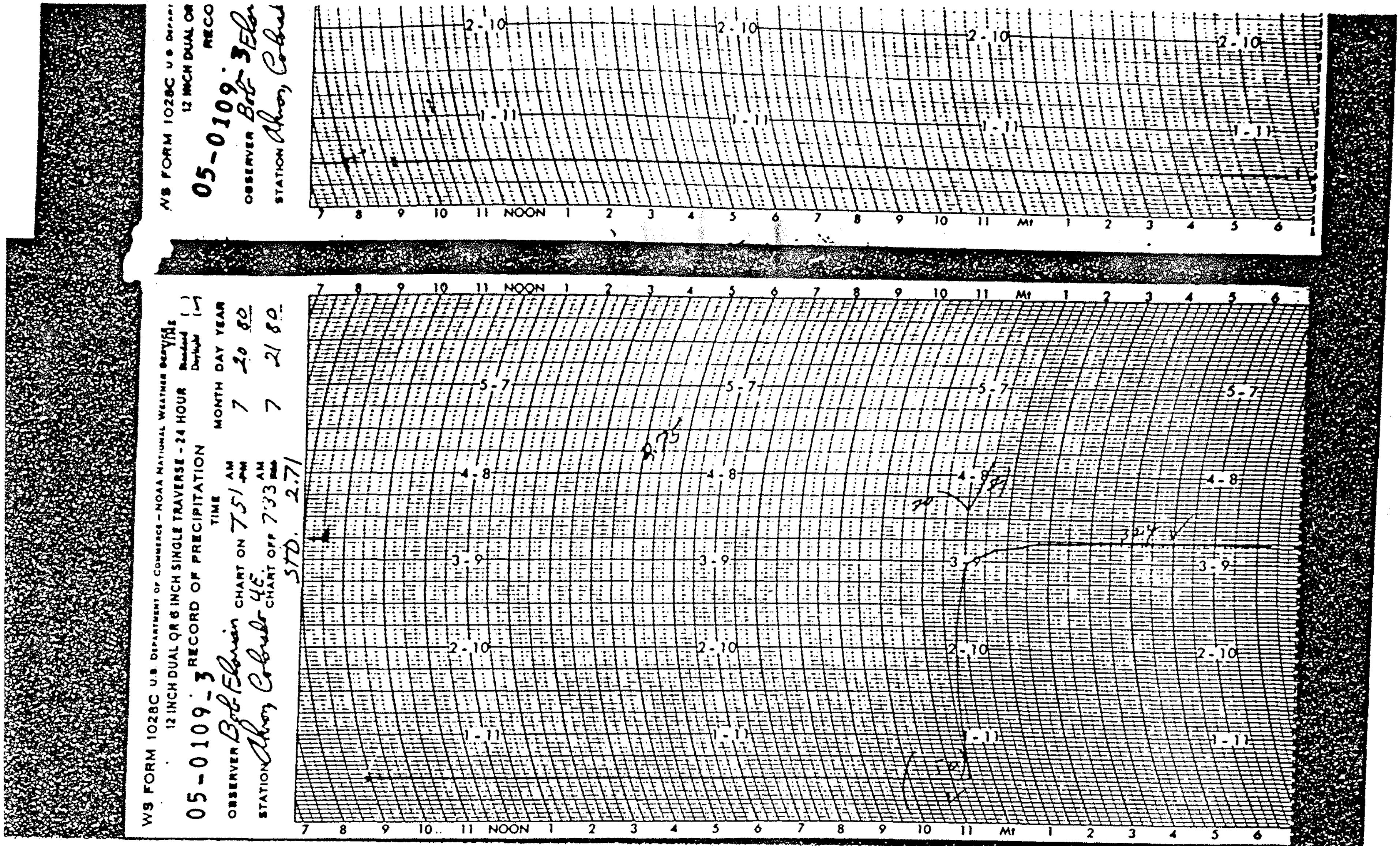

Figure 3. Example of the "typical" pattern presented on recording chart paper used in a recording type precipitation gage during a heavy summer thunderstorm at Akron 4 E.

TABLE III

EXAMPLE OF 5-MINUTE INTERVAL RAINFALL AMOUNTS AS RECORDED IN ONE CASE WITHIN THE USGS SMALL PLOT STUDIES. FOR OTHERS SEE APPENDIX D.

RAINFALL, IN INCHES, JULY 23, 1972
Station #06821300 Near Shaw, Colorado

DATE	TIME	INTERVAL DEPTH	ACCUMULATED DEPTH	DAILY TOTAL	MIDNIGHT DIAL
07-23	1400				5.36 (first reading on tape)
07-23	1655	0.12	0.12		
07-23	1700	0.64	0.76		
07-23	1705	0.37	1.13		
07-23	1710	0.11	1.24		
07-23	1715	0.01	1.25		

STORM TOTAL = 1.25

DURATION	5-MIN	15-MIN	30-MIN	1-HR	3-HR	6-HR	12-HR
TIME	1655	1650	1645	1615			
DEPTH	0.64	1.13	1.25	1.25			
INTENSITY	7.68	4.52	2.50	1.25			

study area, near Shaw, Colorado, is identified as rainfall-runoff station 06821300 on the locator map shown on page 3 of APPENDIX C. The peak 5-minute accumulation of rainfall was .64 inch. When multiplied by 12 this would produce an intensity level 7.68 inches per hour. The peak discharge from this 5.72 mi^2 watershed area occurred some 20 minutes later. Nine of the 11 cases with 5-minute rainfall accumulations above .20 inch came from four locations within 55 miles of the Project Site as a part of the first USGS study listed above. The other two cases occurred at the single location of the second USGS study area located near Deer Trail.

The locations of the eleven 5-minute rainfall accumulation amounts of more than .20 within the USGS small plot studies are shown in Figure 4. At three locations the highest value has been multiplied by 12 to show the peak intensity rate. To illustrate the comparative relationship of all eleven intensity rates at both the 5-minute and the 30-minute time periods the full set of eleven values has been plotted on the "Site Rainfall Intensity-Duration-Frequency Curve" for a 100-year storm at the Project Site which is part of ATTACHMENT LF-3 of the CDH permit. This plot is presented here as Figure 5. As can be seen the plotted annual measurements fall well within the envelop defined by the 100-year storm curve.

VI. HISTORICAL STORMS IN EASTERN COLORADO

Most of the better recorded rainfall and/or flood-water measurements which have been made in Colorado since 1910 have been made in northeastern Colorado. In many instances the streamflow values have been estimated rather than measured. In somewhat fewer instances estimates have been made of not only the patterns of rainfall but the peak storm center amounts. Such estimates are directly dependent on the various assumptions made by a particular analyst. In some instances, particularly when there has been severe flood damage, there is a strong tendency for some exaggeration of the amount of rain "that must have fallen". The set of data in Table IV covers Maximum Flood Discharges For South Platte Tributaries for the period 1922 through 1975. Emphasis has been given to three storm periods for which locations and isohyetal patterns are shown on the maps prepared by the U.S.

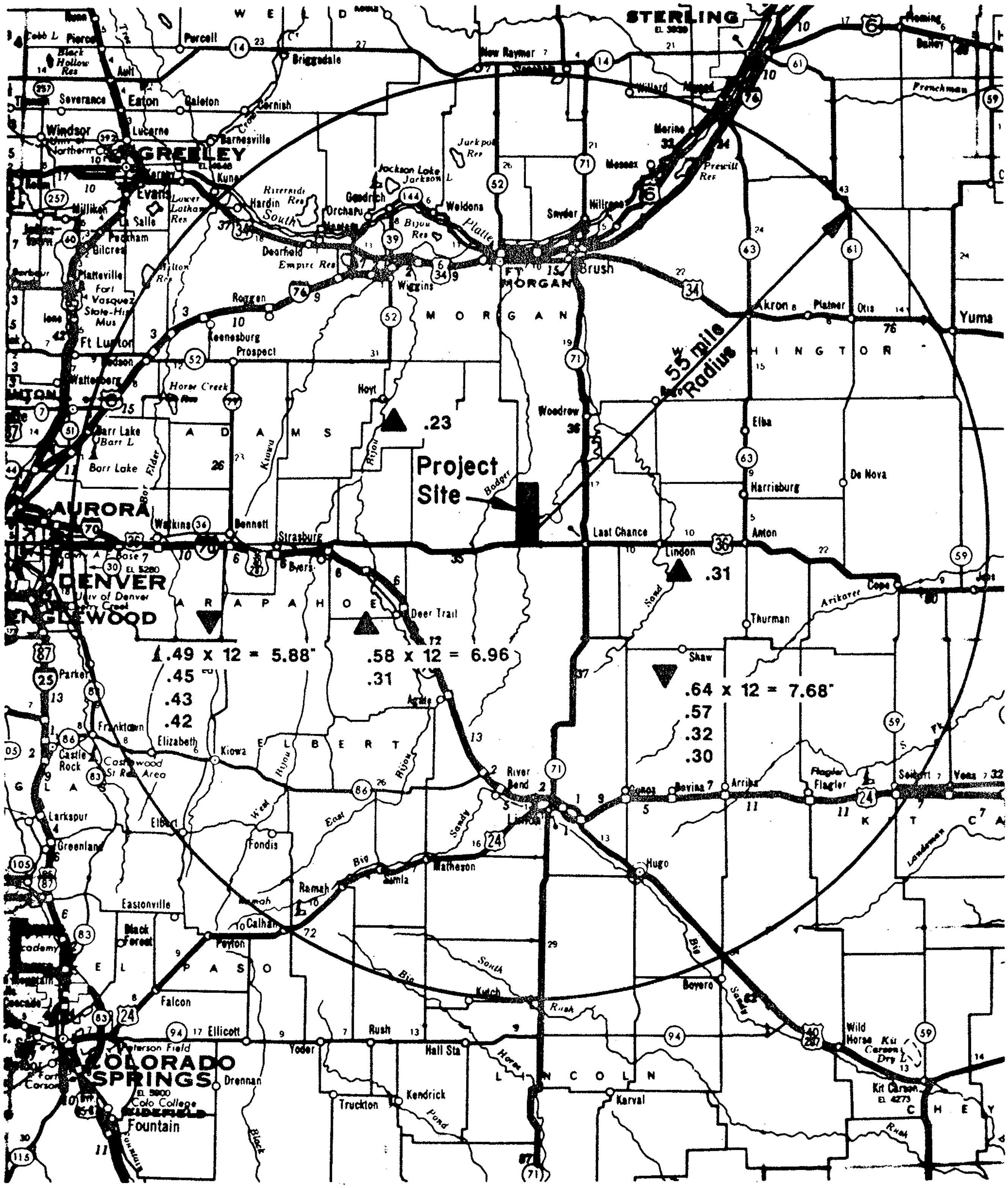

Figure 4 **Peak 5 minute rainfall amounts in USGS small plot studies when 5 minute total was above .20 inch**

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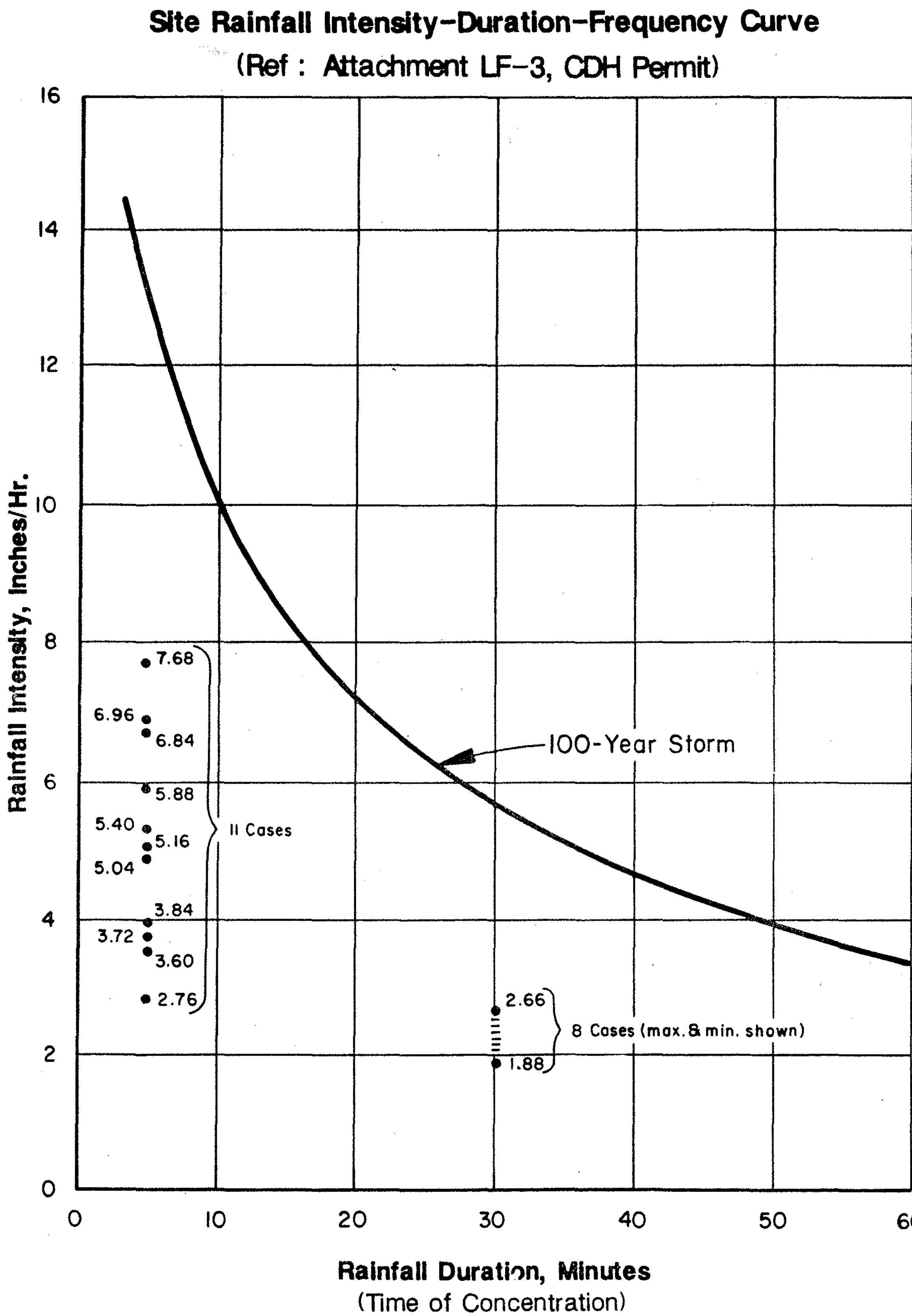

Figure 5

Ranges of measured 5 minute and 30 minute rainfall accumulations within the 11 cases contained in USGS small plot studies within 55 miles of BFI Site. See locations in figure 4

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Table IV.

Maximum Flood Discharges For South Platte River Tributaries

Index	Stream and Location	Date	DA* (sq.mi.)	Q (c.f.s.)	Q/DA (cfs per sq.mi.)
	PLAINS TRIBUTARIES				
1	Bayou Gulch near Mouth	1922	(19)	8,670	456
2	Cherry Cr, Sec 4, T6S, R66W	1922	(87)	17,000	195
3	Cherry Cr Above Castlewood Dam	1933	(100)	35,000	350
4	Kiowa Cr near Elbert	1935	(60)	43,500	725
5	Kiowa Cr, Sec 21, T6S, R63W	1935	(190)	110,000	579
6	Kiowa Cr at Bennett	1935	(266)	75,300	283
7	West Bijou Cr, Sec 13, T8S, R62W	1935	(118)	34,250	290
8	West Bijou Cr near Peoria	1935	(187)	44,400	237
9	Middle Bijou Cr, Sec 26, T7S, R60W	1935	(151)	71,720	472
10	Middle Bijou Cr, Sec 28, T4S, R60W	1935	(230)	143,640	625
11	Toll Gate Cr at 6th Ave	1959	35.8	10,400	291
12	Sand Cr North of Stapleton Airport	1959	175	25,500	146
13	Russellville Gulch near Frankton	1961	16.9	2,900	172
14	Black Wolf Cr 13 miles South of Wray	1962	(25)	17,800	712
15	McIntyre Gulch at Denver Federal Center	1963	3.22	968	301
16	Newlin Cr near Parker	1963	13.6	7,620	560
17	Trib to Cottonwood Cr near Parker	1963	0.65	223	343
18	Cottonwood Cr near Parker	1963	7.81	3,330	426
19	Lone Tree Cr near Parker	1963	1.38	930	674
20	East Plum Cr Above West Plum Cr	1965	(108)	126,000	1,167
21	Piney Cr near Melvin	1965	(21.9)	14,100	644
22	Sand Cr at Sable Ave	1965	113	13,400	119
23	Toll Gate Below East and West Toll Gate	1965	(35.8)	16,000	447
24	Sand Cr Below Toll Gate	1965	187	18,900	101
25	Kiowa Cr sub-watershed near Eastonville	1965	(1.12)	2,600	2,321
26	Kiowa Cr sub-watershed near Elbert	1965	(2.82)	2,010	713
27	Kiowa Cr near Bennett	1965	236	24,900	106
28	East Bijou Cr at Deer Trail	1965	(302)	274,000	907
29	Middle Bijou Cr near Deer Trail	1965	(190)	145,000	763
30	West Bijou Cr near Kiowa	1965	(85.7)	67,200	784
31	Bijou Cr near Wiggins	1965	1,314	466,000	355
32	Cherry Cr at Cherry Cr Reservoir	1965	(146)	58,000	397
33	Plum Cr near Louviers	1965	302	154,000	510
34	Kennedy Drive Drain at Northglenn	1968	0.1	85	850
35	Sand Cr Trib near Landon	1969	3.85	1,540	400
36	Kiowa Cr Trib near Bennett	1970	6.41	2,170	339
37	Middle Bijou Cr Trib near Deer Trail	1970	2.27	465	205
38	Darby Cr near Buchanan	1971	7.39	1,740	235
39	Concourse "D" Drain at Stapleton Airport	1972	0.12	119	992
40	Boulder Cr Trib at Boulder	1972	0.2	152	760
41	Big Dry Cr at Littleton	1973	19	4,400	232
42	Toll Gate Cr Trib at Aurora	1974	0.3	146	487
43	Sand Cr Trib at Denver	1974	0.6	250	417
44	Hillcrest Drain at Northglenn	1975	0.28	107	382
45	Kennedy Drive Drain at Northglenn	1975	0.1	125	1,250

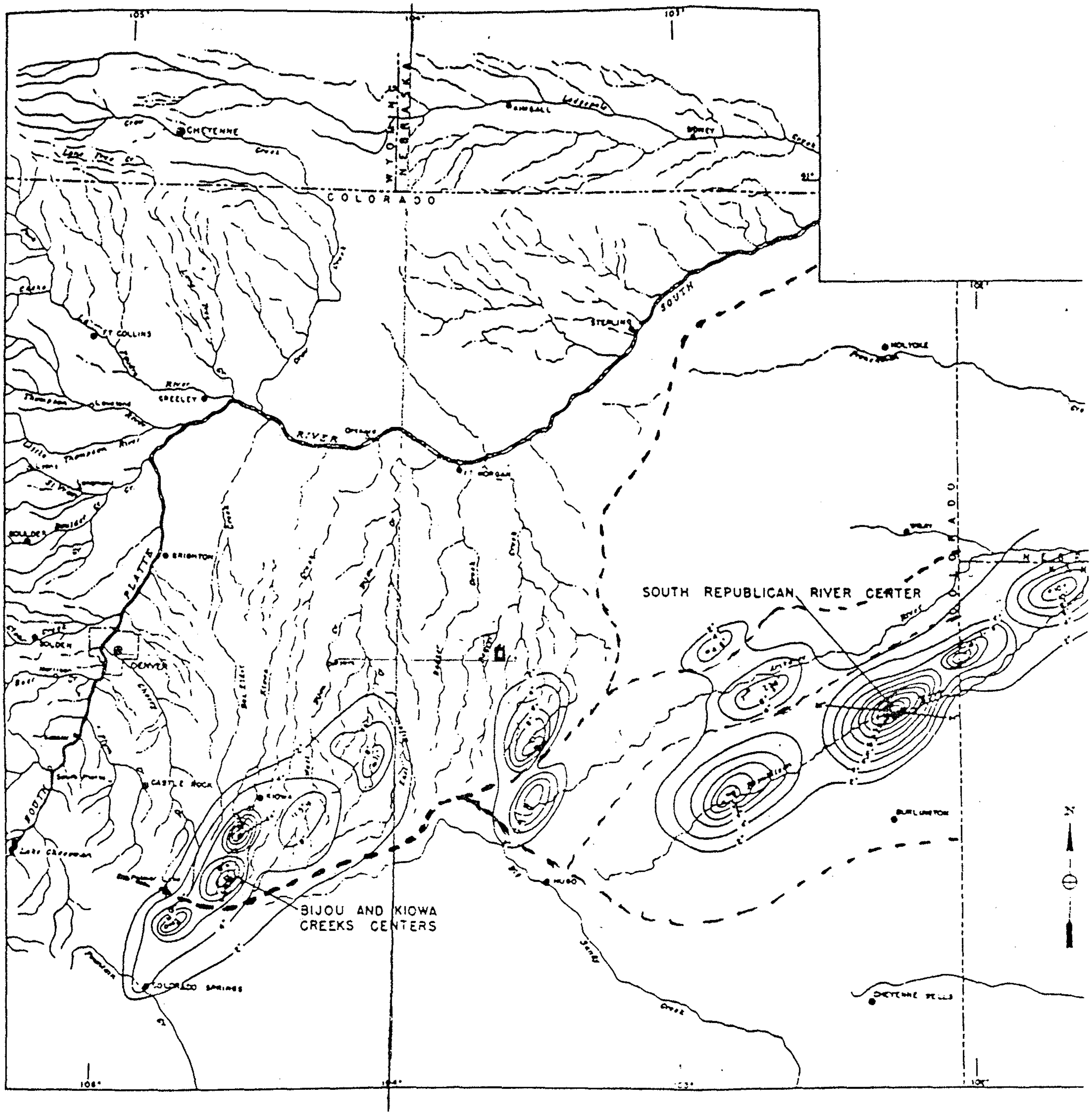
Army Corps of Engineers in 1977. These three maps follow as Figures 6, 7, and 8.

The locations and patterns of the large storm centers add confirmation to the "triggering" influence of the higher terrain along and near the Palmer Ridge to the northeast of Colorado Springs as well as the probable availability of more moisture above the lower terrain near the Kansas border. The elongated patterns along the southwest-to-northeast axis fit the more typical paths of severe thunderstorms in which the tops of the cloud mass reach heights that are stongly influenced by high elevation winds that cause translational movement toward the north or northeast. In each map the Project Site is shown as a small box near the center.

In Figure 6 some dashed lines have been added to show the separation of the various watersheds. The influence of the "triggering" of heavy thunderstorms along and near the Palmer Ridge is probably greatest in the June, 1965 storm. It was in this storm that the highest cfs per square mile value in Table IV is shown. The town of Eastonville, not shown on the map, is about 4 miles north of Falcon, which is shown. The elevation of Eastonville is 7,233 feet above sea level, which is more than 2,300 feet higher than the Project Site. It is important to remember that part of the reason for the somewhat higher precipitaiton amounts along and near the Palmer Ridge derives from the fact that raindrops have a shorter distance to fall between the cloud bases and the ground and, therefore, less chance to evaporate.

All three maps show some decrease in storm intensity with northward progression toward the lower broad valley along the Platte River.

As a follow-on to the large storm center indicated as "SOUTH REPUBLICAN RIVER CENTER" in Figure 6, the same storm was also listed in the HYDROMETEOROLOGICAL REPORT NO. 51 (HRM 51). In that report an estimate was made to indicate that the storm might have been increased by 22% if the moisture of the air when the storm actually happened were to be adjusted upward to the maximum moisture that can be delivered at some possible time in the future. APPENDIX D shows the title page of that report, and the resultant estimated precipitation amounts for various time periods.



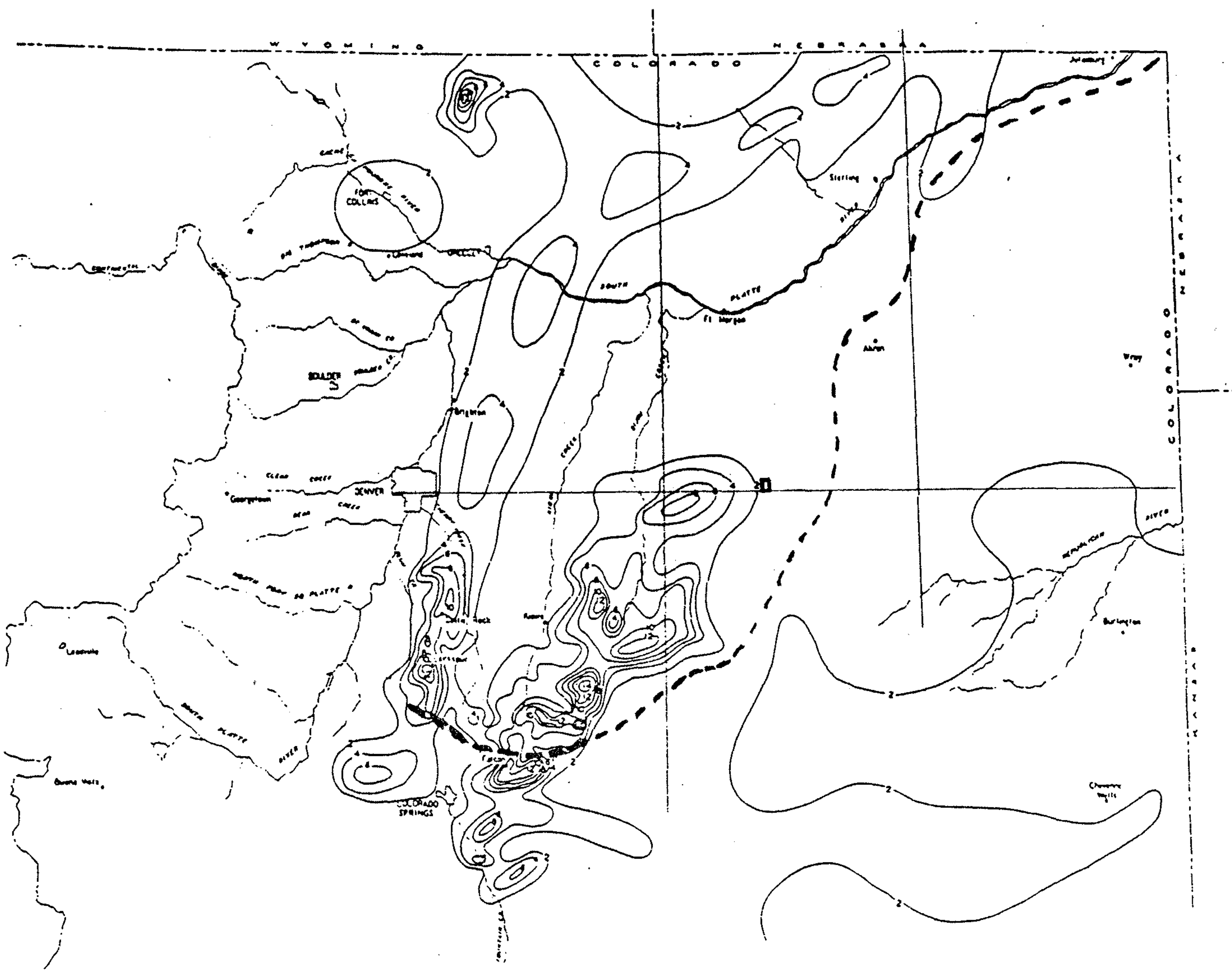
Isohyetal Map for Total Storms

May 1935 Storm
Bijou & Kiowa Centers
(12 hours ending 6p.m. May 30, 1935)
South Republican River Center
(12 hours ending 3a.m. May 31, 1935)

Source :
U.S. Army Engineer District : Omaha
Corps of Engineers Omaha, Nebraska/Sept. 1977

Figure 6

HIGHWAY 36 LAND DEVELOPMENT Co.
HAZARDOUS WASTE TREATMENT,
STORAGE & DISPOSAL FACILITY
BROWNING-FERRIS INDUSTRIES



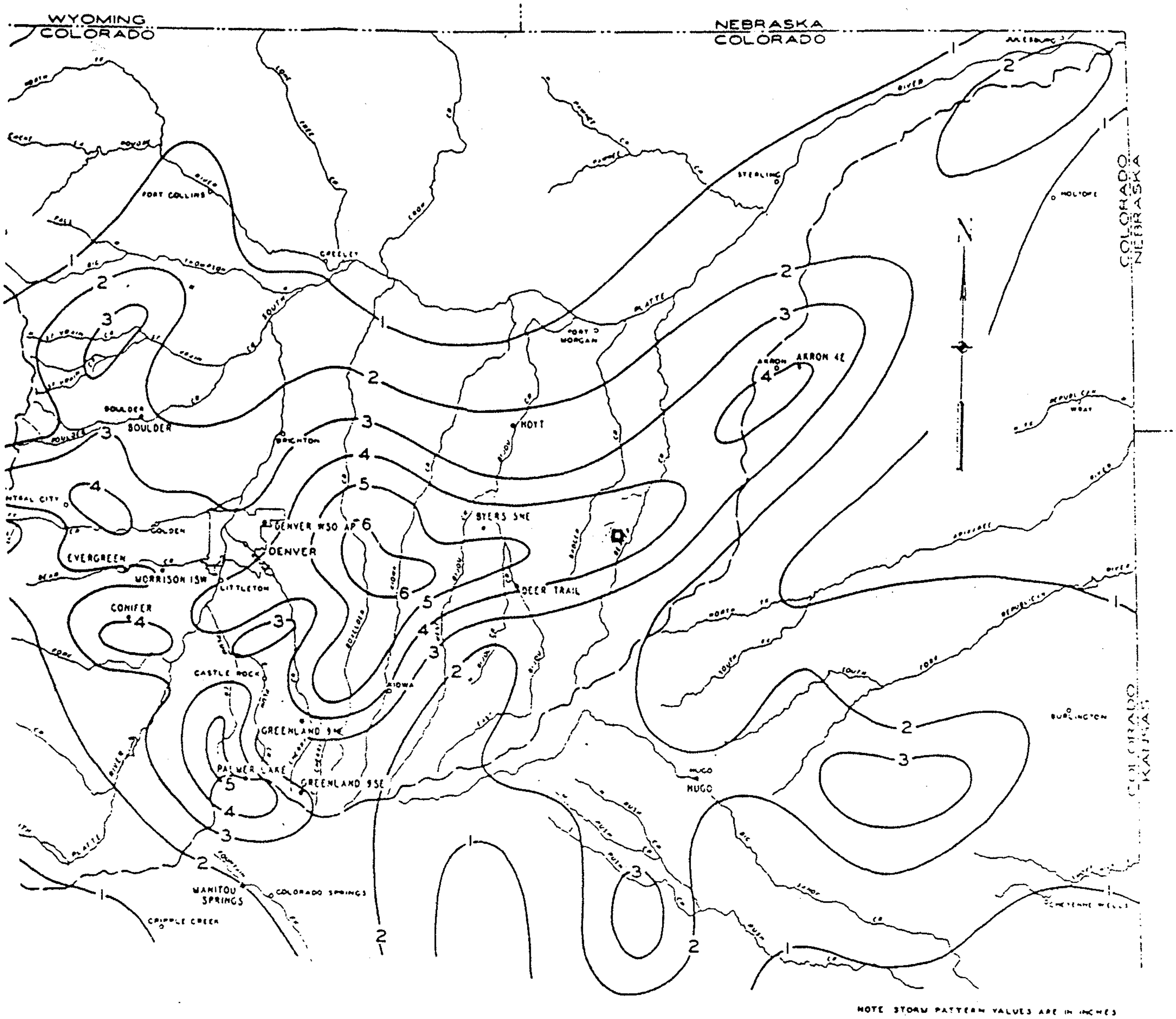
Isohyetal Map for Storm
15th. & 17th. June 1965

Source : **U.S. Army Engineer District : Omaha**
Corps of Engineers Omaha, Nebraska/Sept. 1977

Figure 7

HIGHWAY 36 LAND DEVELOPMENT Co.
HAZARDOUS WASTE TREATMENT,
STORAGE & DISPOSAL FACILITY

BROWNING-FERRIS INDUSTRIES



Isohyetal Map for Storm

5th. & 6th. May 1973

Source : **U.S. Army Engineer District : Omaha**
Corps of Engineers Omaha, Nebraska/Sept. 1977

Figure 8

HIGHWAY 36 LAND DEVELOPMENT Co.
HAZARDOUS WASTE TREATMENT,
STORAGE & DISPOSAL FACILITY

BROWNING-FERRIS INDUSTRIES

Since the first two hours of heavy summer thunderstorms in eastern Colorado are likely to produce the highest fraction of runoff per unit time this investigator has made a rough estimate that 11.6 of the 16.5 inches might have fallen within the first two hours.

In HRM 51 considerable attention was given to high precipitation estimates. Figure 9 of that report, which is reproduced in Appendix D, contains useful information across the entire country regarding the GREATEST 24-HR STATION PRECIPITATION WITHIN EACH STATE CLIMATIC DIVISION. It is the investigator's opinion that, due to one 24-hr amount in eastern Montana of 11.5 inches the authors of HRM 51 chose to move several of the lines farther to the northwest than is warranted by the other data points. I have redrawn three envelopment lines of the greatest 24-hr precipitation within each state climatic division across a large portion of the United States based on what I feel is a more correct interpretation of the data. The measured precipitation peak values within these many climatic divisions fit rather well with the data found within 55 miles of the Project Site in Colorado. The data point labelled 8.0 inches in northeastern Colorado has a geographic location within the foothills of the Rocky Mountains, and would not be representative of the eastern plains area. With 10 to 20 precipitation stations in each climatic division there must have been several thousand station-years of precipitation measurements represented in those divisions reporting PEAK 24-HR AMOUNTS less than 10 inches. It is certainly true that storms could have and did occur at locations where there were no regularly reporting precipitation stations. But the very large geographic areas covered by climatic divisions which have not made peak 24-hr measurements greater than 8 inches clearly speak to the low risk per unit area per limited time period for 24-hr amounts greater than 8 inches.

VII. RAINFALL FREQUENCY ESTIMATES

A tabulation of the annual peak 24-hour precipitation from 718 station years of record has already been presented in Table I of this report. The one highest reported value at each of the 23 stations, the date of occurence, and the period of record within which that highest amount was recorded are

TABLE V

HIGHEST 24-HOUR PRECIPITATION AMOUNTS DURING THE TIME PERIODS COVERED IN THIS ANALYSIS

STATION	GREATEST 24-HR AMT.	DATE OBSERVED	YEAR	PERIOD COVERED	NUMBER YEARS*
AKRON 4 E	4.00	MAY 6	1973	1948-86	37
AKRON FAA AP	5.50	JUL 26	1981	1937-86	49
ARRIBA	5.10	JUN 9	1946	1914-17 1928-58	33
BOVINA 3 NE	2.95	AUG 12	1947	1944-59	14
BYERS 5 ENE	4.40	MAY 5-6	1973	1920-22 1931-86	58
COPE	7.00	AUG 10	1930	1925-42	18
DEER TRAIL	4.12	MAY 5-6	1973	1949-86	32
FLAGLER 2 NW	3.65	SEP 21	1963	1920-27 1950-86	37
FORT MORGAN	4.60	JUL 31	1956	1914-86	69
GENOA 1 W	2.50	JUN 7	1969	1941-82	36
HOYT	5.33	JUL 31	1916	1915-22 1948-86	35
HUGO	2.42	JUL 16	1958	1949-86	36
JOES	5.30	JUL 19-20	1973	1949-86	34
LIMON	2.82	MAY 26	1967	1948-68	17
LIMON 10 SSW	3.72	AUG 19	1965	1914-70	52
LIMON WSMO	2.27	JUL 25	1977	1971-86	15
PARKER 6 E	3.60	MAY 6	1973	1951-86	36
PEVERLY RANCH	2.88	AUG 23	1946	1944-55	12
SEIBERT	4.84	JUL 19	1973	1951-86	29
SHAW 2 E	3.19	AUG 19	1953	1949-86	23
SIMLA	3.84	JUL 9	1957	1950-86	32
SIMPSON	2.15	JUL 17	1924	1916-29	11
THURMAN 3 ENE	3.21	JUL 27	1950	1950-52	2

* Missing data forced the omission of some year's peak precipitation

presented in Table V. However, that single peak value at each station does not yield much information on frequency.

The full sets of annual peak 24-hour precipitation amounts at each station do lend themselves to curve fitting as well as comparative information from one station to another. Initial plots on normal probability paper showed that the data did not fall in a straight line. The procedures for fitting a curve to the data were discussed with experienced hydrologists and consulting meteorologists familiar with precipitation data and frequency analysis. It was determined that an acceptable approach would be to find a procedure which yielded curves that consistently and reasonably matched the data and indicated the "skewedness" in all data sets.

Although some variation would be expected between the precipitation measurements made at the three stations that have recorded data within 10 miles of Limon, that variation might be expected to be small. By combining the three sets, a combined set of 84 values is available to try for a reasonable fit. The results are shown in Figure 9. The first line drawn was the straight line from the 10th percentile point along the bottom scale through the median (the 50th percentile point) and continuing on to the right in a straight line to the 90th percentile value. Such a line shows the abnormality - or "skewdness" that is indicated by the middle 80% of the data set (10 through 90). It is quite obvious that the plotted values are moving away and upward to the right of the median value, as compared with a NORMAL distribution - in which all points would have continued on or very near to a straight line.

The final adjustments <u>away from</u> normal distribution are illustrated in Figure 10. By returning to Figure 9 and by referring to Table VI to see the results applied to the 84 values from the three combined Limon stations the following steps were taken:

- Step 1 Find the median (50th percentile point).
- Step 2 Find the increment between the 50th and 84th points.
- Step 3 Multiply that increment by 4.
- Step 4 Add amount from step 3 to the median and plot on the 99th (1/100) percentile point.

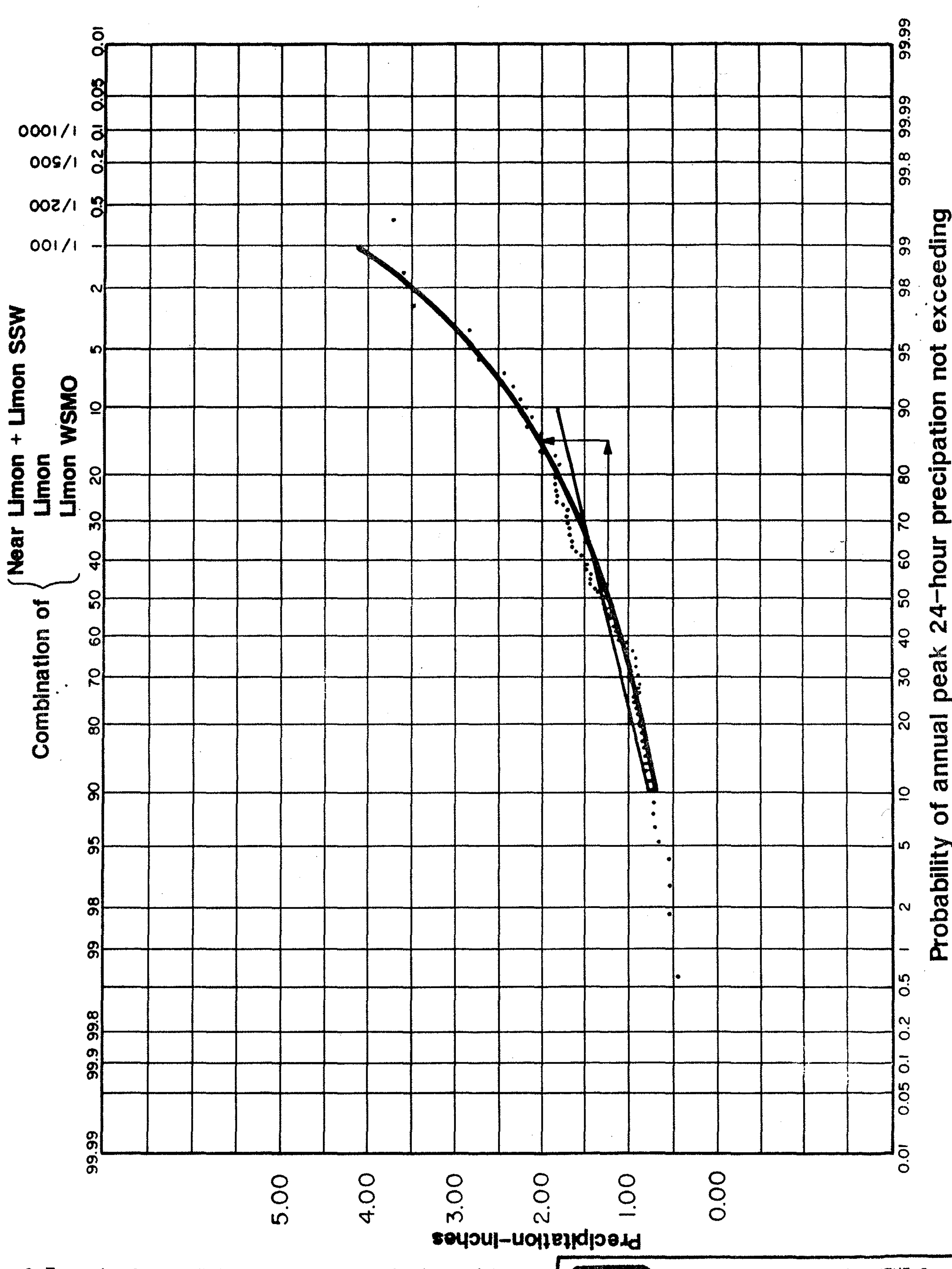


Figure 9 **Example of curve fitting through the combined set of 84 station years of record of the annual peak24-hour precipitation amounts measured at the three stations at or near Limon**

HIGHWAY 36 LAND DEVELOPMENT Co.
HAZARDOUS WASTE TREATMENT,
STORAGE & DISPOSAL FACILITY

BROWNING-FERRIS INDUSTRIES

From: "…OBABILITY AND STATISTICS" by MOSTELLER, ROURKE & …OMAS - Addison-Wesley Publishing Company, Inc.

(d) extends without limit to the left and to the right, and approaches the x-axis very rapidly as we move away from $x = 0$ in either direction.

We shall accept on faith a further property of the normal curve that can be proved by advanced calculus:

(e) the total area under the curve and above the x-axis equals 1.

Property (e) corresponds to the fact that 1 is the probability that the standard normal random variable X takes a value between $-\infty$ and $+\infty$. Properties (a) and (e) imply that the area below the curve and to the left of the y-axis is $\frac{1}{2}$, and so is the area to the right of the y-axis.

How do we use the normal probability distribution? The definition tells us what probabilities are to be assigned to the standard normal random variable. For example, the probability that X takes a value in the interval from $x = a$ to $x = b$ is equal to the measure of the area bounded by the normal curve, the x-axis, and the vertical lines $x = a$ and $x = b$ as indicated by the shaded region in Fig. 6–11.

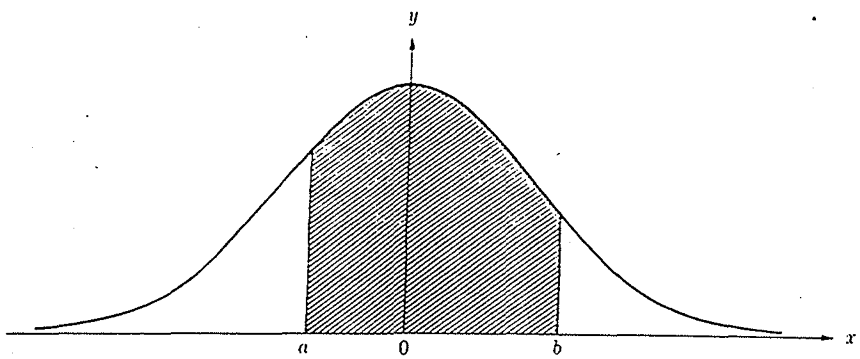


FIG. 6–11. $P(a \leq X \leq b)$ = area of shaded region.

How do we determine the measures of such areas? Recall that the total area under the normal curve is 1. Partial areas of the type shown in Fig. 6–11 can be approximated by rectangles. However, in practice we shall use Table 6–8 (which gives areas from 0 to x at intervals of 0.1, where $0 \leq x \leq 4.0$) or the larger Table III at the back of the book.

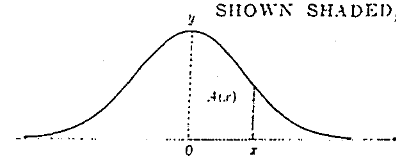
The following examples show how Table 6–8 is used to find probabilities.

EXAMPLE 1. What is the probability that a standard normal random variable takes a value between 0 and 1?

Solution. $P(0 < X < 1) = A(1) = 0.3413$. About 34% of the total probability is between 0 and 1 and, by symmetry, about 68% is between -1 and $+1$.

TABLE 6–8

AREA UNDER THE STANDARD NORMAL CURVE FROM 0 TO x, SHOWN SHADED, IS $A(x)$.



$$y = \frac{1}{\sqrt{2\pi}} e^{-x^2/2}$$

x	Area, $A(x)$	x	Area, $A(x)$
0.0	.0000	2.1	.4821
0.1	.0398	2.2	.4861
0.2	.0793	2.3	.4893
0.3	.1179	2.4	.4918
0.4	.1554	2.5	.4938
0.5	.1915	2.6	.4953
0.6	.2257	2.7	.4965
0.7	.2580	2.8	.4974
0.8	.2881	2.9	.4981
0.9	.3159	3.0	.4987
1.0	.3413	3.1	.4990
1.1	.3643	3.2	.4993
1.2	.3849	3.3	.4995
1.3	.4032	3.4	.4997
1.4	.4192	3.5	.4998
1.5	.4332	3.6	.4998
1.6	.4452	3.7	.4999
1.7	.4554	3.8	.4999
1.8	.4641	3.9	.5000
1.9	.4713	4.0	.5000
2.0	.4772		

Annotations: 50%- MEDIAN- (at 0.0); Approximate Curve Fitting Assumptions; 84% (at 1.0); X 4.0 (at 3.0, "3.0" struck out); x2=99th point in distributive fitted curve; Near

EXAMPLE 2. What is the probability that a standard normal random variable takes a value between -2 and $+2$?

Solution. Since the normal curve is symmetric about the y-axis, the area from -2 to $+2$ is twice the area from 0 to 2:

$$P(-2 < X < 2) = (\text{area from } x = -2 \text{ to } x = +2)$$
$$= 2(\text{area from } x = 0 \text{ to } x = +2)$$
$$= 2A(2)$$
$$= 2(0.4772) = 0.9544.$$

Slightly more than 95% of the total area lies over the interval between -2 and $+2$.

Figure 10. Arbitrary adjustment to "NORMAL" probability distribution to derive a good approximate fit to 20 data sets of annual peak 24-hour precipitation

TABLE VI

APPROXIMATE 24-HOUR PRECIPITATION AMOUNTS AT THE ONCE-IN-100-YEAR LEVEL BASED ON SETS OF HISTORICAL ANNUAL PEAK PRECIPITATION AMOUNTS AT 23 LOCATIONS WITHIN A 55 MILE RADIUS OF THE PROPOSED HIGHWAY 36 WASTE MANAGEMENT FACILITY.

STATION	YEARS OF RECORD	MEDIAN ANNUAL PEAK 24-HR PPT.	.50 TO .84 INCREMENT	INCREMENT TIMES 4	APPROXIMATE 1/100 LEVEL IF 4.40 OR LESS	APPROXIMATE 1/100 LEVEL IF ABOVE 4.40	OUTLIER* AMOUNT GREATER THAN 1/100
AKRON 4 E	38	1.40	.80	3.20		4.60	
AKRON FAA AP	49	1.50	.80	3.20		4.80	5.50
ARRIBA	33	1.14	.76	3.04	4.18		5.10
BOVINA 3 NE	14	1.37	.50	2.00	3.37		
BYERS 5 ENE	58	1.16	.80	3.20	4.36		
COPE	18	1.36	.64	2.56	3.92		7.00
DEER TRAIL	32	1.36	.76	3.04	4.40		
FLAGLER 2 NW	37	1.49	.71	2.84	4.33		
FORT MORGAN	69	1.10	.60	2.40	3.40		4.60
GENOA 1 W	36	1.19	.61	2.44	3.63		
HOYT	35	1.16	.80	3.20	4.36		5.33
HUGO	36	1.26	.75	3.00	4.26		
JOES	34	1.46	.84	3.36		4.82	5.30
LIMON 10 SSW	52						
LIMON	17	1.30	.70	2.80	4.10		
LIMON WSMO	15						
PARKER 6 E	36	1.25	.65	2.60	3.85		
PEVERLY RANCH	12	1.09	.71	2.84	3.93		
SIEBERT	29	1.40	.90	3.60		5.00	
SHAW @ E + THURMAN 3 ENE	25	1.39	.61	2.44	3.83		
SIMLA	32	1.25	.75	3.00	4.25		
SIMPSON	11	1.29	.51	2.04	3.33		

* "An OUTLIER in a set of data is an observation that appears to be inconsistent with the remainder of that set of data" - Singh - HANDBOOK OF APPLIED METEOROLOGY, Chapter 15, 1985

The procedure described above was followed in curve fitting twenty data sets, with the three Limon stations combined and Thurman 3 ENE added to nearby Shaw 2 E. All 20 curves appear in APPENDIX E and follow in order the same sequence as shown in Table VI.

Due to the special concern for any stations that might have a 1/100 rainfall amount that would exceed 4.4 inches (CDH Permit, Part II, Section E.1.a.vii. aa), two different columns were set up in Table VI. At 16 of the 20 locations the 1/100 year amount did not exceed 4.4 inches. In four instances the 1/100 year amount did exceed 4.4 inches, but the highest was not above 5.0 inches.

There were six annual peak 24-hour amounts indentified as outliers. However, within a total sample of 718 values the 7th value from the top would be at the 1/100 level. These outliers, therefore, tend to prove the validity of the statistical approach because they represent events occuring beyond the 1/100 level.

Although there is some variation from one station to another in the 20 curves and the derived 1/100 levels cover a range of values from 3.33 to 5.00 inches it seemed appropriate to this investigator to examine the full set of all data combined. This has been done and the results are presented in Table VII and in Figure 11 and 12. From the full set of 718 values each fifth percentile value was derived. The first column of Table VII can be read in terms of probability at intervals of .05 leading up to 1.00, or they can be treated as percentages of time when the maximum 24-hour annual precipitation will be equal to or less than the amount shown in the second column. Figure 11 presents the data shown in Table VII in graphical form. Note that 5.00 inches is treated as the 99th percentile point, or 1/100. The 7.00-inch outlier has been plotted just below the top line on the graph to permit somewhat higher values for extended periods of time.

The composite data set of 718 values fit the smooth curve shown in Figure 12. Throughout the central portion of the chart there are seven values for each percentile value. Near the ends there are six values beyond the 1st and six values beyond the 99th percentile points. The dashed line beyond the 99th percentile point indicates that the reliability of information derived from

TABLE VII

PROBABILITY OF THE ANNUAL 24-HOUR PEAK RAINFALL AMOUNTS BEING AT OR BELOW THE AMOUNTS INDICATED - BASED ON 718 STATION YEARS OF DATA FROM 23 LOCATIONS WITHIN A 55 MILE RADIUS OF THE PROPOSED HIGHWAY 36 WASTE MANAGEMENT FACILITY

PROBABILITY	PRECIPITATION
1.00 (100 Yr.)	5.00 Inches
.95	3.10
.90	2.44
.85	2.13
.80	1.87
.75	1.77
.70	1.64
.65	1.53
.60	1.44
.55	1.35
.50	1.26
.45	1.21
.40	1.14
.35	1.08
.30	1.01
.25	.95
.20	.88
.15	.80
.10	.71
.05	.60

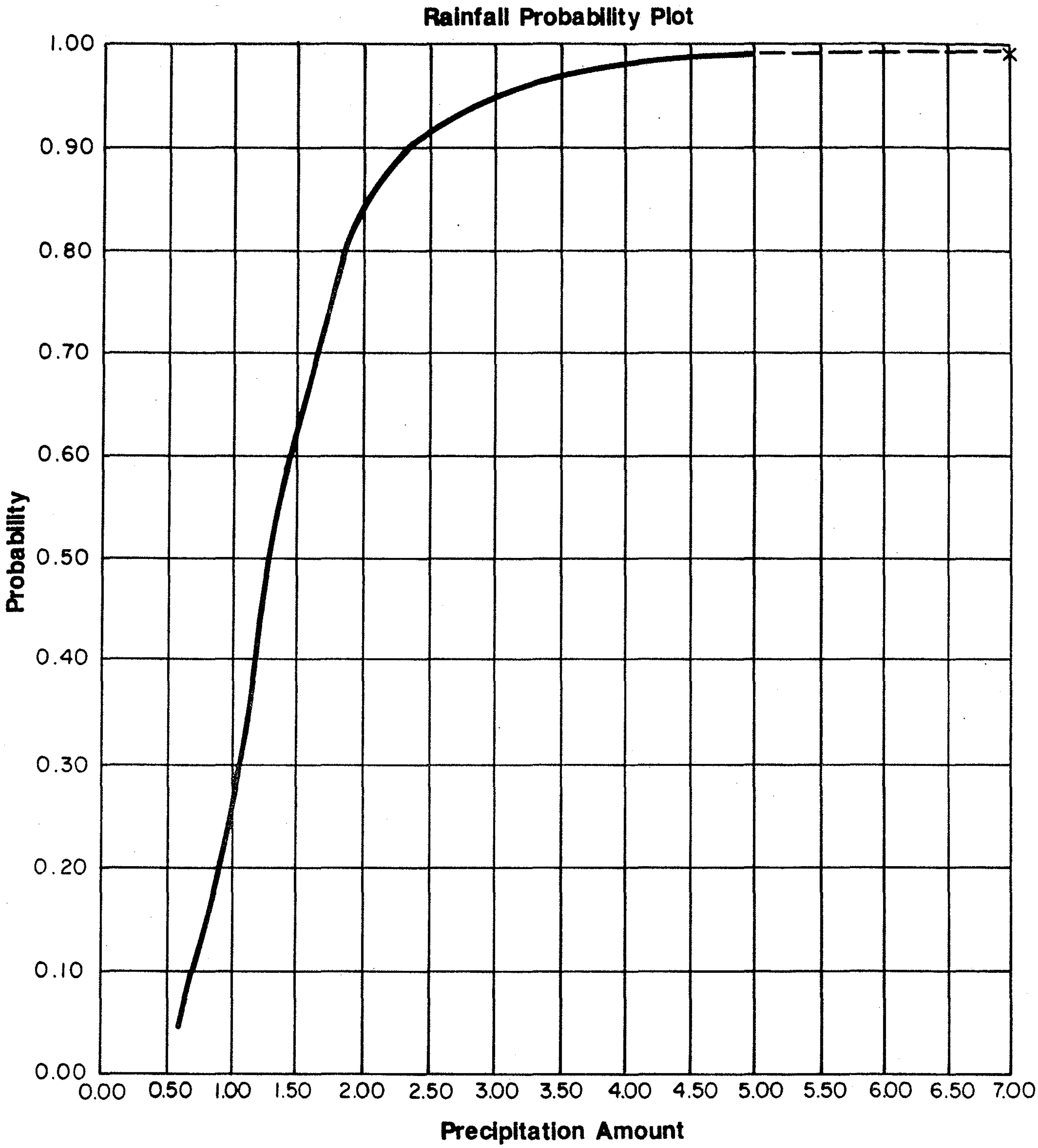


Figure 11 **Probability that 24 hour precipitation will be less than indicated amount**

HIGHWAY 36 LAND DEVELOPMENT Co.
HAZARDOUS WASTE TREATMENT,
STORAGE & DISPOSAL FACILITY

BROWNING-FERRIS INDUSTRIES

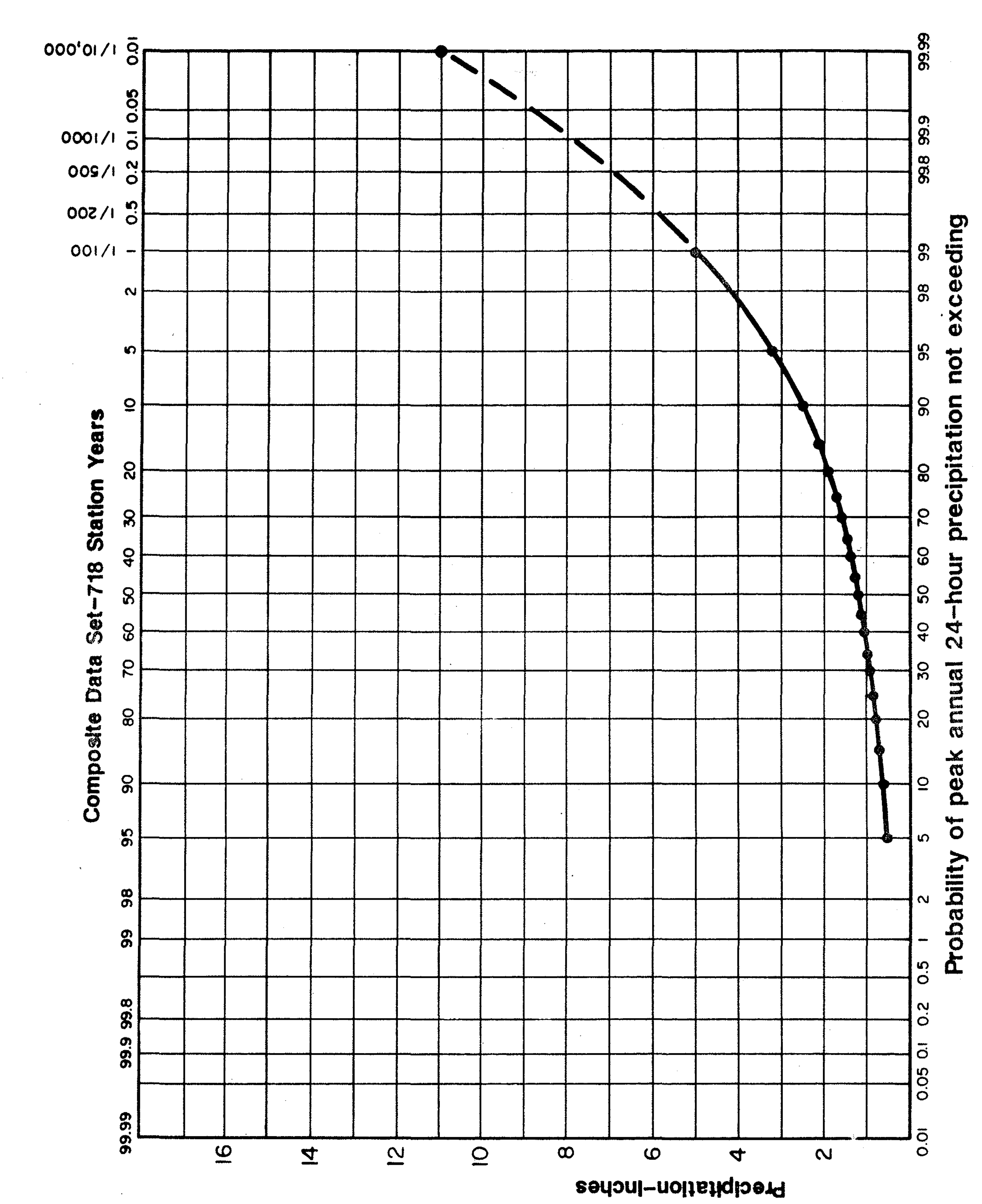


Figure 12 **Fitted frequency curve of annual peak 24-hour precipitation amounts based on the composite of 718 station years of measured data at 23 locations within 55 miles of the Project Site. Data points are shown for every 5th. precintile level and the 99th. precentile level (1/100) within the full set of data**

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STORAGE & DISPOSAL FACILITY

BROWNING-FERRIS INDUSTRIES

this portion of the curve is suspect. Estimation of precipitation values for 1/1000 and 1/10000 years from a data sampling period of less than 100 years is not good statistical practice and results in very unreliable information. The derived estimates for 200 and 500 years should be of greater reliability.

Having prepared the composite curve from the full set of data, I should point out that the values so derived will be conservatively high for the Project Site since a disproportionatly high fraction of the precipitation measurements came from the stations that lie along comparatively higher ground in the southern portion of the 55-mile circle surrounding the Project Site.

VIII. HAIL ESTIMATES

The specific depth of hail in not a routine observation made by meteorological recording stations. The major airport stations throughout the United States prepare monthly summaries of major storms of various kinds in which they identify the type of "stormy" weather such as hail, wind, lightning, tornado, flooding, heavy thunderstorm, etc. They also prepare word descriptions of these storms. In many instances they identify the estimated dollar losses involved. The source of such information may come from unofficial sources such as newspaper articles. In identifying the approximate economic losses involved, the meteorologists who prepare the summaries use the followng categories for loss ranges varying from 1 to 9.

Storm damages are placed in categories ranging from 1 to 9:

1. Less than $50
2. $50 to $500
3. $500 to $5,000
4. $5,000 to $50,000
5. $50,000 to $500,000
6. $500,000 to $5 Million
7. $5 Million to $50 Million
8. $50 Million to $500 Million
9. $500 Million to $5 Billion

The following note is added to these reports:

> Note: This publication contains our best information on storms, but due to the difficulties inherent in collection of this type of data, it is not all inclusive.

It is not unusual to see or hear of instances in which "more than a foot of hail fell at such-and-such a location." Hail does not fall in such amounts so as to uniformly cover the ground to such a depth. The measurement of all hail that falls is included within the precipitation measurements. The observer must wait until the hail melts to be able to measure its water equivalent.

The statements regarding "one or more foot of hail" generally refer to places along water courses where hail collected upstream has accumulated at some obstruction. A typical situation is shown in Figure 13 to illustrate the principle involved. Hail falling on a surface will remain stationary unless the area is subjected to sheet flow or flooding. In such cases, the flowing water will gather and concentrate the hail. The hail will continue to be moved on the flowing water surface until an obstacle such as a hedge row or submerged culvert is encountered. At that point, the hail will become trapped and the water will continue to move through. Figure 13 represents a roadside ditch and culvert situation typical to the project area. In that sample, a 0.25-inch hail fall collecting on the surface of the channel only (ignoring other hail transported from adjacent areas by sheet flow) would result in a 3-inch deep layer of hail at the culvert inlet.

In a study entiled "The Relationships between Hail and Rain in Kansas, Nebraska, and Eastern Colorado", which was done by this investigator in 1968 and 1969, it was found that the most damaging hail, most particularly as related to crop damage, occurred with comparatively small amounts of coincident rain. The title page of that report and a one page segment of that report are presented in APPENDIX F.

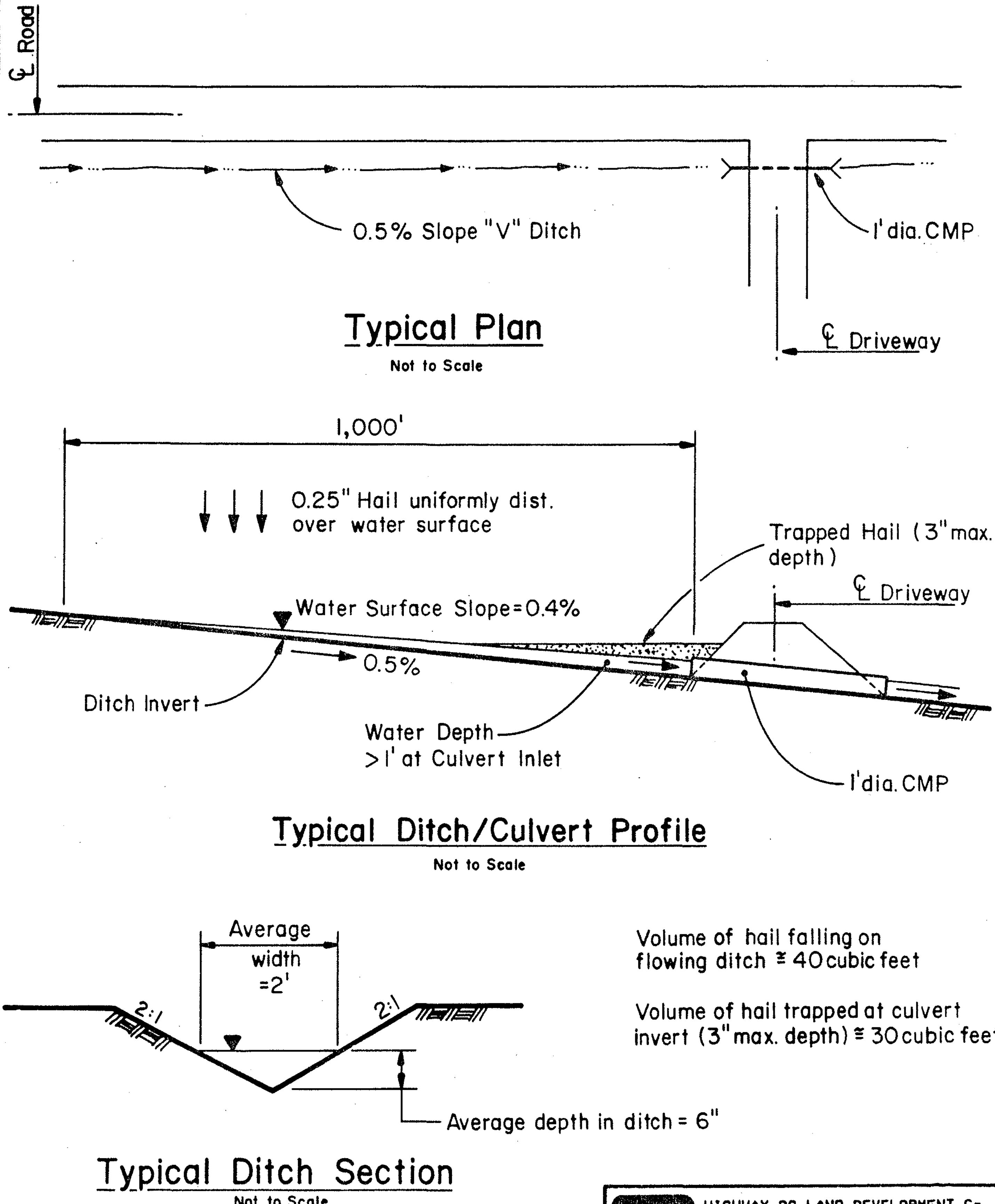

Figure 13 **Schematic of typical hail fall situation**

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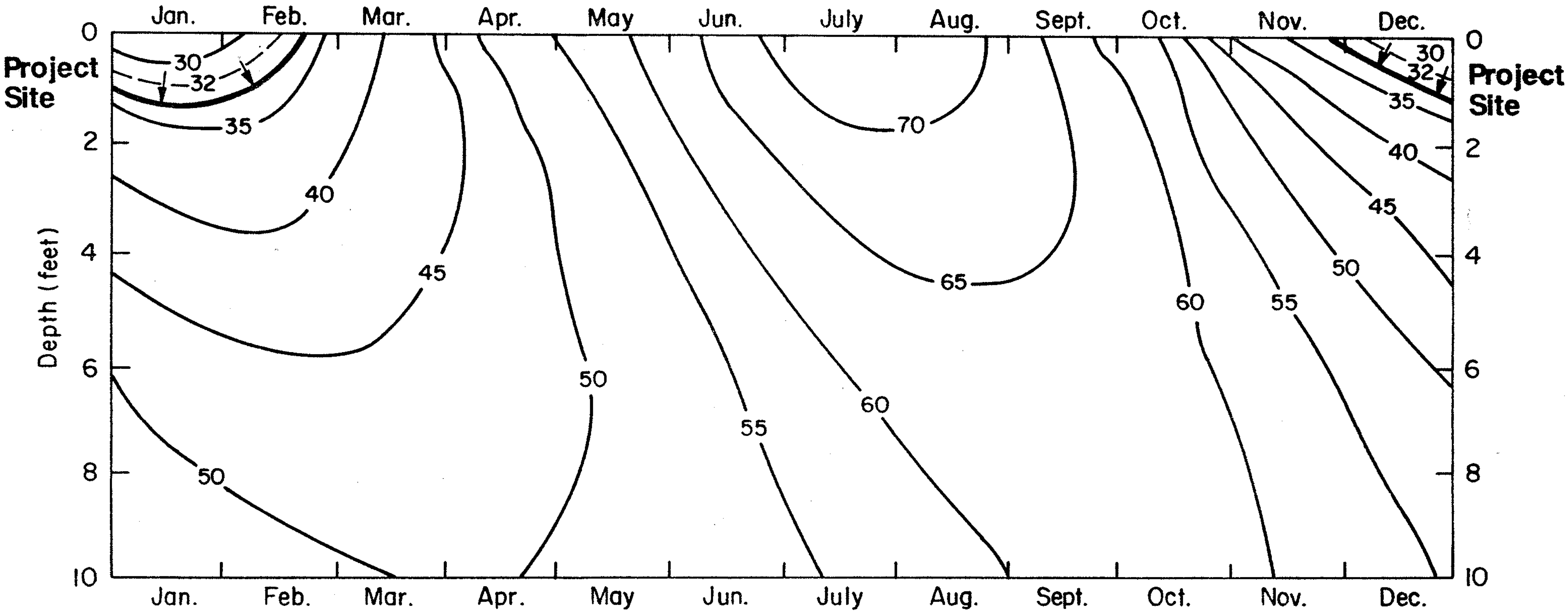
Fort Collins Soil Temperatures (Degrees F°)

Main Campus, Average of 7a.m. and 7p.m. values, 1977–1984



Legend :

Fort Collins Data

Estimated Soil Temperature During Winter for Project Site–See Text

Source : **Colorado Climate Center**
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado

Figure 14 **Estimated mean frost depth at the Project Site based on comparative frost depth measurements made in Fort Collins, Colorado**

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IX. FROST DEPTH

Very few frost depth measurements are made in Colorado. A set of measured data was collected on the Main Campus of the Colorado State University in Fort Collins for a seven year period. Although the material has not been published, the results of that study, and an appropriate adjustment from Fort Collins to the Project Site, are presented in Figure 14.

Comparative air temperatures between Fort Collins and five sites within a radius of 55 miles of the Project site for the three winter months of December through February were used to estimate the expected mean depth of frost at the Project Site. The station with a long record of mean monthly temperatures nearest to the Project site is Byers 5 ENE which had a three-month record of mean temperatures that was the same as at Fort Collins. However, due to a somewhat lower potential for snow cover this investigator is estimating that the mean frost depth would be approximately 6 inches lower at the Project Site that it is at Fort Collins. As a further safety factor for the comparatively colder winter it is recommended that protection to a depth of up to three feet would be on the safe side. As further confirmation, the Denver and Adams County Planning Departments utilize a 36-inch frost depth as a structural design criteria.

X. WIND SPEED ESTIMATES

The mean annual wind speed at the Project Site is estimated near 11 miles per hour. During winter months, the wind speed is expected to reach the low 40s at least once. The maximum wind speed with a 50-year return period interval is estimated at 54 miles per hour.

Reference wind speed statistics include this investigator's participation in the development of the WIND ENERGY RESOURCE ATLAS, SOUTHERN ROCKY MOUNTAIN REGION in 1980. Other reference data on wind recurrence speeds for various time intervals came from the HANDBOOK ON GEOPHYSICS FOR AIR FORCE DESIGNERS published by the United States Air Force.

XI PROBABLE MAXIMUM PRECIPITATION

As quoted in Section II of this report, CDH requires the permittee to estimate the magnitude of a Probable Maximum Precipitation event (PMP). CDH defines the PMP as a 10,000 year event for the purposes of this permit.

An estimate of the magnitude of such an event is presented in Figure 12 subject to the qualification taken in Section VII of this report.

By strict definition, a PMP is the probable maximum precipitation event which could occur assuming a set of optimum but reasonable physical conditions all occuring simultaneously. By this definition, the magnitude of a PMP is calculated based on evaluating physical constraints such as the limiting volume of water that can be held in an atmospheric column and not on performing statistical analyses of historical rainfall events. Since a PMP is a hypothetical event, many of the assumptions used to derive it tend to be subjective.

PMP's, by definition, do not have recurrence intervals associated with them. As an example, Hyrodmeteorological Report No. 55 (HMR 55) purposely did not place any time limit as to when or within what time-period-of-return a projected PMP might be expected.

A PMP cannot be used as a data point to develop an intensity-recurrence curve such as Figure 12 because the recurrence portion of the point's coordinate is not defined.

A PMP is sometimes compared to an event with a recurrence interval predicted by statistical methods. For instance, if a PMP predicts 20 inches of precipitation for a watershed and a statistical analysis predicts a 20-inch event with a recurrence interval of 100,000 years for the same watershed, one could say that the PMP is equivalent to a 100,000 year event. Note that by changing assumptions regarding the physical conditions of a storm, the magnitude of the PMP can be adjusted to be equivalent to any desired recurrence interval. Studies cited below suggest that the equivalent recurrence intervals for the HMR 55 PMP's are substantially larger than 10,000 years.

On page 2 of NOAA Technical Report ERL 388-APCL 41 on the METEOROLOGICAL ASPECTS OF THE BIG THOMPSON FLASH FLOOD OF 31 JULY 1976, a summary diagram appears that show the cumulative rainfall isohyetal lines for the period 31 July - 2 August. There were two areas, one of nearly 15 square miles near Glen Comfort and another of nearly 10 square miles to the southwest of Ted's Place, that experienced total storm amounts of 10 or more inches. That Figure 2 and a superimposed portion of the 72-hr PMP estimated values from HMR No. 55 have been combined to form Figure 15 of this report. The map scale is slightly different on the PMP map than it is on the Big Thompson Flood map. To help focus on the same general area, the vertical section near Estes Park and Loveland is nearly matching. To show comparative values, the high precipitation center near Glen Comfort on the Flood Map is identified as the blacked-out area just to the northeast of Estes Park on the PMP Map - falling mostly between the 36 and 38 inch isohyet lines. The above-10-inch area to the southwest of Ted's Place on the Flood Map is repeated near the 42-inch isohyet line on the PMP Map.

A paleoflood study made by Dr. J. E. Costa in 1978* placed the Big Thompson Flood in a realistic 8,000 to 10,000-year return period. Since the PMP values are over three times the flood values, it can be inferred that the PMP return period must be significantly greater (i.e., several orders of magnitude) than the return period for this particular event.

Other comparative studies have been made to relate the applicability of HMR-55 data to actual engineering design and construction projects. Some of the problems that appear to have affected the applicability of HMR-55 are discussed in APPENDIX G, which is a segment of a report prepared for estimating the requirements for re-building dam structures and/or spillways on the Santa Fe River above Santa Fe, New Mexico. As as result of that study, PMP estimated values that are about 1/3 as high as those in HMR-55 are now approved for use by the State of New Mexico's State Engineer.

*Costa, J.E. (1978). "Colorado Big Thompson Flood, Geologist Evidence of a Rare Hydrologic Event." Geology 6:617-620.

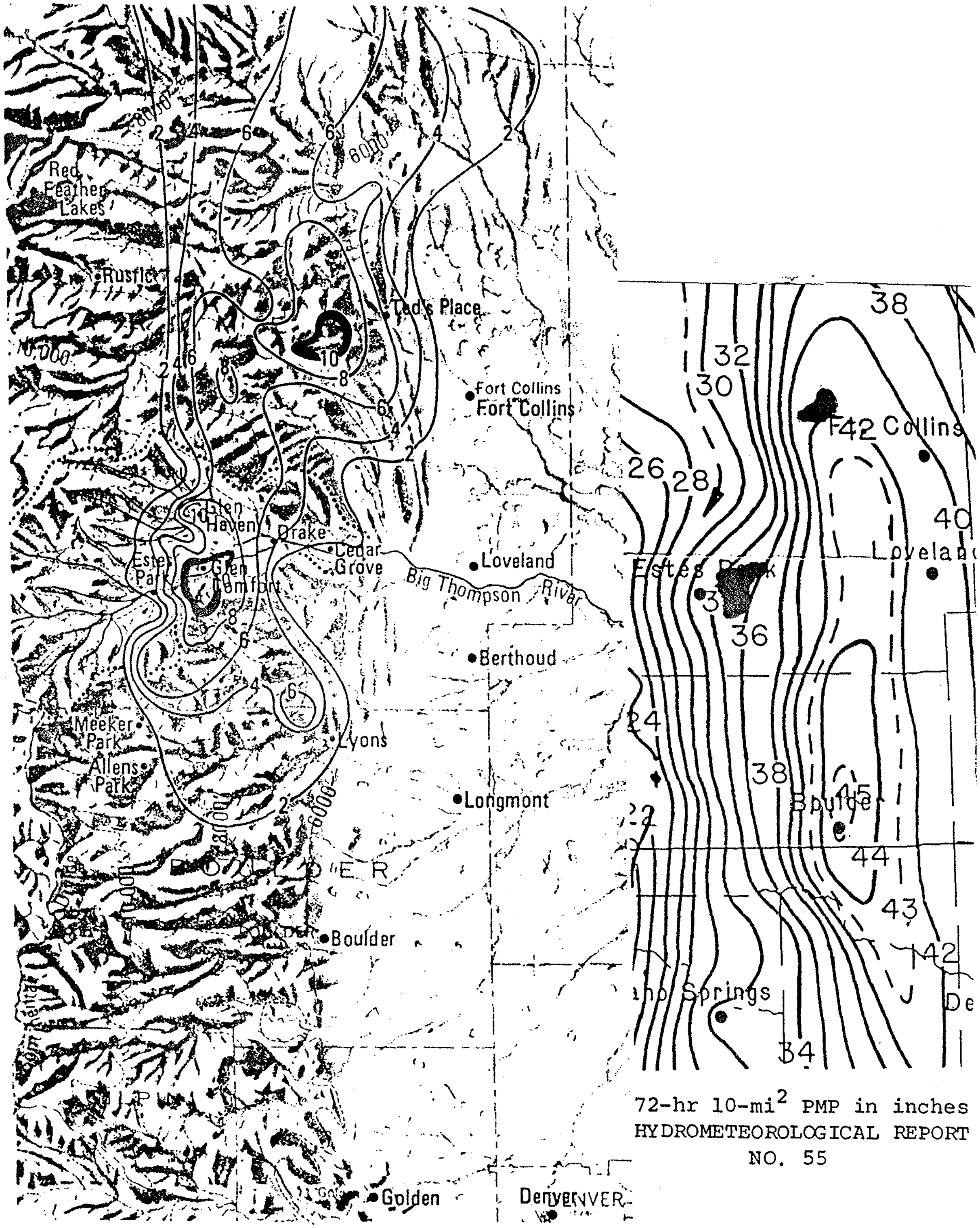

Figure 2. Big Thompson and North Fork of the Big Thompson drainages. Towns within and near the flash flood area are identified. Cumulative rainfall isohyets (black lines) for the period 31 July–2 August 1976 are shown. Terrain contours (orange lines) are in feet above mean sea level. The precipitation summary and isohyetal map were prepared by the National Weather Service Central Region Headquarters in cooperation with other Federal agencies.

Figure 15, Comparison between Big Thompson Flood and 72-hr PMP estimates.

It is this investigator's opinion that one major deficiency in the preparation of HMR-55 was the extremely limited peer review process prior to publication. A second criticism is that HMR-55 does not discuss any methods for relating the PMP to a comparable statistical event. Without this information, it is impossible to evaluate the relative significance of the PMP when designing projects with long term (i.e., 1,000 year plus) service lives.

In cross checking data sources for this study, several discrepancies between HMR-55 and other documents were identified. In one case, the Corps of Engineers have not assigned the Hale, Colorado storm of late May 1935 any "serial" number in their catalog of historical floods. In another, a different moisture adjustment value was used for the same Hale storm data in HMR-51 than was used in HMR-55. That discrepancy is shown in Figure 16.

Finally, HMR-55 recognizes the difficulties of studying extreme precipitation events occuring in small watersheds. The following is quoted from the PREFACE of the report: "As meteorological knowledge of the causes and variation of extreme precipitation events increases, some changes may appear necessary to the estimates made in this report. Such changes may be required for the higher elevations and smaller area sizes where our observational data and detailed knowledge may be most deficient."

Loren W. Crow CCM
LOREN W. CROW CONSULTANTS, INC.

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

HYDROMETEOROLOGICAL REPORT NO. 51

STORM INDEX NO. 56 (-) DATE 5/30-31/1935
RAINFALL CENTER HALE,CO MOIST.ADJ. 1.22

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24
10	16.5	22.2	22.2	22.2
100	11.0	15.4	15.4	15.4
200	9.9	12.6	12.6	12.6
1000	4.6	7.2	7.2	7.2
5000	1.9	3.5	3.8	4.0

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U.S. DEPARTMENT OF COMMERCE
TIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF ARMY
CORPS OF ENGINEERS

U.S. DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION

HYDROMETEOROLOGICAL REPORT NO. 55

Storm Index No. 101
Max. Rainfall Center:

Date - 5/30-31/35
Hale, CO
Moisture Adjustment 156

Storm Assignment No. MR 3-28A
Lat. 39°36' Long. 102°08'

Maximum average depth of rainfall in inches

Area (mi^2)	Duration of rainfall in hours 6	12	18	24
10	16.5	22.2	22.2	22.2
100	11.0	15.4	15.4	15.4
200	9.9	12.6	12.6	12.6
1000	4.6	7.2	7.2	7.2
5000	1.9	3.5	3.8	4.0

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Figure 16. Example of the same set of data described in two HMR Reports.

APPENDIX A

Hourly precipitation record for all days with two or more inches of precipitation in the 24 hours ending at midnight at 10 stations using recording precipitation gages for most summers during the period 1949 through 1986.

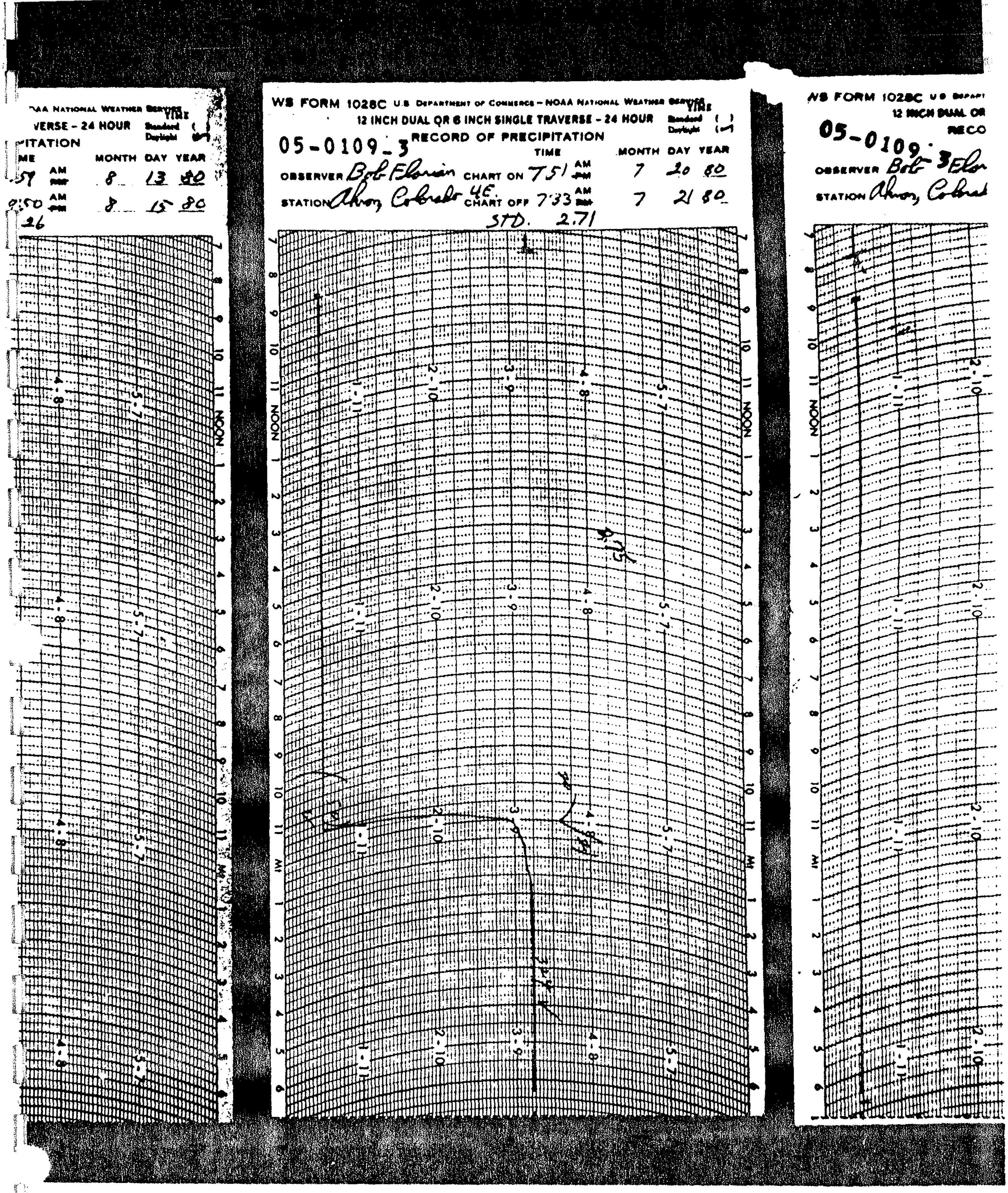
50109AKRON 4 E							4009	10309	4540		3														
501091955 726	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	219	5	9	14	10	8	265
501091957 726	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105	130	25	2	0	0	0	0	0	262
501091966 6 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	136	5	0	3	98	242
501091968 724	2	72	15	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	102	27	31	19	273
501091968 814	1	15	16	0	1	8	82	29	2	0	16	0	0	0	0	0	0	0	41	1	0	0	0	0	212
501091973 5 6	0	0	0	0	0	2	2	17	19	48	28	62	104	22	19	22	16	3	4	1	2	1	1	1	374
501091978 829	0	1	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	115	50	25	5	0	205
501091980 720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	207	61	268
501091981 717	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	283	71	355
51179BYERS 5 ENE							3945	10408	5100		4														
511791951 8 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	94	14	16	7	205
511791951 8 3	17	64	67	57	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	209
511791957 517	0	231A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2311
511791962 6 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	225A	0	0	0	0	2251
511791962 630	0	0	0	0	0	0	1	1	0	0	0	1	118	88	7	0	0	1	1	3	0	0	0	0	221
511791965 615	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	60	20	145	44	0	0	274
511791969 5 7	5	7	7	9	2	1	1	3	1	4	1	53	99	8	6	2	1	11	22	18	4	2	7	4	278
511791973 5 6	10	10	50	0	0	0	40	40	20	20	20	30	30	40	30	10	20	20	0	0	10	0	0	10	410
511791974 721	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	210	10	10	0	10	0	240
511791975 529	20	20	10	30	10	10	20	10	20	20	20	0	10	10	0	0	0	0	0	0	0	0	0	0	210
52162DEER TRAIL							3937	10403	5180		4														
521621961 731	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	210	15	5	0	0	0	0	230
521621965 615	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	18	60	144	40	0	0	0	0	264
521621973 5 6	0	2	3	1	1	50	64	29	13	13	25	27	16	19	18	6	26	23	10	5	4	5	8	3	371
521621975 530	0	0	0	0	0	0	313A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3141
521621976 521	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	71	36	9	29	23	15	34	35	18	279
521621977 611	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0A	0	305A	6	0	0	0	0	0	0	3111
521621977 720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	78	85	20	13	21	1	4	227
54155HOYT							4000	10405	5000		4														
541551951 8 3	1	5	2	168	13	1	0	0	0	0	0	0	14	78	3	0	1	0	0	0	0	0	0	0	286
541551965 6 4	0	0	0	0	0	0	0	0	0	0	0	0	3	65	24	14	24	38	11	13	1	3	2	9	207
541551966 719	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	157	28	28	7	1	0	0	263
541551971 828	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	10	28	136	33	4	24	19	258
541551973 5 6	0	0	0	0	0	0	1	10	59	13	8	8	20	15	23	28	23	13	7	3	3	3	0	1	238
541551976 521	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	34	30	45	50	40	0A	2011
54172HUGO							3908	10328	5030		1														
541721958 716	1	2	2	0	0	4	0	0	0	0	0	0	0	0	0	0	50	182	1	0	0	0	0	0	242
541721960 6 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	134	85	0	0	4	0	0	0	0	223
541721965 723	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	135	5	2	239
541721965 819	44	27	56	27	18	5	9	7	4	1	1	4	3	2	5	0	0	0	0	0	0	0	0	0	213
541721973 5 6	0	0	0	0	0	0	0	0	0	0	15	10	29	32	15	42	11	11	15	10	5	9	3	3	210
541721976 6 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	150	24	214
541721978 6 5	0	0	0	0	0	0	0	0	0	0	0	0	0	230A	0	0	0	0	0	0	0	0	0	0	2301
541721983 712	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	10	110	20	10	0	210

54380JOBS								3939	10241		4270	3														
543801949	5 7	0	0	0	0	0	0	200A	2	2	0	2	0	10	14	25	4	7	3	2	7	1	0	0	2	281I
543801955	614	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	221	49	6	0	305
543801962	630	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3	0	0	1	13	40	46	7	77	67	257
543801963	920	0	0	0	0	0	0	0	33	5	0	1	36	106	48	1	0	0	0	0	0	0	0	0	1	231
543801970	611	0	0	0	0	0	140A	0	0	1	36	4	0	0	0	0	3	3	0	1	3	7	9	4	1	212I
543801973	719	0	0	0	0	0	0	68	117	85	70	54	43	40	48	0	0	0	0	0	0	0	0	1	1	527
543801974	6 8	6	18	16	17	17	16	0	0	0	0	0	3	16	24	16	28	19	19	19	13	7	6	5	1	266
543801977	721	127	139	16	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	287
543801980	723	0	14	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	30	93	0	0	0	204
56326PARKER 6 E								3932	10439		6310	4														
563261958	5 8	11	17	0	0	5	18	1	4	4	1	0	0	0	0	1	32	34	24	18	20	11	6	9	7	223
563261965	6 4	0	0	0	0	0	0	0	0	0	0	0	12	30	27	16	16	27	17	18	15	9	11	7	7	212
563261970	611	24	63	27	26	14	1	19	31	10	12	2	0	4	1	0	4	2	7	6	5	5	7	8	2	280
563261983	723	0	0	0	0	0	0	0	0	0	0	0	0	0	10	150	30	10	10	0	0	0	0	0	0	210
57519SEIBERT								3918	10252		4700	3														
575191958	716	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	151	123	4	0	0	0	0	278
575191963	8 3	1	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	181	45	90	12	9	7	3	353
575191973	719	0	0	0	1	11	38	190	34	5	187	17	0	0	0	0	0	0	0	0	0	0	0	0	1	484
575191974	6 8	41	34	15	111	9	0	0	1	0	0	0	1	9	29	17	17	26	24	19	16	6	4	2	4	385
575191975	530	0	0	0	0	0	290A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	290I
575191977	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	170	30	200
575191978	829	0	0	0	20	10	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	20	150	30	20	260
57557SHAW 2 E								3933	10321		5180	3														
575571953	819	0	0	0	0	0	0	0	0	0	0	0	0	0	19	235	55	10	0	0	0	0	0	0	0	319
575571954	725	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	119	39	15	19	6	0	0	0	0	200
575571964	530	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	216A	0	0	0	0	0	0	0	0	216I
575571983	628	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	396A	0	0	0	0	0	0	396I
57664SIMLA								3909	10405		6020	1														
576641954	714	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	59	130	14	11	8	4	0	287
576641957	7 9	0	0	0	0	0	0	0	0	0	0	0	0	0	3	97	281	3	0	0	0	0	0	0	0	384
576641957	8 4	0	0	220A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	220I
576641959	715	0	0	0	0	0	0	0	0	0	0	0	0	0	196	4	3	0	0	2	0	0	0	0	0	205
576641961	711	0	0	3	0	0	0	0	0	0	0	0	0	0	3	157	13	20	26	12	0	0	0	0	0	234
576641967	526	0	0	0	0	0	0	12	30	25	15	13	27	29	25	10	7	1	13	15	8	0	0	2	0	232
576641977	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	199	11	9	16	14	264
576641977	725	0	0	0	0	0	0	0	100A	0	0	0	0	0	0	0	0	61	40	39	2	2	1	0	0	245I

APPENDIX B

Copies of detailed precipitation recording charts covering nine instances when 2-hour amounts were near or above two inches.

Akron 4 E	July 20-21,	1980
Akron 4 E	July 17-18,	1981
Deer Trail	July 31,	1961
Joes	June 14,	1955
Joes	July 19,	1973
Seibert	July 16,	1958
Seibert	July 19,	1973
Simla	July 9,	1957
Simla	July 20,	1977


WS FORM 1028C U.S. DEPARTMENT OF COMMERCE – NOAA NATIONAL WEATHER SERVICE
12 INCH DUAL OR 6 INCH SINGLE TRAVERSE - 24 HOUR
RECORD OF PRECIPITATION
05-0109-3
TIME
Standard
Daylight
MONTH DAY YEAR
OBSERVER Bob Florian
CHART ON 7:51 AM 7 20 80
STATION Akron, Colorado 4E.
CHART OFF 7:33 AM 7 21 80
STD. 2.71
NOON

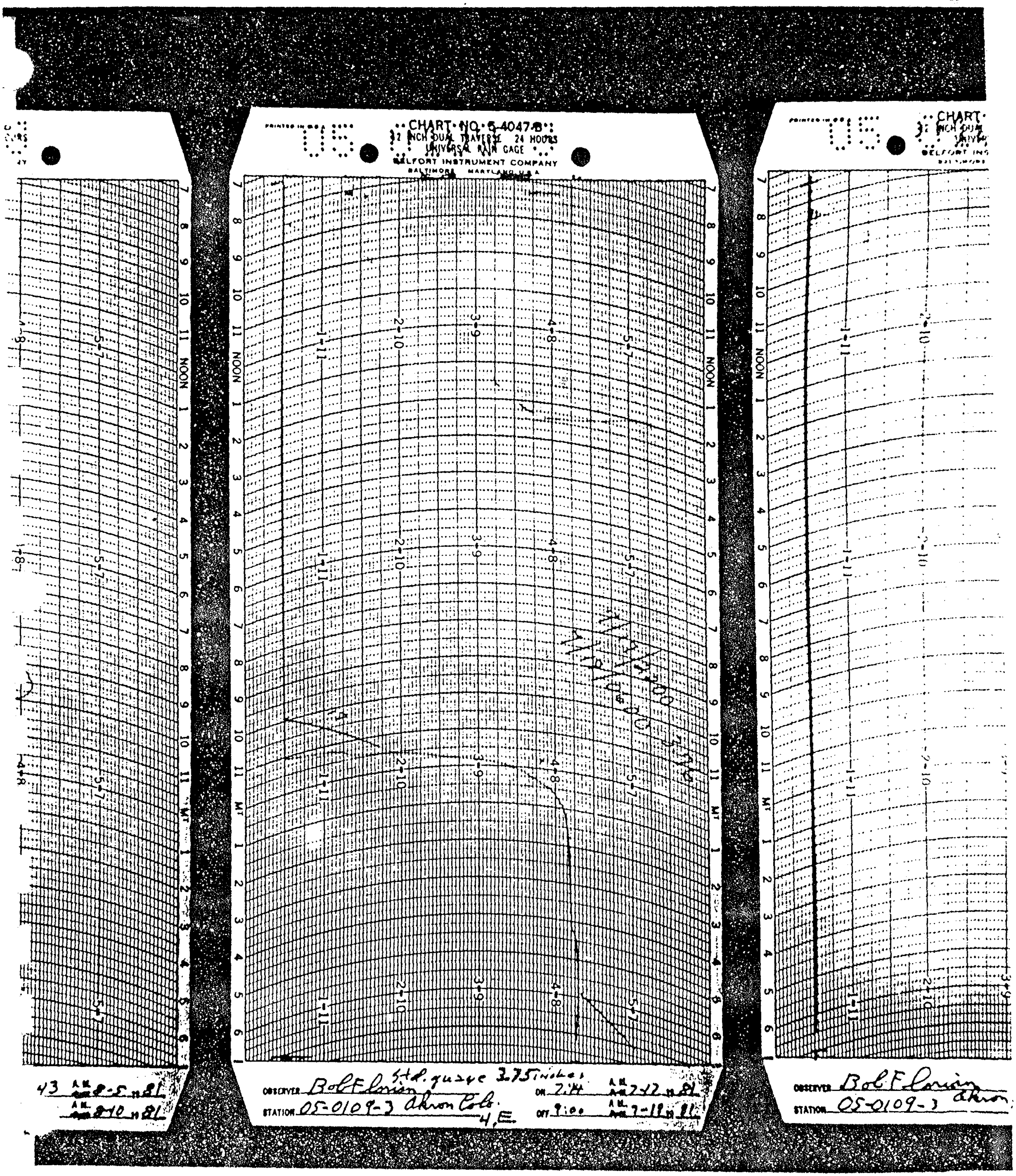
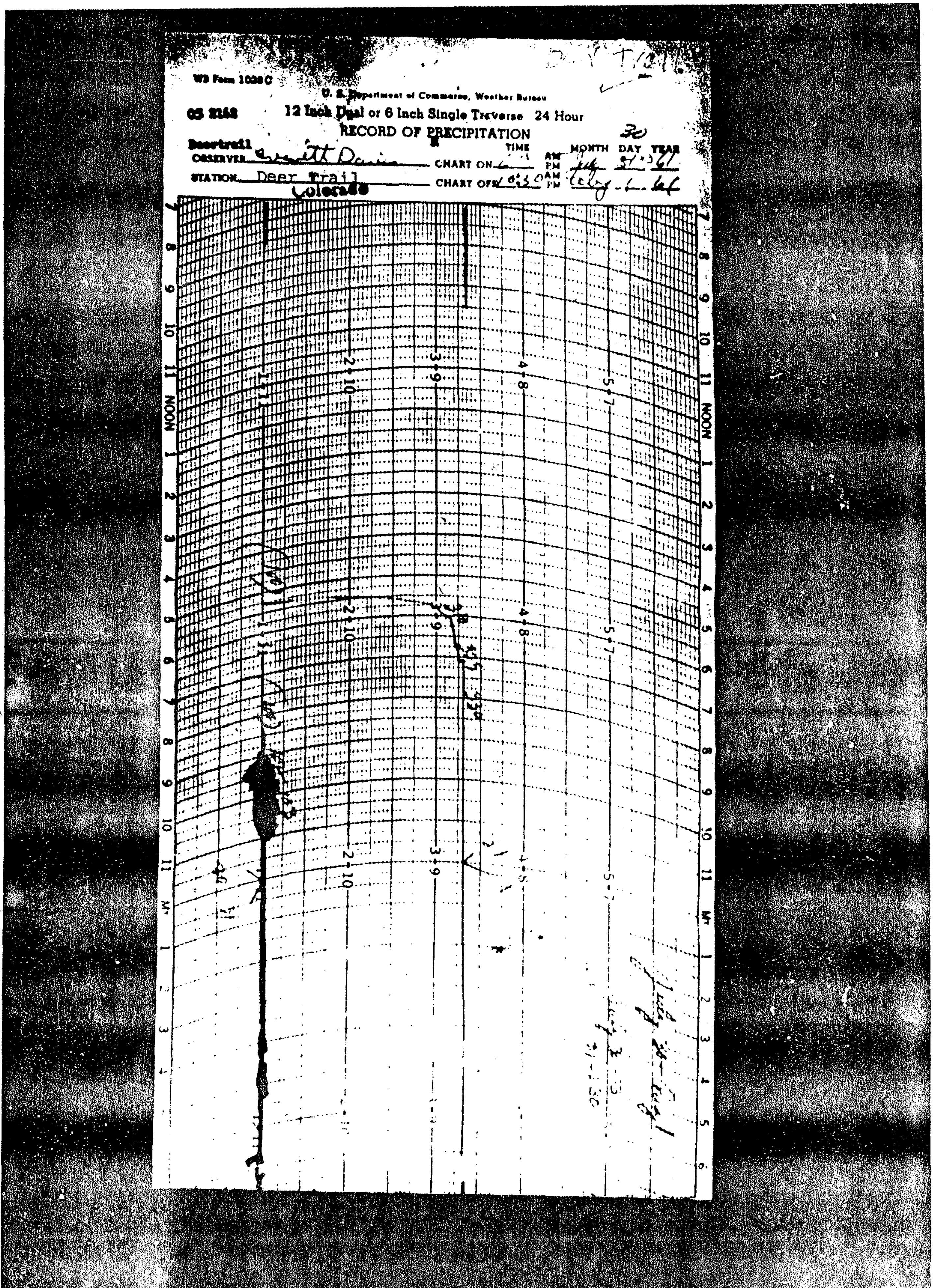
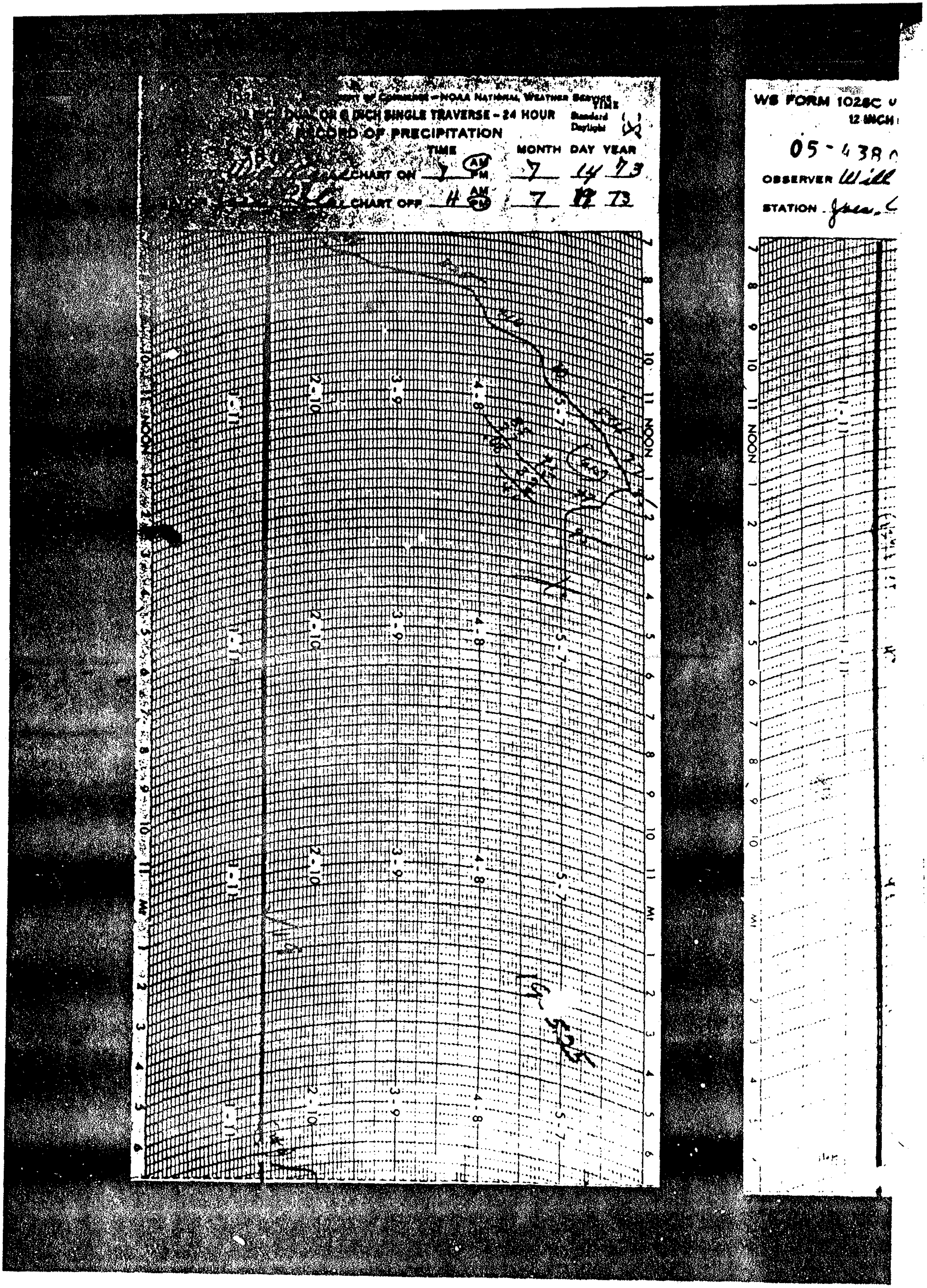
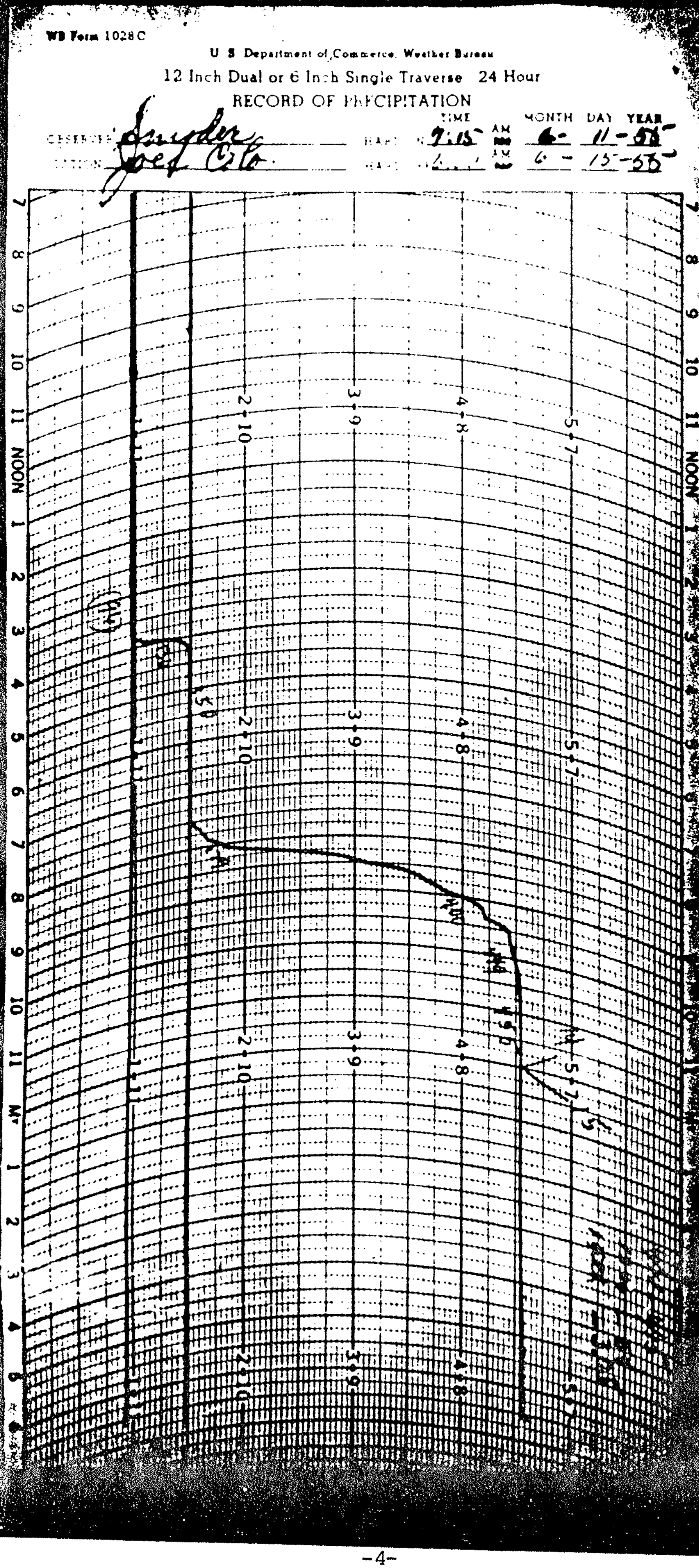
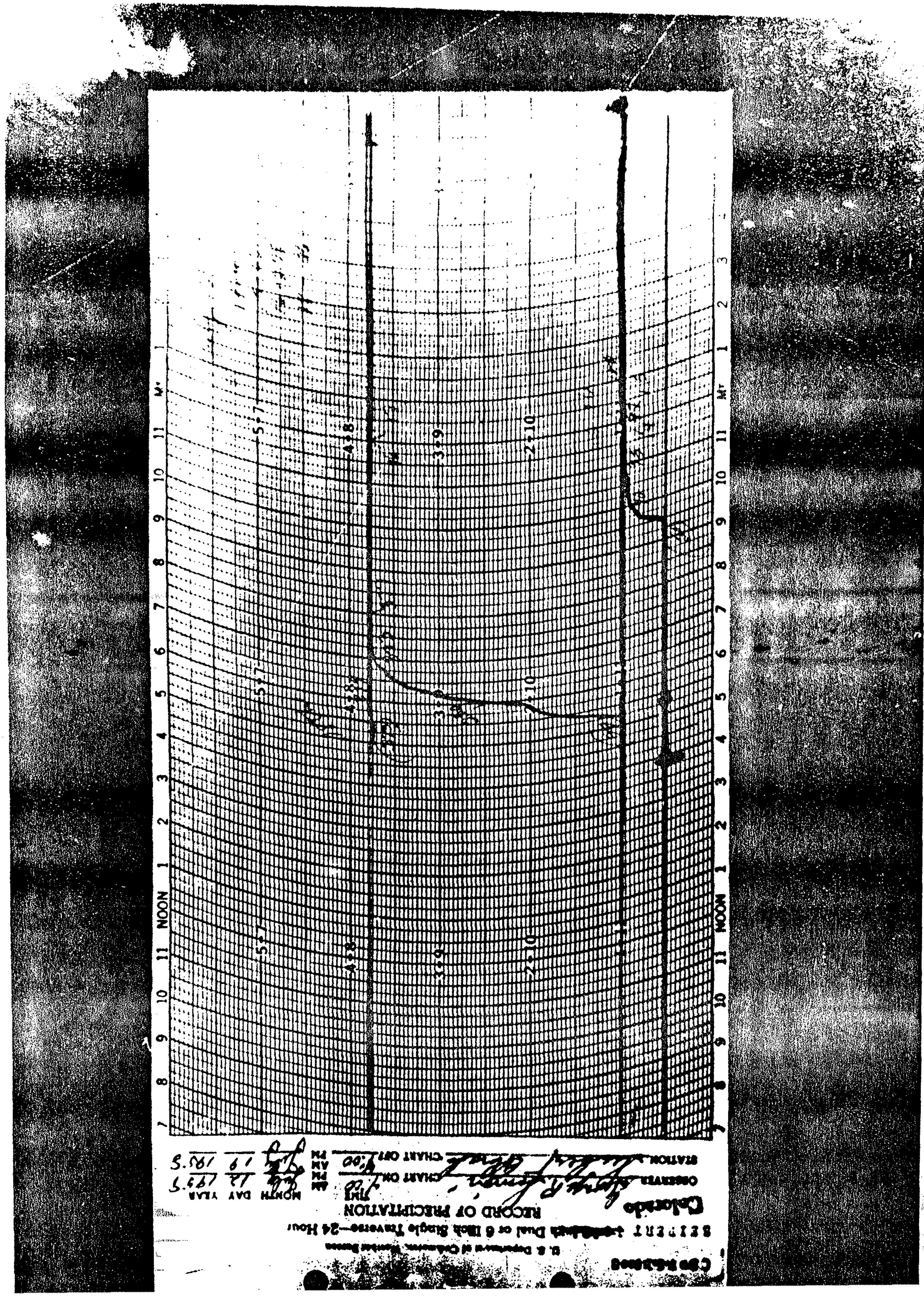


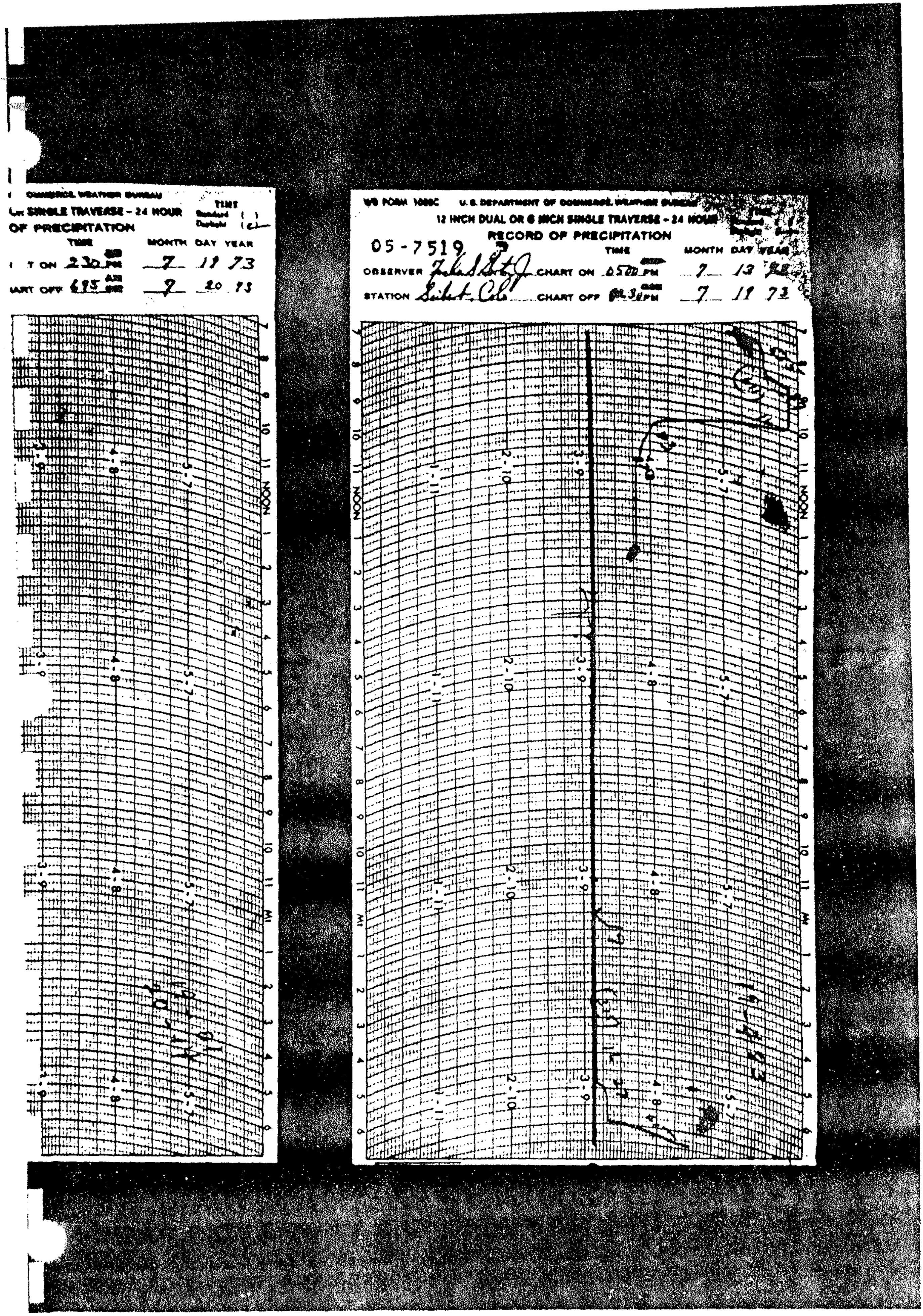
CHART NO. 5-4047-B
12 INCH DUAL TRAVERSE 24 HOURS
UNIVERSAL RAIN GAGE
BELFORT INSTRUMENT COMPANY
BALTIMORE MARYLAND U.S.A
OBSERVER Bob Florian
Std. gauge 3.75 inches
STATION 05-0109-3 Akron Colo. 4 E
ON 7:44 AM 7-12 19 81
OFF 9:00 AM 7-19 19 81
OBSERVER Bob Florian
STATION 05-0109-3 Akron

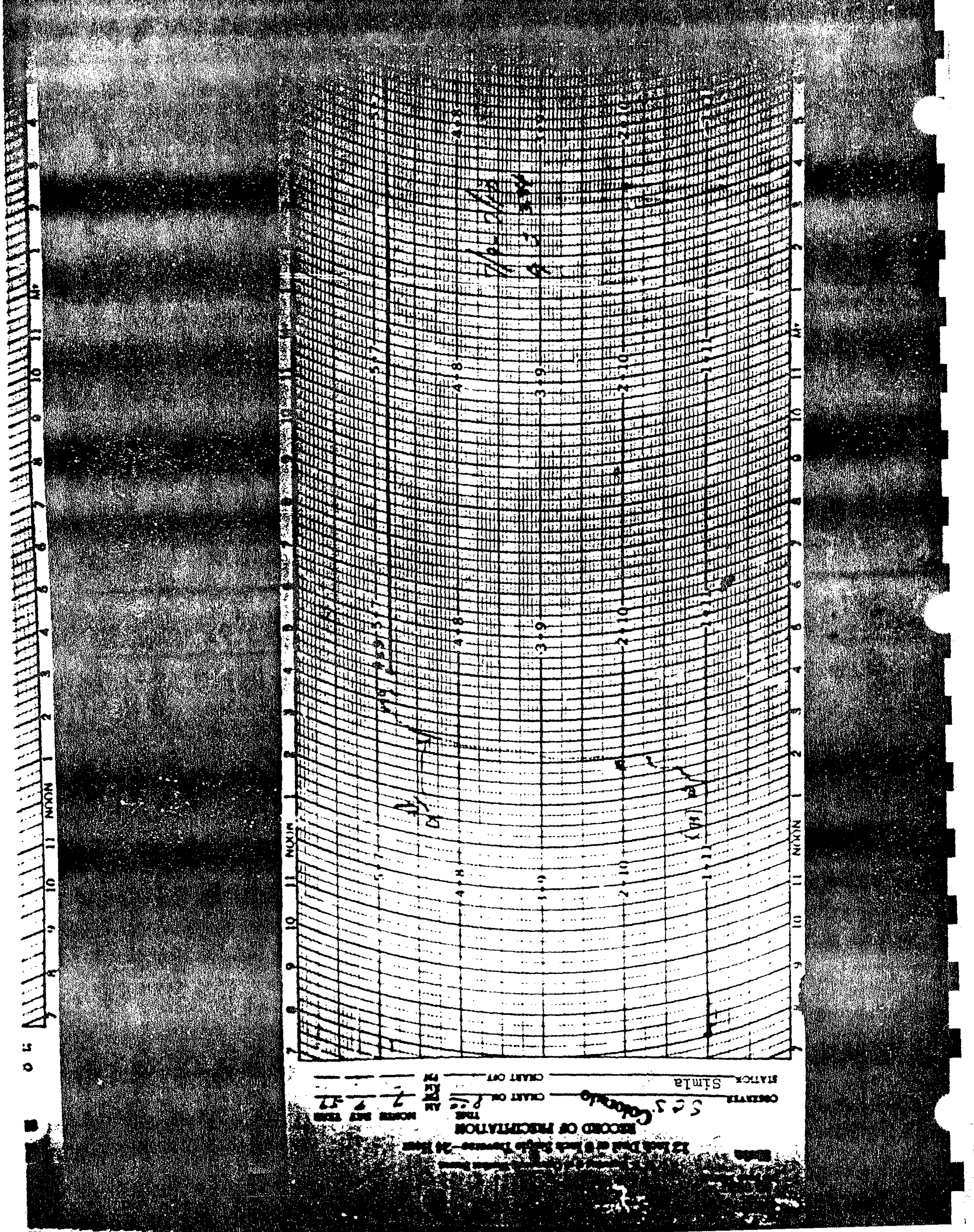

WB Form 1026C
U. S. Department of Commerce, Weather Bureau
05 2148
12 Inch Dual or 6 Inch Single Traverse 24 Hour
RECORD OF PRECIPITATION
Deertrail
OBSERVER
STATION Deer Trail
Colorado
TIME
CHART ON
CHART OFF
AM
PM
MONTH
DAY
YEAR
NOON
2·10
3·9
4·8
5·7

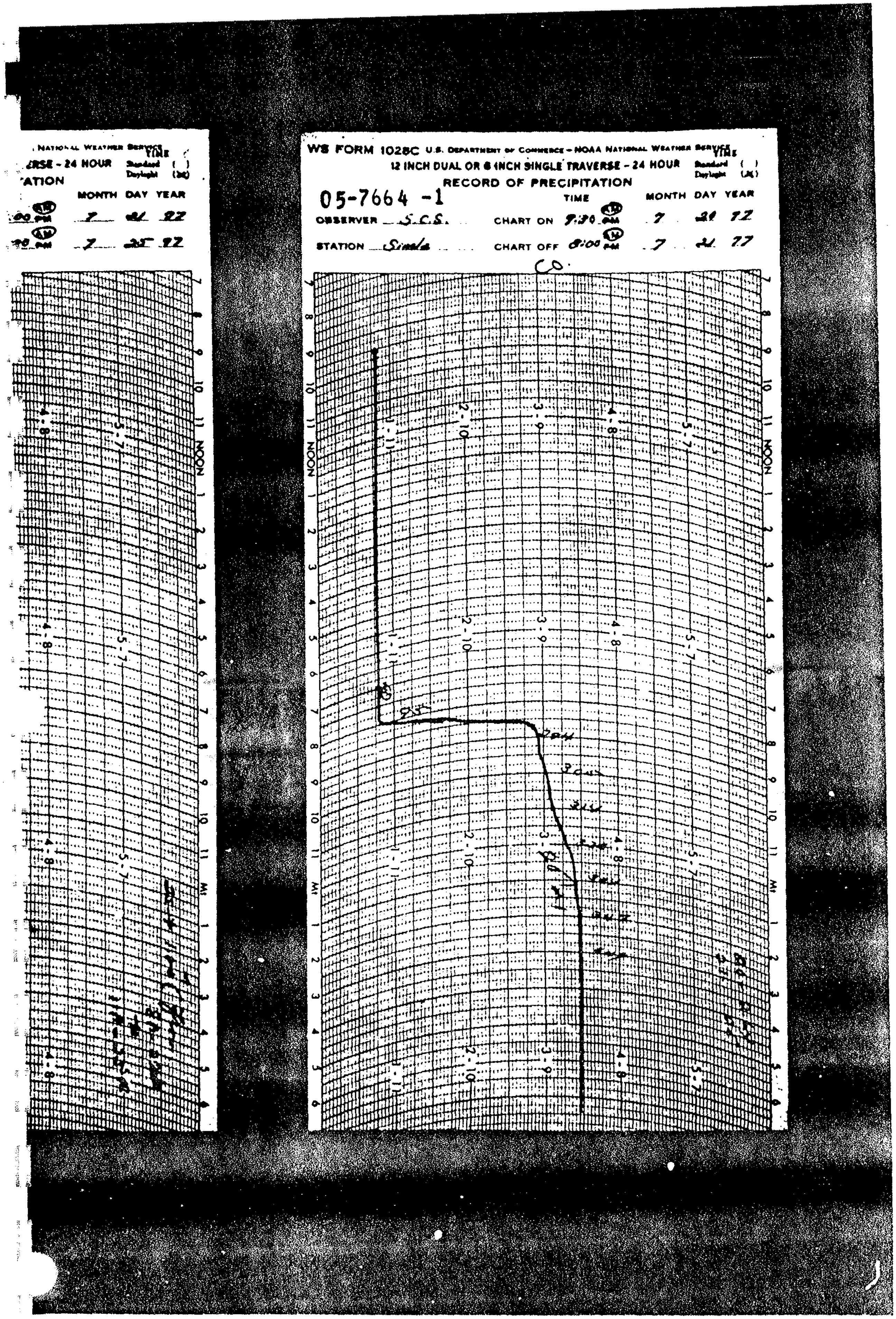

SINGLE TRAVERSE - 24 HOUR
RECORD OF PRECIPITATION
TIME Standard Daylight
TIME MONTH DAY YEAR
CHART ON
CHART OFF
WS FORM 1028C
12 INCH
05-438
OBSERVER
STATION


WB Form 1028C
U S Department of Commerce, Weather Bureau
12 Inch Dual or 6 Inch Single Traverse 24 Hour
RECORD OF PRECIPITATION
TIME
MONTH DAY YEAR
Snyder 9:15 AM 6- 11-55
Joes Colo. 6 - 15-55
NOON
M
2·10
3·9
4·8
5·7
1·11


RECORD OF PRECIPITATION
Colorado
MONTH DAY YEAR
OBSERVER
STATION
CHART ON
CHART OFF
NOON
M


SINGLE TRAVERSE - 24 HOUR
OF PRECIPITATION
TIME
MONTH DAY YEAR
WB FORM 1009C U.S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
12 INCH DUAL OR 6 INCH SINGLE TRAVERSE - 24 HOUR
RECORD OF PRECIPITATION
05-7519
OBSERVER
CHART ON
STATION
CHART OFF
NOON
MI


RECORD OF PRECIPITATION
MONTH DAY YEAR
TIME
CHART ON
CHART OFF
OBSERVER
STATION Simla
NOON


WS FORM 1028C U.S. DEPARTMENT OF COMMERCE – NOAA NATIONAL WEATHER SERVICE
12 INCH DUAL OR 6 INCH SINGLE TRAVERSE – 24 HOUR
RECORD OF PRECIPITATION
05-7664 -1
TIME
MONTH DAY YEAR
OBSERVER
CHART ON
STATION
CHART OFF
NOON

APPENDIX C

Precipitation data from United States Geological Survey Small Plot Studies.

RAINFALL-RUNOFF DATA FROM SMALL WATERSHEDS IN COLORADO, OCTOBER 1977 THROUGH SEPTEMBER 1980

By Betty J. Cochran, Donald R. Minges, Robert D. Jarrett,

and Jack E. Veenhuis

U.S. GEOLOGICAL SURVEY

Open-File Report 82-873

Prepared in cooperation with the

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT,

GENERAL SERVICES ADMINISTRATION,

COLORADO DIVISION OF HIGHWAYS, and the

U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION

Lakewood, Colorado
1983

The data will be analyzed to establish relationships between storm rainfall and associated runoff from the basins. These relationships will be defined by application of a hydrologic model and other techniques as indicated by Gonzalez and Ducret (1971).

To derive maximum benefit from a relatively short period of data collection, the emphasis in these studies will be on the application of the hydrologic model approach. Use of a model calibrated by actual rainfall-runoff data will allow a long-term runoff record to be synthesized from long-term rainfall records available in the general area. This method is described in detail by Lichty, Dawdy, and Bergmann (1968). A flood-frequency relation for each study basin will then be defined by using the synthetic long-term flood record. To regionalize the resulting flood-frequency relations, a regression equation technique will be used as described by Benson (1962). These equations will show the general relations between peak discharges of selected frequencies and the hydrologic characteristics of any small drainage basin within the study area.

Purpose and Scope

Throughout the period of study there has been considerable demand by other investigators for basic rainfall-runoff information. The purpose of this interim basic-data release is to present all significant rainfall-runoff data collected from the beginning of the studies to the end of the 1971 storm season. This type of report will be released periodically as the studies progress.

Instrumentation

Detailed records of rainfall and stream stage are collected at each station by the operation of two digital recorders, which code the data on 16-channel paper tape at 5-minute intervals. Use of a single timer provides for simultaneous actuation of both recorders.

The stage gage is mounted in the stream channel and generally consists of a vertical 4-inch standard galvanized iron pipe well with a metal shelter mounted on the top to house the recorder. The intake to the well consists of six $\frac{1}{4}$-inch holes in a standard 4-inch cap on the bottom of the pipe. Five holes are evenly spaced on the upstream face of the cap and one is centered in the downstream face. Experiments have shown that this arrangement of holes assures nearly equivalent water stages in the stream and the gage well through a wide range of stream velocity.

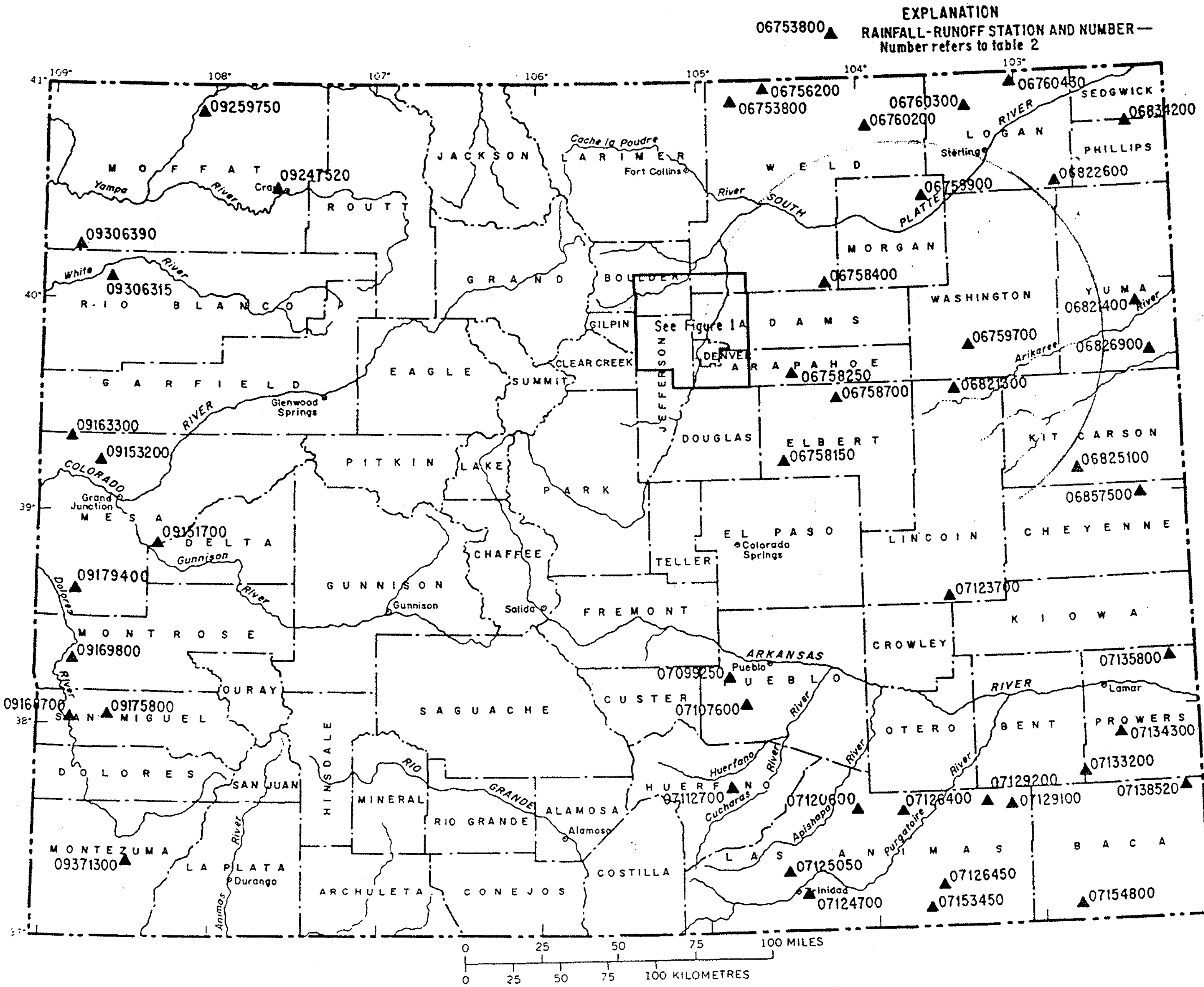


Figure 2.--Distribution of rainfall-runoff stations in eastern and western Colorado.

06821300 NORTH FORK ARIKAREE RIVER TRIBUTARY NEAR SHAW, COLO.--CONTINUED

5.72 mi²

RAINFALL AUG. 9, 1974

RAINFALL, IN INCHES, DURING INDICATED INTERVAL

DATE	TIME	RAINFALL	DATE	TIME	RAINFALL	DATE	TIME	RAINFALL
8-09	1400	0.02	8-09	1450	0.04	8-09	1855	0.03
8-09	1405	0.02	8-09	1455	0.39	8-09	1900	0.07
8-09	1415	0.01	8-09	1500	0.57	8-09	1905	0.01
8-09	1420	0.01	8-09	1505	0.17	8-09	1915	0.01
8-09	1425	0.01	8-09	1510	0.13	8-09	1920	0.01
8-09	1430	0.02	8-09	1515	0.02	8-09	1925	0.01
8-09	1440	0.01	8-09	1520	0.01	8-09	1930	0.02
8-09	1445	0.01	8-09	1525	0.01	8-09	1935	0.01
			8-09	1530	0.01			
			8-09	1620	0.01			

STORM TOTAL = 1.64

DURATION	5 MIN	15 MIN	30 MIN	1 HR
TIME	1455	1450	1445	1415
DEPTH	0.57	1.13	1.32	1.38
INTENSITY	6.84	4.52	2.64	1.38

RUNOFF AUG. 9, 1974

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
8-09	1450	0.0	8-09	1740	8.9	8-09	2030	5.0
8-09	1455	3.0	8-09	1745	8.3	8-09	2035	4.8
8-09	1500	4.0	8-09	1750	7.8	8-09	2040	4.6
8-09	1505	4.4	8-09	1755	7.4	8-09	2045	4.6
8-09	1510	3.8	8-09	1800	7.2	8-09	2050	4.4
8-09	1515	6.4	8-09	1805	6.8	8-09	2055	4.2
8-09	1520	9.2	8-09	1810	6.4	8-09	2100	4.0
8-09	1525	150	8-09	1815	6.2	8-09	2105	4.0
8-09	1530	193	8-09	1820	6.0	8-09	2110	4.0
8-09	1535	179	8-09	1825	5.6	8-09	2115	3.9
8-09	1540	151	8-09	1830	5.6	8-09	2120	3.9
8-09	1545	122	8-09	1835	6.2	8-09	2125	3.8
8-09	1550	98	8-09	1840	7.0	8-09	2130	3.8
8-09	1555	80	8-09	1845	7.6	8-09	2135	3.8
8-09	1600	68	8-09	1850	7.8	8-09	2140	3.7
8-09	1605	57	8-09	1855	7.6	8-09	2145	3.0
8-09	1610	44	8-09	1900	7.8	8-09	2150	2.5
8-09	1615	38	8-09	1905	7.6	8-09	2155	2.1
8-09	1620	32	8-09	1910	7.4	8-09	2200	1.7
8-09	1625	28	8-09	1915	7.4	8-09	2205	1.4
8-09	1630	25	8-09	1920	7.2	8-09	2210	1.2
8-09	1635	22	8-09	1925	7.2	8-09	2215	1.0
8-09	1640	21	8-09	1930	7.0	8-09	2220	0.8
8-09	1645	19	8-09	1935	6.8	8-09	2225	0.7
8-09	1650	18	8-09	1940	6.6	8-09	2230	0.6
8-09	1655	17	8-09	1945	6.4	8-09	2235	0.5
8-09	1700	16	8-09	1950	6.2	8-09	2240	0.4
8-09	1705	15	8-09	1955	6.0	8-09	2245	0.3
8-09	1710	14	8-09	2000	5.8	8-09	2250	0.3
8-09	1715	13	8-09	2005	5.6	8-09	2255	0.2
8-09	1720	12	8-09	2010	5.6	8-09	2300	0.2
8-09	1725	11	8-09	2015	5.4	8-09	2305	0.1
8-09	1730	10	8-09	2020	5.4	8-09	2310	0.1
8-09	1735	9.8	8-09	2025	5.2	8-09	2315	0.1

NOTE.--Discharge below 3.7 ft^3/s estimated.

KANSAS RIVER BASIN

06821300 NORTH FORK ARIKAREE RIVER TRIBUTARY NEAR SHAW, COLO.--CONTINUED

5.72 mi²

RUNOFF MAY 11, 1972

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
5-11	0420	14	5-11	0520	61	5-11	0620	24
5-11	0425	50	5-11	0525	59	5-11	0625	21
5-11	0430	92	5-11	0530	56	5-11	0630	19
5-11	0435	96	5-11	0535	53	5-11	0635	16
5-11	0440	95	5-11	0540	51	5-11	0640	14
5-11	0445	93	5-11	0545	48	5-11	0645	12
5-11	0450	90	5-11	0550	44	5-11	0650	10
5-11	0455	84	5-11	0555	40	5-11	0655	7.0
5-11	0500	79	5-11	0600	37	5-11	0700	5.0
5-11	0505	72	5-11	0605	33	5-11	0705	4.0
5-11	0510	71	5-11	0610	30	5-11	0710	3.0
5-11	0515	67	5-11	0615	27	5-11	0715	1.0

NOTE.--Discharge below 50 ft^3/s estimated.

RAINFALL, IN INCHES, JULY 23, 1972

DATE	TIME	INTERVAL DEPTH	ACCUMULATED DEPTH	DAILY TOTAL	MIDNIGHT DIAL
07-23	1400				5.36 (FIRST READING ON TAPE)
07-23	1655	0.12	0.12		
07-23	1700	0.64	0.76		
07-23	1705	0.37	1.13		
07-23	1710	0.11	1.24		
07-23	1715	0.01	1.25		

STORM TOTAL = 1.25

DURATION	5_MIN	15_MIN	30_MIN	1_HR	3_HR	6_HR	12_HR
TIME	1655	1650	1645	1615			
DEPTH	0.64	1.13	1.25	1.25			
INTENSITY	7.68	4.52	2.50	1.25			

RUNOFF JULY 23, 1972

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
7-23	1700	50	7-23	1800	220	7-23	1900	115
7-23	1705	116	7-23	1805	203	7-23	1905	100
7-23	1710	229	7-23	1810	199	7-23	1910	95
7-23	1715	449	7-23	1815	196	7-23	1915	85
7-23	1720	1,010	7-23	1820	190	7-23	1920	75
7-23	1725	960	7-23	1825	182	7-23	1925	65
7-23	1730	720	7-23	1830	169	7-23	1930	50
7-23	1735	494	7-23	1835	160	7-23	1935	40
7-23	1740	362	7-23	1840	152	7-23	1940	30
7-23	1745	306	7-23	1845	146	7-23	1945	20
7-23	1750	265	7-23	1850	138	7-23	1950	10
7-23	1755	241	7-23	1855	131	7-23	1955	5.0

NOTE.--Discharge below 50 ft^3/s estimated.

06821300 NORTH FORK ARIKAREE RIVER TRIBUTARY NEAR SHAW, COLO--CONTINUED

5.72 mi.²

RAINFALL JULY 25, 1979

RAINFALL, IN INCHES, DURING INDICATED INTERVAL

DATE	TIME	RAINFALL	DATE	TIME	RAINFALL	DATE	TIME	RAINFALL
7-25	1735	0.01	7-25	1750	0.07	7-25	1810	0.10
7-25	1740	0.06	7-25	1755	0.05	7-25	1815	0.02
7-25	1745	0.03	7-25	1800	0.14	7-25	1820	0.01
			7-25	1805	0.12			

STORM TOTAL = 0.61

DURATION	5 MIN	15 MIN	30 MIN	1 HR
TIME	1755	1755	1740	1730
DEPTH	0.14	0.36	0.51	0.61
INTENSITY	1.68	1.44	1.02	0.61

RUNOFF JULY 25, 1979

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
7-25	1800	3.0	7-25	1855	9.8	7-25	1950	1.8
7-25	1805	5.0	7-25	1900	8.9	7-25	1955	1.3
7-25	1810	42	7-25	1905	8.0	7-25	2000	1.0
7-25	1815	68	7-25	1910	7.6	7-25	2005	0.7
7-25	1820	57	7-25	1915	7.2	7-25	2010	0.5
7-25	1825	41	7-25	1920	6.8	7-25	2015	0.4
7-25	1830	26	7-25	1925	6.6	7-25	2020	0.3
7-25	1835	19	7-25	1930	5.0	7-25	2025	0.2
7-25	1840	15	7-25	1935	3.8	7-25	2030	0.2
7-25	1845	13	7-25	1940	2.9	7-25	2035	0.1
7-25	1850	11	7-25	1945	2.2	7-25	2040	0.1

NOTE.--Discharge below 6.6 ft³/s estimated.

RAINFALL AUG. 9-10, 1979

RAINFALL, IN INCHES, DURING INDICATED INTERVAL

DATE	TIME	RAINFALL	DATE	TIME	RAINFALL	DATE	TIME	RAINFALL
8-09	1800	0.01	8-09	2235	0.01	8-10	0355	0.02
8-09	1805	0.01	8-09	2240	0.01	8-10	0400	0.01
8-09	1610	0.01	8-09	2245	0.02	8-10	0405	0.01
8-09	1815	0.02	8-09	2250	0.03	8-10	0410	0.01
8-09	1820	0.03	8-09	2255	0.02	8-10	0415	0.01
8-09	1825	0.02	8-09	2300	0.02	8-10	0420	0.01
8-09	1830	0.02	8-09	2305	0.02	8-10	0425	0.01
8-09	1840	0.01	8-09	2310	0.01	8-10	0430	0.01
8-09	2100	0.01	8-09	2315	0.02	8-10	0435	0.01
8-09	2110	0.03				8-10	0440	0.01
8-09	2115	0.03				8-10	0445	0.01
8-09	2120	0.06	8-10	0235	0.14	8-10	0530	0.01
8-09	2125	0.07	8-10	0240	0.32	8-10	0740	0.01
8-09	2130	0.10	8-10	0245	0.19	8-10	0745	0.01
8-09	2135	0.13	8-10	0250	0.26	8-10	0750	0.01
8-09	2140	0.05	8-10	0255	0.25	8-10	0755	0.02
8-09	2145	0.08	8-10	0300	0.09	8-10	0800	0.02
8-09	2150	0.05	8-10	0305	0.07	8-10	0805	0.02
8-09	2155	0.02	8-10	0310	0.02	8-10	0810	0.02
8-09	2200	0.07	8-10	0315	0.02	8-10	0815	0.01
8-09	2205	0.07	8-10	0320	0.01	8-10	0820	0.01
8-09	2210	0.05	8-10	0325	0.01	8-10	0825	0.01
8-09	2215	0.04	8-10	0335	0.02	8-10	0830	0.01
8-09	2220	0.04	8-10	0340	0.01	8-10	0835	0.01
8-09	2225	0.02	8-10	0345	0.02	8-10	0840	0.01
8-09	2230	0.03	8-10	0350	0.01	8-10	0850	0.01

STORM TOTAL = 2.99

DURATION	5 MIN	15 MIN	30 MIN	1 HR
TIME	0235	0235	0230	0230
DEPTH	0.32	0.77	1.25	1.38
INTENSITY	3.84	3.08	2.50	1.38

06821300 NORTH FORK ARIKAREE RIVER TRIBUTARY NEAR SHAW, COLO--CONTINUED

5.72 mi²

RUNOFF AUG. 9, 1978

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
8-09	1355	3.0	8-09	1525	24	8-09	1655	5.2
8-09	1400	222	8-09	1530	21	8-09	1700	4.8
8-09	1405	265	8-09	1535	19	8-09	1705	4.6
8-09	1410	248	8-09	1540	16	8-09	1710	4.2
8-09	1415	198	8-09	1545	14	8-09	1715	3.2
8-09	1420	147	8-09	1550	13	8-09	1720	2.5
8-09	1425	114	8-09	1555	12	8-09	1725	1.9
8-09	1430	94	8-09	1600	10	8-09	1730	1.5
8-09	1435	83	8-09	1605	9.5	8-09	1735	1.2
8-09	1440	75	8-09	1610	8.9	8-09	1740	0.9
8-09	1445	67	8-09	1615	8.3	8-09	1745	0.7
8-09	1450	55	8-09	1620	7.8	8-09	1750	0.5
8-09	1455	47	8-09	1625	7.4	8-09	1755	0.4
8-09	1500	40	8-09	1630	7.0	8-09	1800	0.3
8-09	1505	35	8-09	1635	6.6	8-09	1805	0.3
8-09	1510	33	8-09	1640	6.4	8-09	1810	0.2
8-09	1515	31	8-09	1645	6.0	8-09	1815	0.1
8-09	1520	28	8-09	1650	5.6	8-09	1820	0.1

NOTE.--Discharge below 4.2 ft³/s estimated.

RAINFALL JULY 16, 1979

RAINFALL, IN INCHES, DURING INDICATED INTERVAL

DATE	TIME	RAINFALL	DATE	TIME	RAINFALL	DATE	TIME	RAINFALL
7-16	1730	0.01	7-16	1745	0.28	7-16	1810	0.02
7-16	1735	0.16	7-16	1750	0.30	7-16	1820	0.03
7-16	1740	0.15	7-16	1755	0.21	7-16	1825	0.01
			7-16	1800	0.04			
			7-16	1805	0.01			

STORM TOTAL = 1.22

DURATION	5 MIN	15 MIN	30 MIN	1 HR
TIME	1745	1740	1730	1725
DEPTH	0.30	0.79	1.14	1.22
INTENSITY	3.60	3.16	2.28	1.22

RUNOFF JULY 16, 1979

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
7-16	1755	3.0	7-16	1930	17	7-16	2115	5.0
7-16	1800	89	7-16	1935	16	7-16	2120	4.8
7-16	1805	143	7-16	1940	16	7-16	2125	4.6
7-16	1810	116	7-16	1945	15	7-16	2130	3.6
7-16	1815	69	7-16	1950	14	7-16	2135	2.9
7-16	1820	38	7-16	1955	13	7-16	2140	2.3
7-16	1825	24	7-16	2000	12	7-16	2145	1.9
7-16	1830	23	7-16	2005	11	7-16	2150	1.5
7-16	1835	37	7-16	2010	10	7-16	2155	1.2
7-16	1840	54	7-16	2015	9.5	7-16	2200	0.9
7-16	1845	53	7-16	2020	8.9	7-16	2205	0.7
7-16	1850	48	7-16	2025	8.3	7-16	2210	0.6
7-16	1855	40	7-16	2030	7.8	7-16	2215	0.5
7-16	1900	31	7-16	2035	7.6	7-16	2220	0.4
7-16	1905	25	7-16	2040	7.2	7-16	2225	0.3
7-16	1910	22	7-16	2045	6.8	7-16	2230	0.3
7-16	1915	20	7-16	2050	6.6	7-16	2235	0.2
7-16	1920	19	7-16	2055	6.2	7-16	2240	0.1
7-16	1925	18	7-16	2100	6.0	7-16	2245	0.1
			7-16	2105	5.6			
			7-16	2110	5.4			

NOTE.--Discharge below 4.6 ft³/s estimated.

06758700 MIDDLE BIJOU CREEK TRIBUTARY NEAR DEER TRAIL, COLO.--CONTINUED

2.27 mi^2 ? see 1.74 page 664

RAINFALL JULY 20-21, 1977

RAINFALL, IN INCHES, DURING INDICATED INTERVAL

DATE	TIME	RAINFALL	DATE	TIME	RAINFALL	DATE	TIME	RAINFALL
7-20	1715	0.04	7-20	2105	0.04	7-20	2330	0.02
7-20	1720	0.08	7-20	2110	0.02	7-20	2335	0.01
7-20	1725	0.02	7-20	2115	0.01	7-20	2340	0.02
7-20	1855	0.03	7-20	2120	0.01	7-20	2345	0.02
7-20	1900	0.29	7-20	2125	0.01	7-20	2350	0.01
7-20	1905	0.58	7-20	2130	0.01	7-20	2355	0.01
7-20	1910	0.16	7-20	2135	0.02	7-20	2400	0.01
7-20	1915	0.08	7-20	2140	0.01			
7-20	1920	0.11	7-20	2145	0.01	7-21	0005	0.01
7-20	1925	0.11	7-20	2150	0.01	7-21	0010	0.01
7-20	1930	0.05	7-20	2155	0.02	7-21	0015	0.01
7-20	1935	0.12	7-20	2200	0.01	7-21	0020	0.01
7-20	1940	0.16	7-20	2205	0.02	7-21	0030	0.01
7-20	1945	0.09	7-20	2210	0.02	7-21	0115	0.01
7-20	1950	0.05	7-20	2215	0.03	7-21	0130	0.01
7-20	1955	0.14	7-20	2220	0.02	7-21	0140	0.01
7-20	2000	0.17	7-20	2225	0.03	7-21	0150	0.01
7-20	2005	0.31	7-20	2230	0.04	7-21	0200	0.01
7-20	2010	0.29	7-20	2235	0.02	7-21	0205	0.01
7-20	2015	0.20	7-20	2240	0.02	7-21	0215	0.01
7-20	2020	0.18	7-20	2245	0.01	7-21	0220	0.01
7-20	2025	0.14	7-20	2250	0.02	7-21	0225	0.01
7-20	2030	0.13	7-20	2255	0.01	7-21	0230	0.01
7-20	2035	0.06	7-20	2300	0.02	7-21	0240	0.01
7-20	2040	0.06	7-20	2305	0.01	7-21	0255	0.01
7-20	2045	0.03	7-20	2310	0.02	7-21	0430	0.01
7-20	2050	0.01	7-20	2315	0.02	7-21	0450	0.01
7-20	2055	0.02	7-20	2320	0.02	7-21	0515	0.01
7-20	2100	0.07	7-20	2325	0.02			

STORM TOTAL = 4.61

DURATION	5 MIN	15 MIN	30 MIN	1 HR
TIME	1900	1855	1855	1930
DEPTH	0.58	1.03	1.33	1.98
INTENSITY	6.96	4.12	2.66	1.98

RUNOFF JULY 20-21, 1977

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
7-20	1855	20	7-20	2010	940	7-20	2125	28
7-20	1900	26	7-20	2015	1028	7-20	2130	18
7-20	1905	77	7-20	2020	1256	7-20	2135	12
7-20	1910	83	7-20	2025	1290	7-20	2140	8.2
7-20	1915	172	7-20	2030	1130	7-20	2145	5.4
7-20	1920	242	7-20	2035	855	7-20	2150	3.8
7-20	1925	373	7-20	2040	620	7-20	2155	2.4
7-20	1930	572	7-20	2045	321	7-20	2200	1.6
7-20	1935	632	7-20	2050	273	7-20	2205	1.1
7-20	1940	640	7-20	2055	192	7-20	2210	0.7
7-20	1945	664	7-20	2100	91	7-20	2215	0.5
7-20	1950	572	7-20	2105	59	7-20	2220	0.3
7-20	1955	564	7-20	2110	38	7-20	2225	0.2
7-20	2000	592	7-20	2115	34	7-20	2230	0.1
7-20	2005	740	7-20	2120	29	7-20	2235	0.1

06759700 SAND CREEK TRIBUTARY NEAR LINDON, COLO.--CONTINUED

2.35 mi²

RAINFALL, IN INCHES, AUG. 29, 1972

DATE	TIME	INTERVAL DEPTH	ACCUMULATED DEPTH	DAILY TOTAL	MIDNIGHT DIAL
08-29-72	1300				4.94 (FIRST READING ON TAPE)
08-29	1545	0.03	0.03		
08-29	1550	0.26	0.29		
08-29	1555	0.31	0.60		
08-29	1600	0.24	0.84		
08-29	1605	0.10	0.94		
08-29	1610	0.02	0.96		
08-29	1615	0.01	0.97		

STORM TOTAL = 0.97

DURATION	5_MIN	15_MIN	30_MIN	1_HR	3_HR	6_HR	12_HR
TIME	1550	1545	1540	1515			
DEPTH	0.31	0.81	0.96	0.97			
INTENSITY	3.72	3.24	1.92	0.97			

RUNOFF AUG. 29,1972

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
8-29	1605	16	8-29	1820	69	8-29	2040	20
8-29	1610	48	8-29	1825	65	8-29	2045	19
8-29	1615	74	8-29	1830	62	8-29	2050	18
8-29	1620	140	8-29	1835	57	8-29	2055	17
8-29	1625	155	8-29	1840	54	8-29	2100	16
8-29	1630	171	8-29	1845	51	8-29	2105	15
8-29	1635	165	8-29	1850	47	8-29	2110	14
8-29	1640	159	8-29	1855	45	8-29	2115	13
8-29	1645	152	8-29	1900	44	8-29	2120	12
8-29	1650	187	8-29	1905	43	8-29	2125	11
8-29	1655	222	8-29	1910	42	8-29	2130	11
8-29	1700	225	8-29	1915	41	8-29	2135	10
8-29	1705	228	8-29	1920	40	8-29	2140	9.0
8-29	1710	205	8-29	1925	38	8-29	2145	8.0
8-29	1715	185	8-29	1930	37	8-29	2150	7.0
8-29	1720	163	8-29	1935	36	8-29	2155	6.0
8-29	1725	141	8-29	1940	35	8-29	2200	6.0
8-29	1730	122	8-29	1945	34	8-29	2205	6.0
8-29	1735	115	8-29	1950	33	8-29	2210	5.0
8-29	1740	107	8-29	1955	31	8-29	2215	5.0
8-29	1745	98	8-29	2000	28	8-29	2220	4.0
8-29	1750	91	8-29	2005	27	8-29	2225	4.0
8-29	1755	87	8-29	2010	26	8-29	2230	3.0
8-29	1800	84	8-29	2015	25	8-29	2235	3.0
8-29	1805	80	8-29	2020	24	8-29	2240	2.0
8-29	1810	77	8-29	2025	23	8-29	2245	2.0
8-29	1815	73	8-29	2030	22	8-29	2250	1.0
			8-29	2035	21			

NOTE.--Discharge below 8.0 ft³/s estimated.

06758700 MIDDLE BIJOU CREEK TRIBUTARY NEAR DEER TRAIL, COLO.

LOCATION.--Lat 39°29'33", long 104°09'46", in SE¼SE¼ sec.25, T.6 S., R.61 W., Elbert County, on right bank 300 ft (91 m) downstream from gas-line crossing, 10.4 mi (16.7 km) southwest of Deer Trail, and 16 mi (26 km) southeast of Byers.

DRAINAGE AREA.--1.74 mi² (4.51 km²) of which 0.06 mi² (0.16 km²) is probably noncontributing, revised.

PERIOD OF RECORD.--Apr. 30, 1970, to October 1979 (discontinued).

GAGE.--Flood-hydrograph and rainfall recorders (dual digitals).

REMARKS.--Basin cover is natural prairie vegetation.

STAGE-DISCHARGE RELATION.--Rating developed on basis of step-backwater analysis of reach of natural stream channel and slope-area measurements at discharges of 500 ft³/s (14.2 m³/s) and 1,290 ft³/s (36.5 m³/s).

EXTREMES.--Water year 1978: Maximum discharge, 285 ft³/s (8.07 m³/s) Aug. 10; no flow most of year.
Water year 1979: Maximum discharge, 880 ft³/s (25.0 m³/s) July 17; no flow most of year.
Period of record: Maximum discharge, 1,290 ft³/s (36.5 m³/s) July 20, 1977; no flow most of each year.

RAINFALL AUG. 10, 1978

RAINFALL, IN INCHES, DURING INDICATED INTERVAL

DATE	TIME	RAINFALL	DATE	TIME	RAINFALL	DATE	TIME	RAINFALL
8-10	1555	0.01	8-10	1600	0.10	8-10	1620	0.01
			8-10	1605	0.03			
			8-10	1610	0.01			

STORM TOTAL = 0.16

DURATION	5 MIN	15 MIN	30 MIN	1 HR
TIME	1555	1550	1550	1550
DEPTH	0.10	0.14	0.16	0.16
INTENSITY	1.20	0.56	0.32	0.16

RUNOFF AUG. 10, 1978

DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE	DATE	TIME	DISCHARGE
8-10	1555	21	8-10	1630	40	8-10	1715	2.0
8-10	1600	202	8-10	1635	34	8-10	1720	1.2
8-10	1605	285	8-10	1640	32	8-10	1725	0.7
8-10	1610	199	8-10	1645	28	8-10	1730	0.4
8-10	1615	122	8-10	1650	23	8-10	1735	0.3
8-10	1620	67	8-10	1655	14	8-10	1740	0.2
8-10	1625	45	8-10	1700	8.4	8-10	1745	0.1
			8-10	1705	5.2			
			8-10	1710	3.2			

NOTE.--Discharge below 23 ft³/s estimated.

RAINFALL JULY 17, 1979

RAINFALL, IN INCHES, DURING INDICATED INTERVAL

DATE	TIME	RAINFALL	DATE	TIME	RAINFALL	DATE	TIME	RAINFALL
7-17	1710	0.01	7-17	1730	0.08	7-17	1755	0.06
7-17	1715	0.07	7-17	1735	0.07	7-17	1800	0.07
7-17	1720	0.31	7-17	1740	0.13	7-17	1805	0.04
7-17	1725	0.23	7-17	1745	0.17	7-17	1810	0.02
			7-17	1750	0.14			

STORM TOTAL = 1.40

DURATION	5 MIN	15 MIN	30 MIN	1 HR
TIME	1715	1715	1715	1710
DEPTH	0.31	0.62	0.99	1.39
INTENSITY	3.72	2.48	1.98	1.39

PLATTE RIVER BASIN

06758400 GOOSE CREEK NEAR HOYT, COLO.--Continued

3.75 mi²

RAINFALL SEPT. 16, 1969

DATE	TIME	INTERVAL DEPTH	ACCUMULATED DEPTH	DAILY TOTAL	MIDNIGHT DIAL
09-16-69	1215				3.98 (FIRST READING ON TAPE)
09-16	1250	0.02	0.02		
09-16	1255	0.06	0.08		
09-16	1300	0.01	0.09		
09-16	1305	0.02	0.11		
09-16	1310	0.03	0.14		
09-16	1315	0.05	0.19		
09-16	1320	0.02	0.21		
09-16	1330	0.05	0.26		
09-16	1335	0.17	0.43		
09-16	1340	0.23	0.66		
09-16	1345	0.18	0.84		
09-16	1350	0.06	0.90		
09-16	1355	0.15	1.05		
09-16	1400	0.15	1.20		
09-16	1405	0.13	1.33		
09-16	1410	0.05	1.38		
09-16	1415	0.02	1.40		
09-16	1420	0.05	1.45		
09-16	1425	0.03	1.48		
09-16	1430	0.01	1.49		
09-16	1435	0.01	1.50		
09-16	1445	0.01	1.51		

STORM TOTAL = 1.51

DURATION	5_MIN	15_MIN	30_MIN	1_HR	3_HR	6_HR	12_HR
TIME	1335	1330	1330	1325			
DEPTH	0.23	0.58	0.94	1.27			
INTENSITY	2.76	2.32	1.88	1.27			

RUNOFF SEPT. 16, 1969

GAGE HEIGHT, IN FEET, AND DISCHARGE, IN CUBIC FEET PER SECOND, AT INDICATED TIME

DATE	TIME	GAGE HEIGHT	DISCHARGE	DATE	TIME	GAGE HEIGHT	DISCHARGE	DATE	TIME	GAGE HEIGHT	DISCHARGE
9-16	0850	10.00	0	9-16	0945	14.00	150	9-16	1215	12.18	24
9-16	0855	10.15	0	9-16	0950	14.84	300	9-16	1240	11.92	17
9-16	0900	10.34	1.0	9-16	1030	14.85	303	9-16	1320	11.62	12
9-16	0915	11.02	5.0	9-16	1050	14.23	184	9-16	1400	11.39	8.6
9-16	0920	11.09	5.5	9-16	1110	13.62	106	9-16	1510	11.08	5.5
9-16	0930	11.41	8.8	9-16	1125	13.17	68	9-16	1610	10.95	4.3
9-16	0935	11.60	12	9-16	1140	12.79	47	9-16	1755	10.87	3.7
9-16	0940	12.62	39	9-16	1200	12.40	31	9-16	2400	10.87	3.7

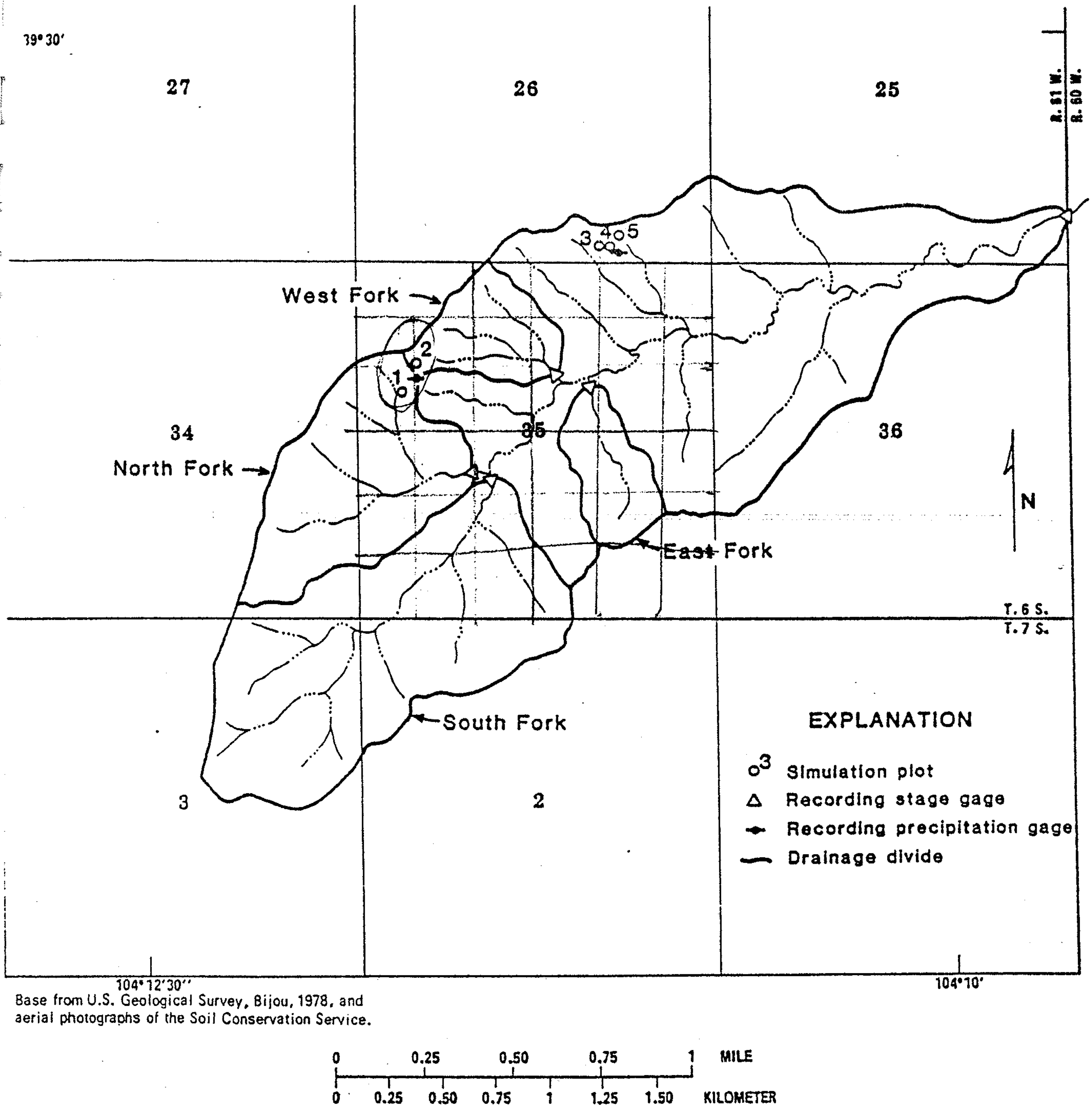


Figure 1.--Willow Gulch drainage basin and location of instrumentation.

APPENDIX D

Estimated precipitation amounts - as adjusted upward with maximizing moisture availability - from historical storm near Hale, Colorado.

Also included is a possible re-drawing of three envelopment lines of the greatest 24-hr precipitation (in.) within each State climatic division. - from Figure 9 on page 25

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

HYDROMETEOROLOGICAL REPORT NO. 51

Probable Maximum Precipitation Estimates, United States East of the 105th Meridian

Prepared by
Louis C. Schreiner and John T. Riedel
Hydrometeorological Branch
Office of Hydrology
National Weather Service

WASHINGTON, D.C.
June 1978

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APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 49 (GM 5-1) DATE 6/30-7/2/1932
RAINFALL CENTER STATE FISH HATCHERY,TX MOIST.ADJ.=116

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	42
	DURATION OF RAINFALL IN HOURS						
10	13.3	19.5	30.0	31.7	32.9	33.6	33.7
100	11.2	15.8	23.7	25.8	26.8	27.5	27.7
200	10.3	14.3	21.2	23.8	24.9	25.5	25.7
1000	7.7	10.5	15.5	19.0	20.2	20.7	20.9
5000	4.8	6.8	9.8	13.5	14.9	15.3	15.6
10000	3.6	5.2	7.4	10.3	11.3	11.6	11.8
20000	2.4	3.6	4.9	7.0	7.7	7.9	8.1

STORM INDEX NO. 50 (NA 1-20A) DATE 9/16-17/1932
RAINFALL CENTER SCITUATE,RI MOIST.ADJ.=148

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48
	DURATION OF RAINFALL IN HOURS						
10	7.0	10.2	11.9	12.2	12.2	12.2	12.2
200	6.8	10.2	11.1	11.6	11.6	11.6	11.6
1000	5.8	8.6	9.5	10.2	10.2	10.2	10.2
5000	4.0	6.5	7.3	7.9	8.1	8.2	8.2
10000	3.2	5.5	6.5	6.9	7.2	7.4	7.5

STORM INDEX NO. 51 (NA 1-20B) DATE 9/16-17/1932
RAINFALL CENTER RIPOGENUS DAM,ME MOIST.ADJ.=127

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30
	DURATION OF RAINFALL IN HOURS				
10	7.7	8.1	8.4	8.6	8.7
100	6.9	8.0	8.3	8.5	8.6
200	6.5	7.8	8.1	8.3	8.5
1000	5.2	7.2	7.5	7.7	7.9
5000	3.6	6.1	6.4	6.7	6.9
10000	3.0	5.5	5.9	6.3	6.5

STORM INDEX NO. 53 (SW 2-11) DATE 4/3-4/1934
RAINFALL CENTER CHEYENNE,OK MOIST.ADJ.=149

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18
	DURATION OF RAINFALL IN HOURS		
10	17.3	20.8	21.3
100	14.4	17.1	17.7
200	13.3	15.7	16.4
1000	9.1	10.7	11.1

STORM INDEX NO. 54 (LMV 4-21) DATE 5/16-20/1935
RAINFALL CENTER SIMMESPORT,LA MOIST.ADJ.=128

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60	72	96
	DURATION OF RAINFALL IN HOURS									
10	13.8	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
100	13.1	13.2	13.3	13.3	13.3	13.3	13.3	13.3	13.4	13.4
200	12.5	12.6	12.7	12.7	12.7	12.7	12.7	12.7	12.8	12.8
1000	10.2	10.3	10.4	10.4	10.5	10.7	10.8	10.8	10.9	11.0
5000	7.1	7.6	7.7	7.7	8.1	8.3	8.7	8.8	8.8	8.8
10000	5.7	6.2	6.3	6.4	6.9	7.2	7.7	7.8	7.8	7.8
20000	4.1	4.7	4.9	5.0	5.5	5.7	6.5	6.6	6.7	6.8
50000	2.0	2.6	2.9	3.2	3.4	3.7	4.6	4.9	5.0	5.3

STORM INDEX NO. 56 (- -) DATE 5/30-31/1935
RAINFALL CENTER HALE,CO MOIST.ADJ.=122

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24
	DURATION OF RAINFALL IN HOURS			
10	16.5	22.2	22.2	22.2
100	11.0	15.4	15.4	15.4
200	9.9	12.6	12.6	12.6
1000	4.6	7.2	7.2	7.2
5000	1.9	3.5	3.8	4.0

IF 70% in 2 Hours Highest = 11.55" ???

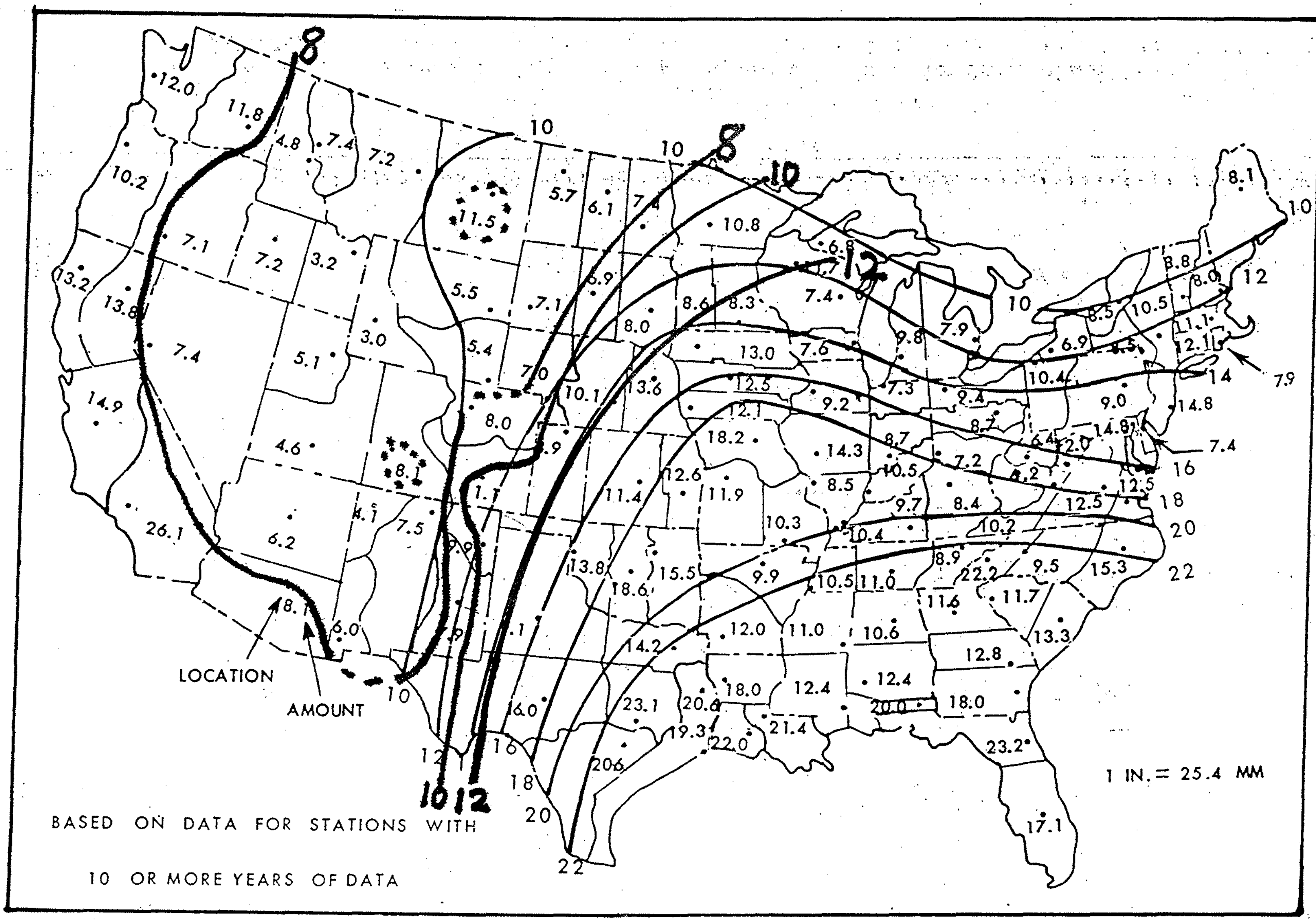


Figure 9.--Envelopment of the greatest 24-hr station precipitation (in.) within each State climatic division (through 1970).

USE OF RAINFALL-SIMULATOR DATA

IN PRECIPITATION-RUNOFF MODELING STUDIES

By Gregg C. Lusby and Robert W. Lichty

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4159

Prepared in cooperation with the

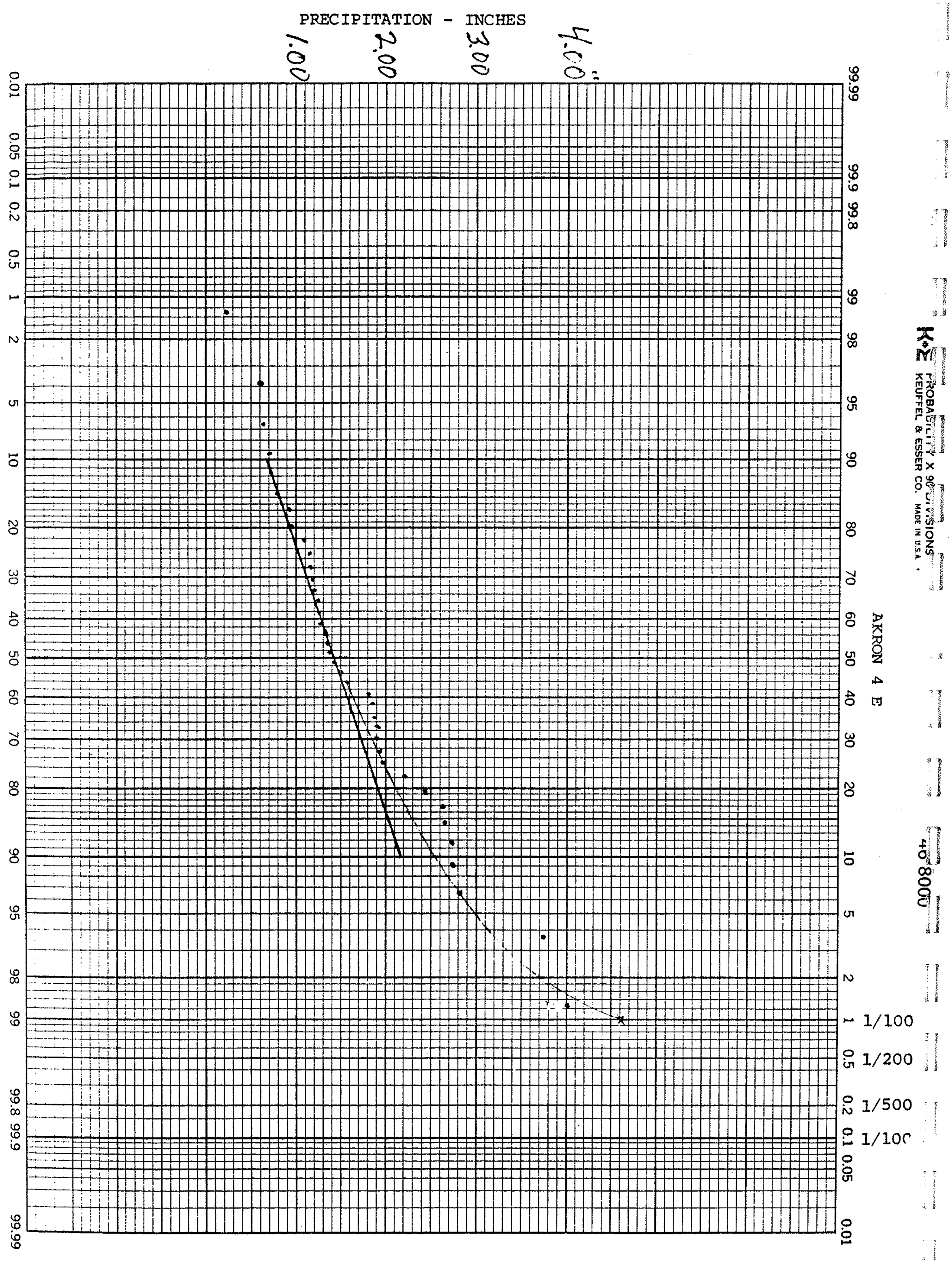
U.S. BUREAU OF LAND MANAGEMENT

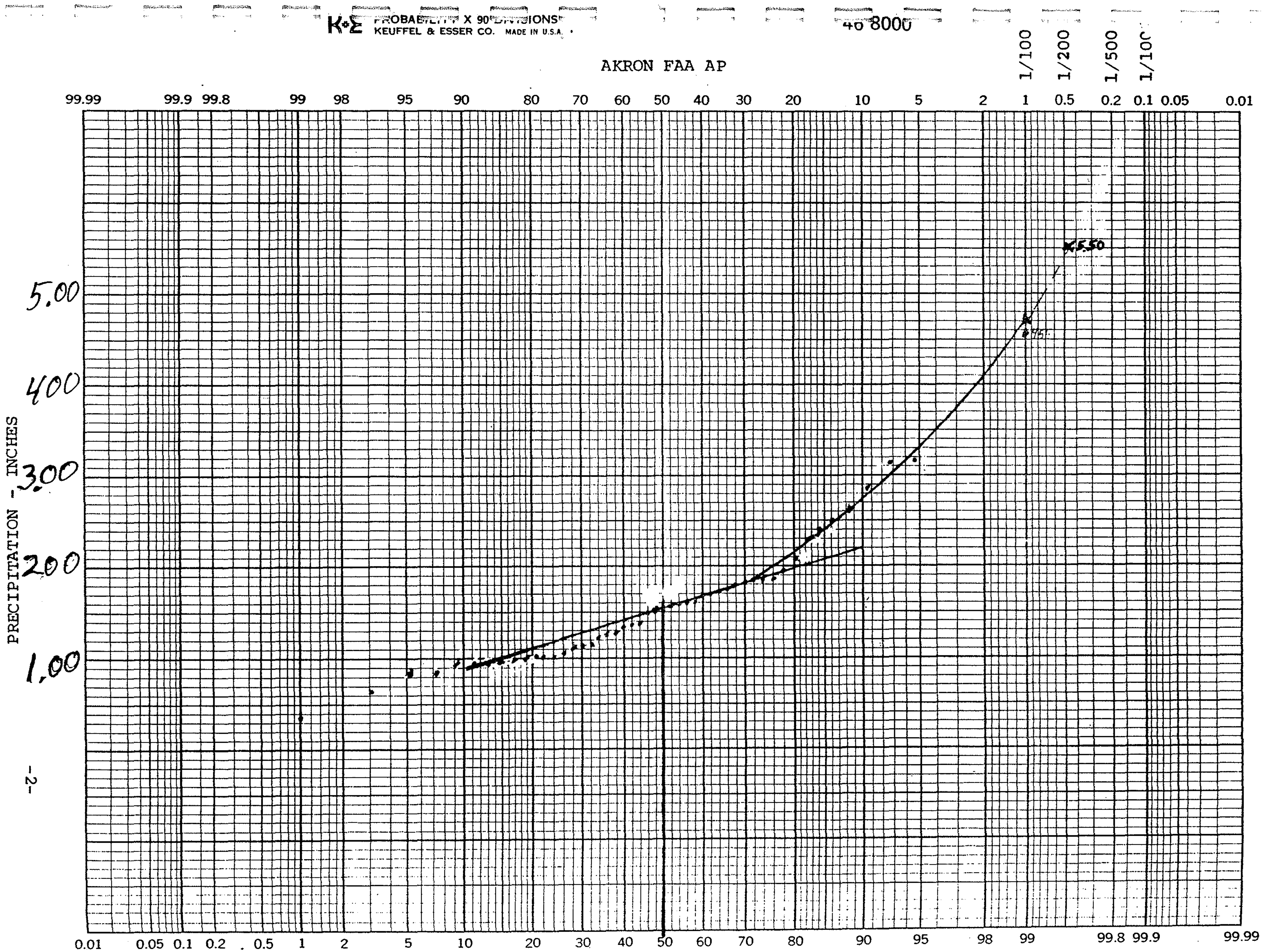
Denver, Colorado

1983

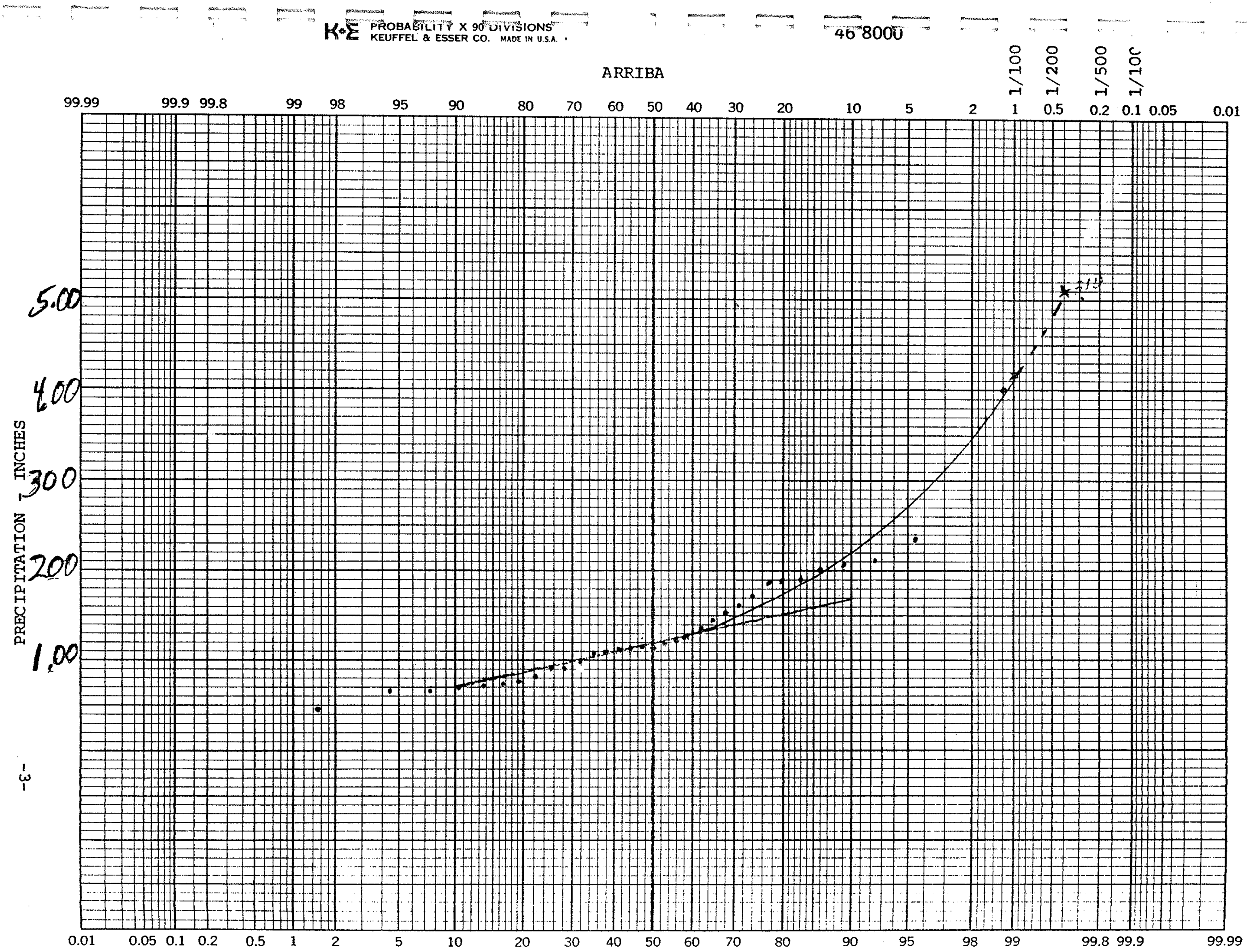
APPENDIX E

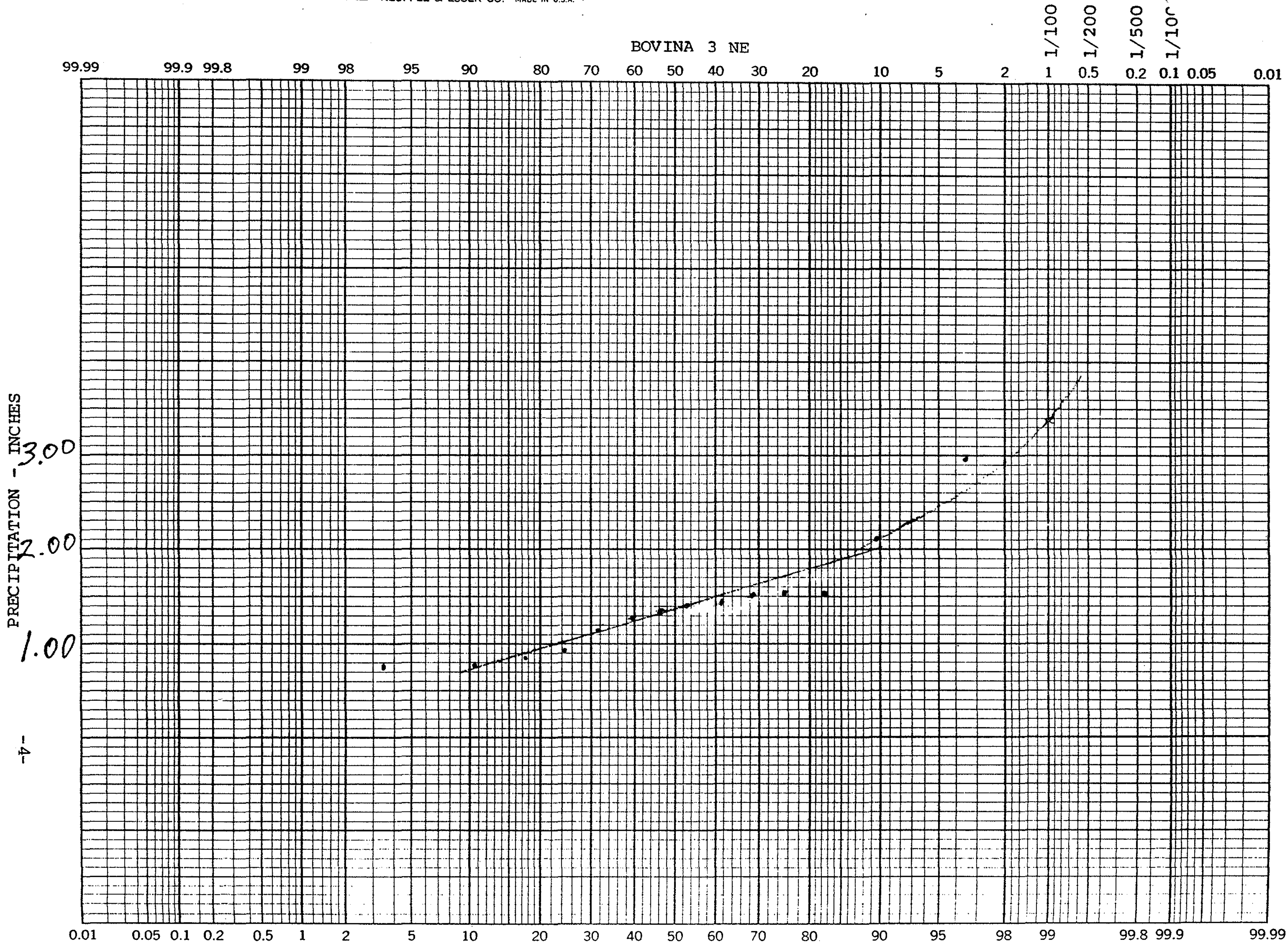
Fitted curves for 20 sets of annual peak 24-hour precipitation amounts - presented in sequence as listed in Table IV.

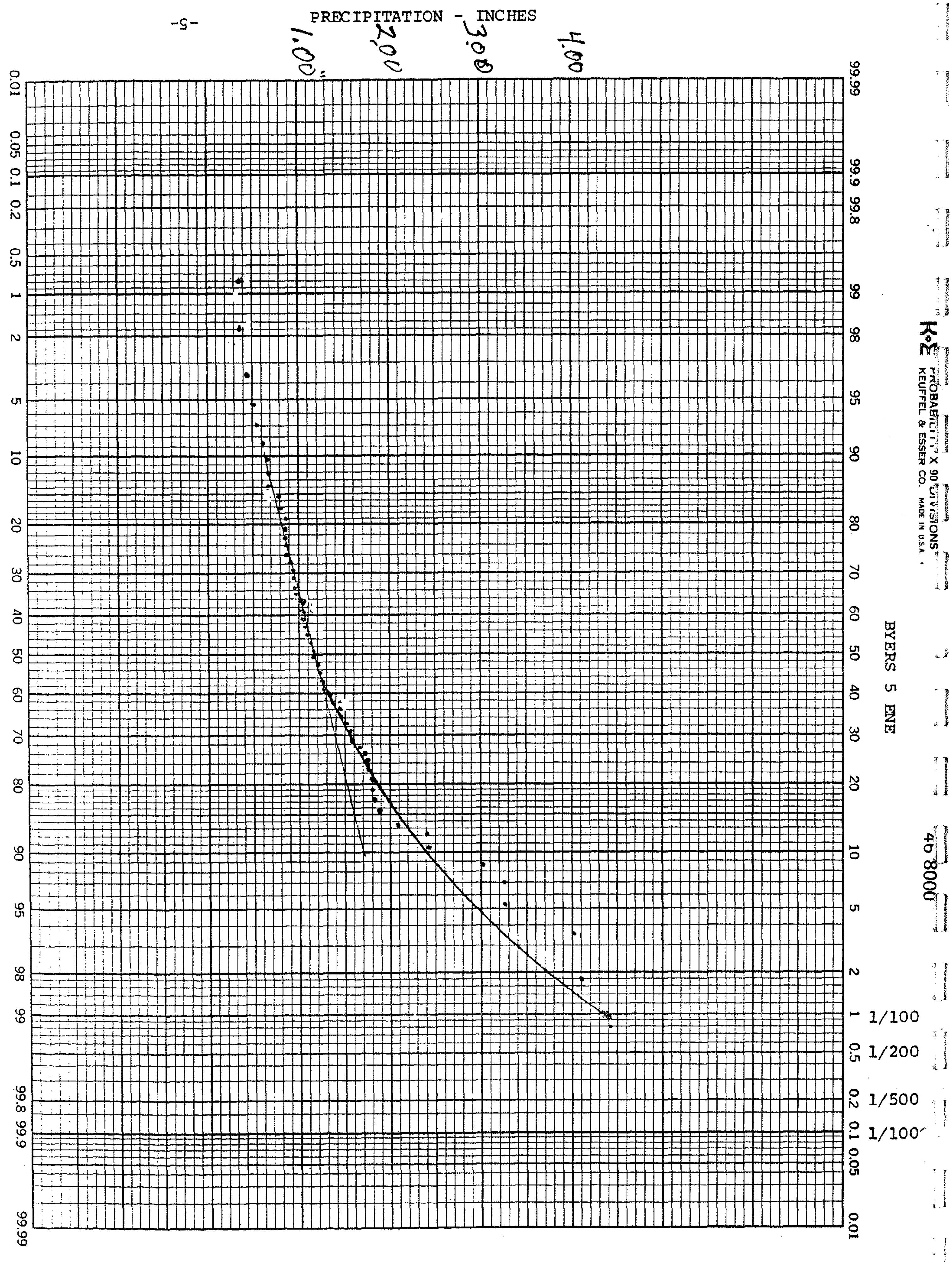

PRECIPITATION - INCHES
1.00
2.00
3.00
4.00"
AKRON 4 E
K&E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000
1/100
1/200
1/500
1/100


K•E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000
AKRON FAA AP
PRECIPITATION - INCHES
1.00
2.00
3.00
4.00
5.00
5.50
1/100
1/200
1/500
1/1000
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99

-2-

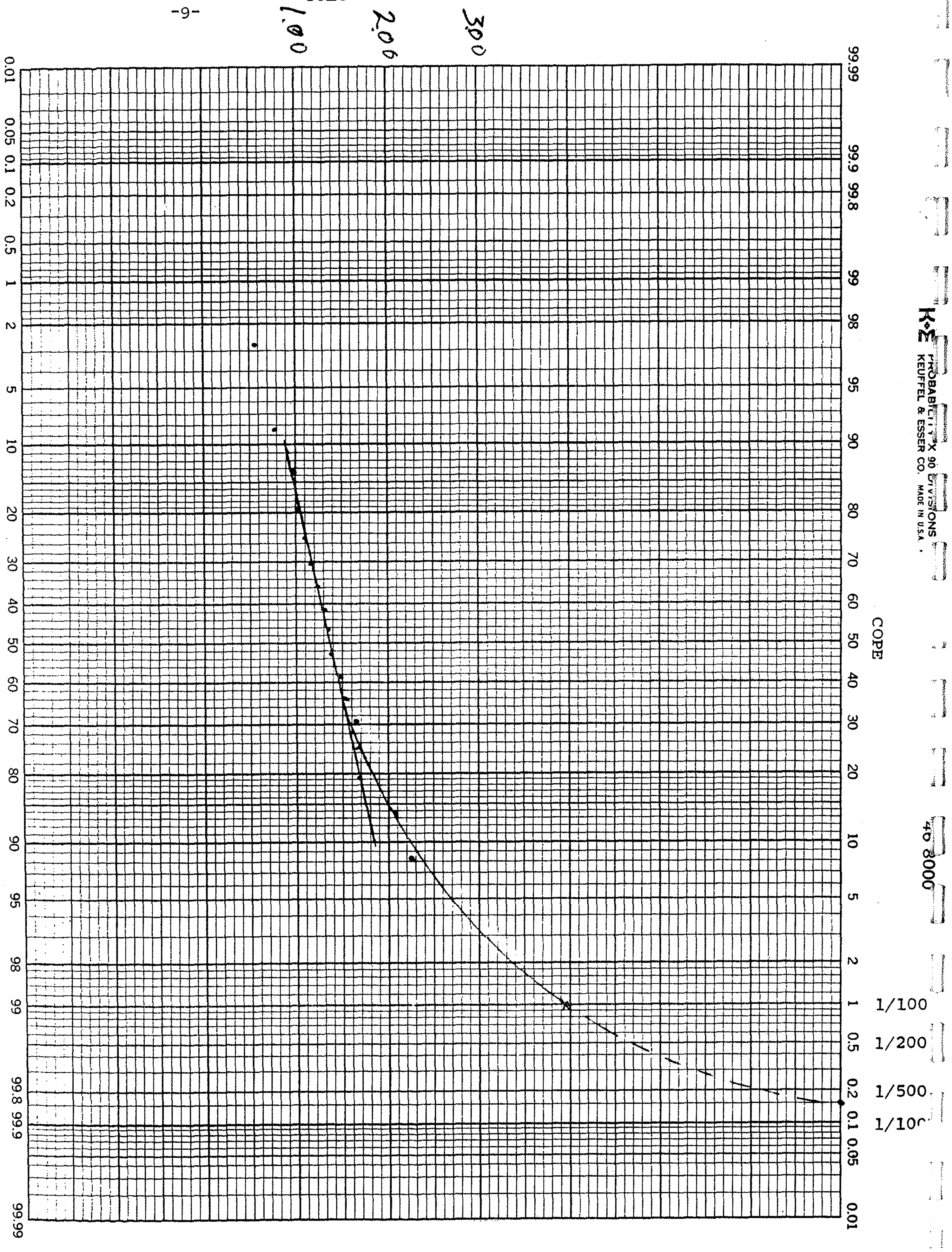

K•E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000
ARRIBA
1/100
1/200
1/500
1/10C
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
PRECIPITATION - INCHES
5.00
4.00
3.00
2.00
1.00
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

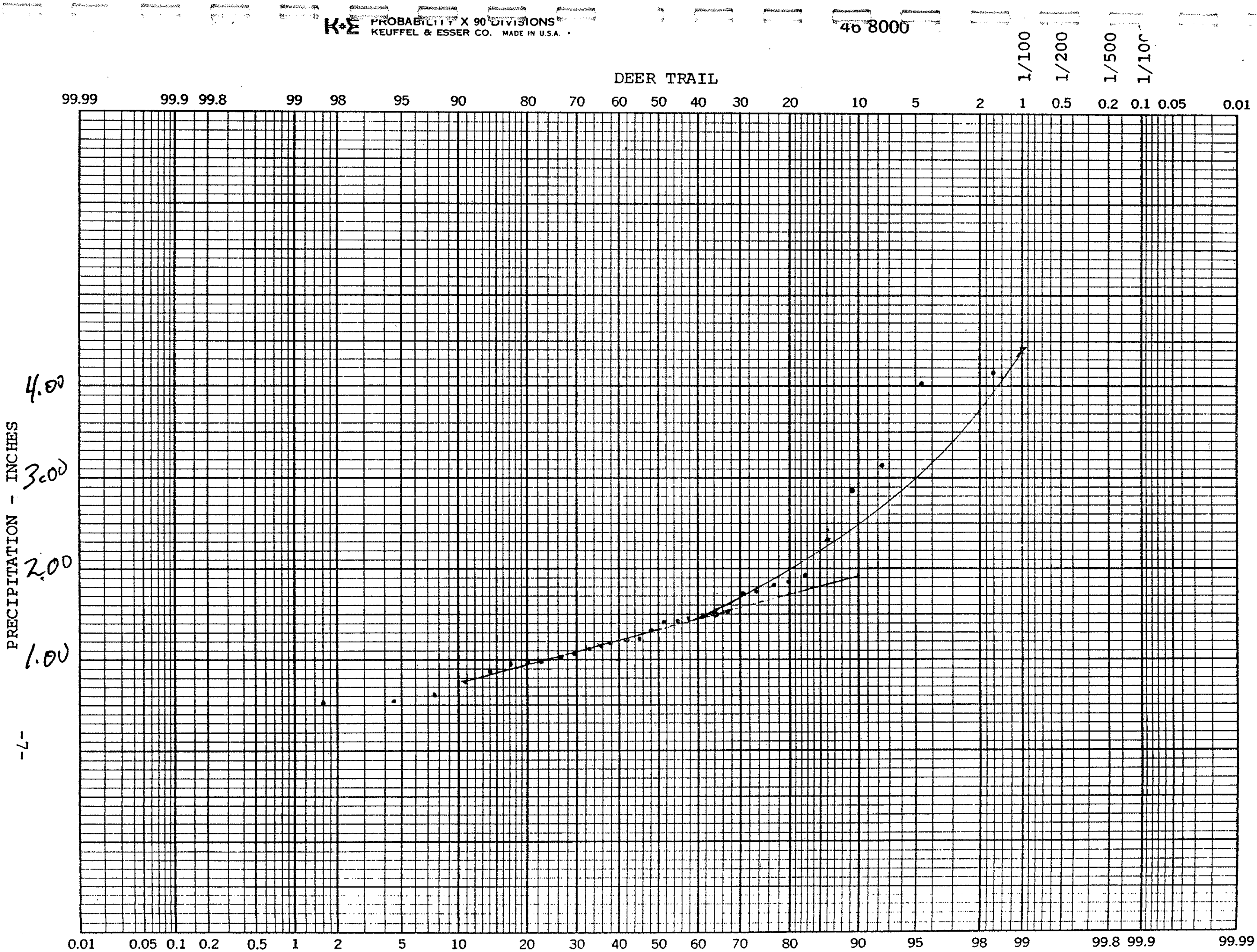

BOVINA 3 NE
PRECIPITATION - INCHES
1.00
2.00
3.00
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
1/100
1/200
1/500

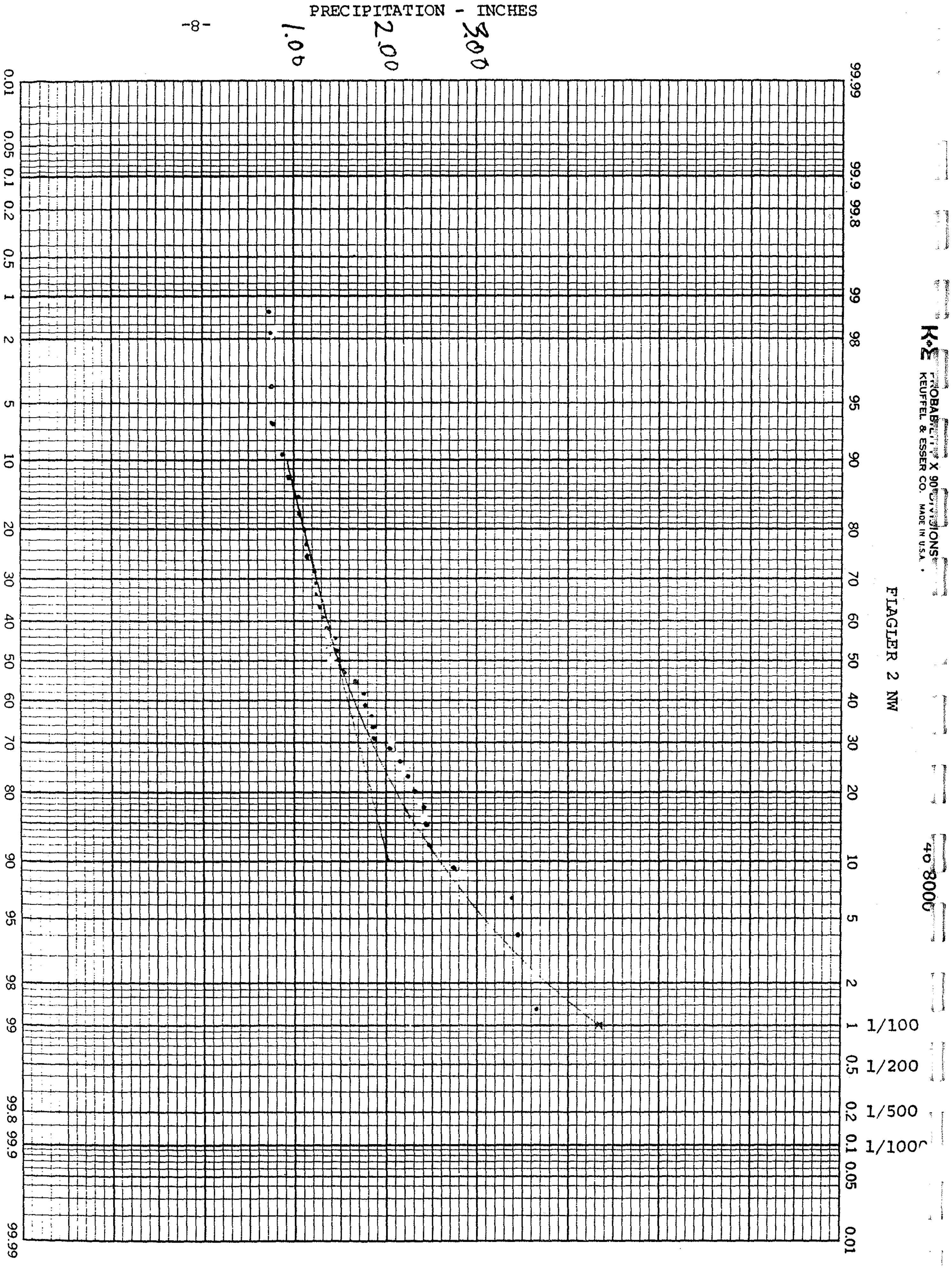


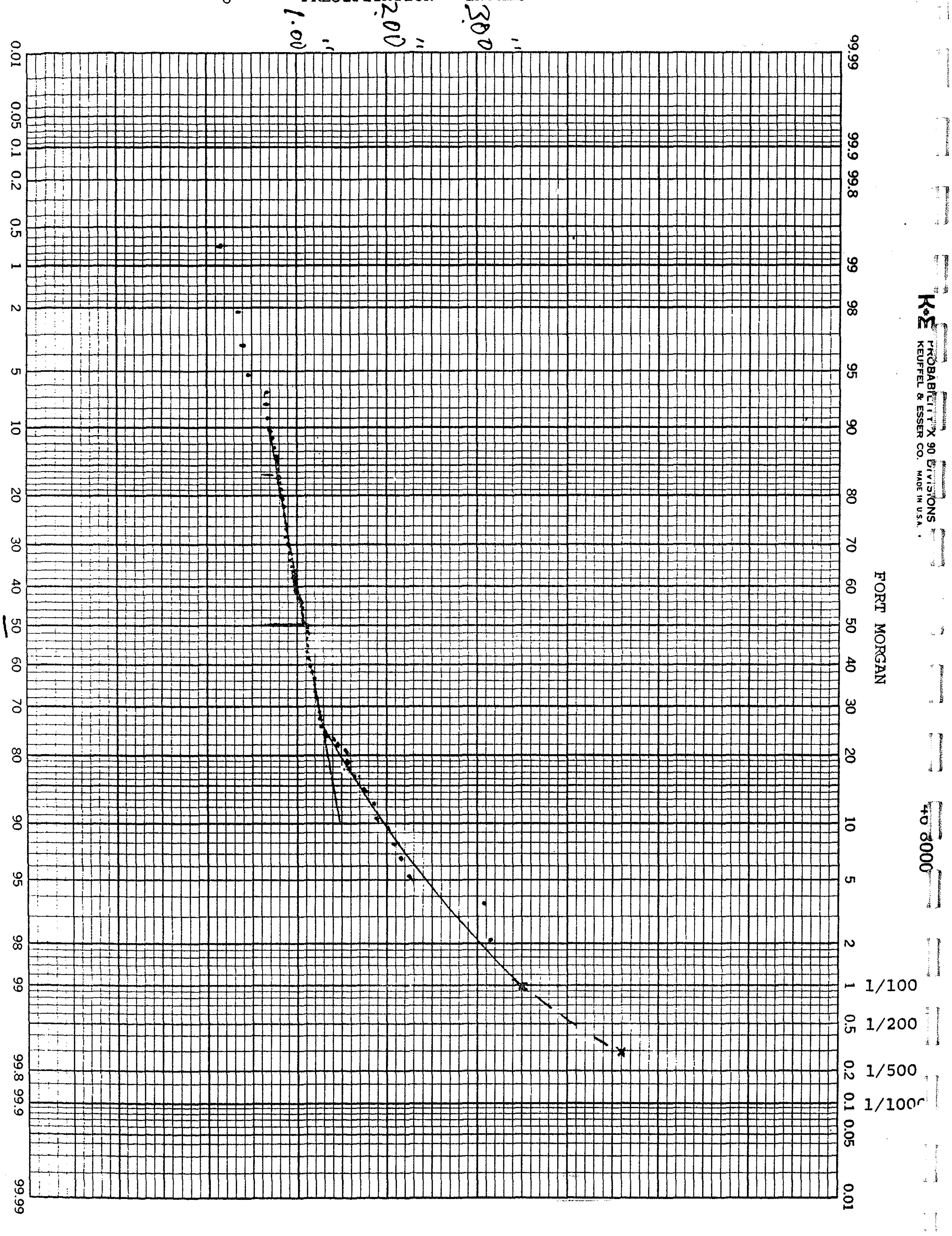
PRECIPITATION - INCHES
1.00"
2.00
3.00
4.00
BYERS 5 ENE
K+E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000
1/100
1/200
1/500
1/1000

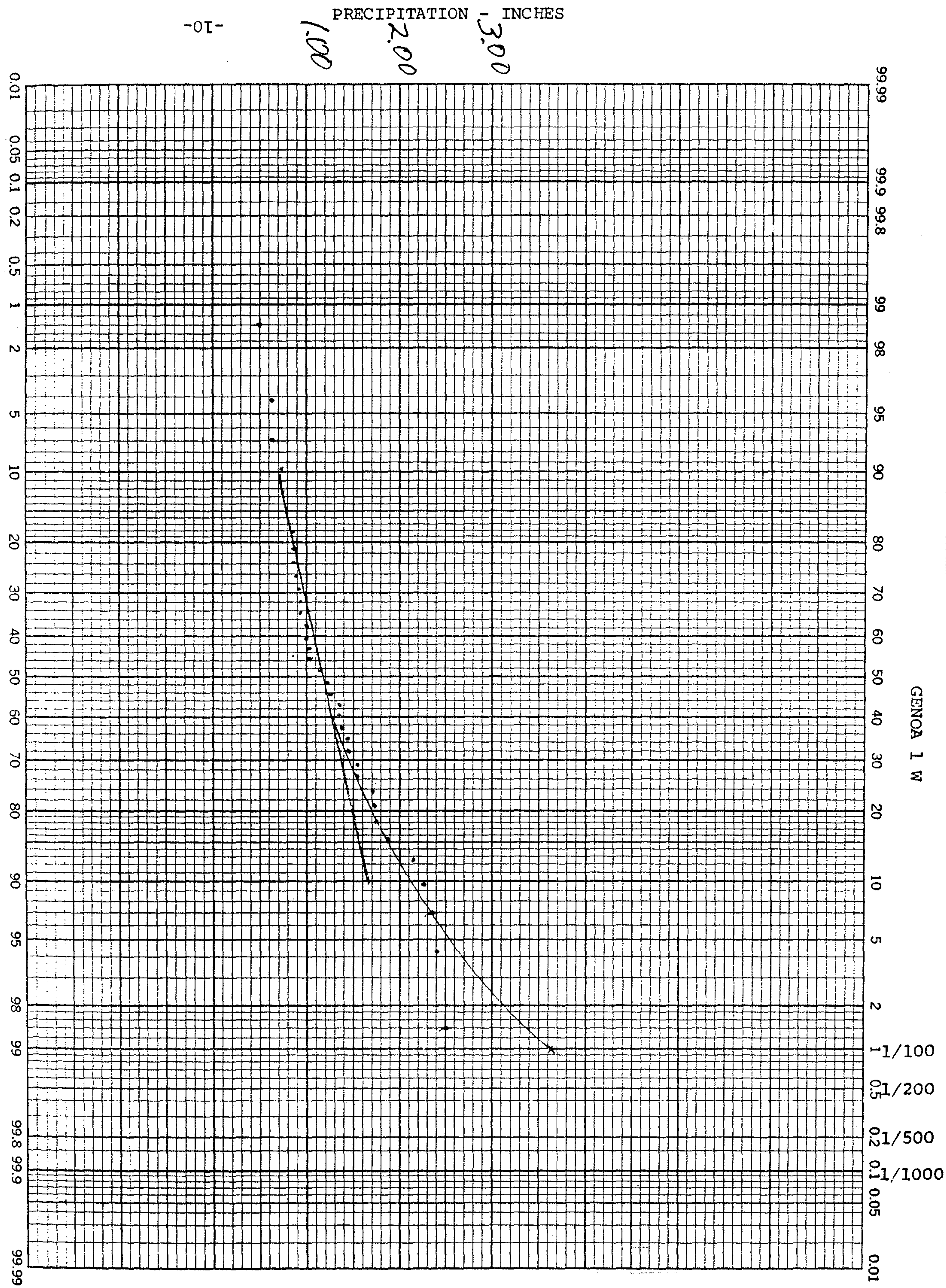
PRECIPITATION - INCHES

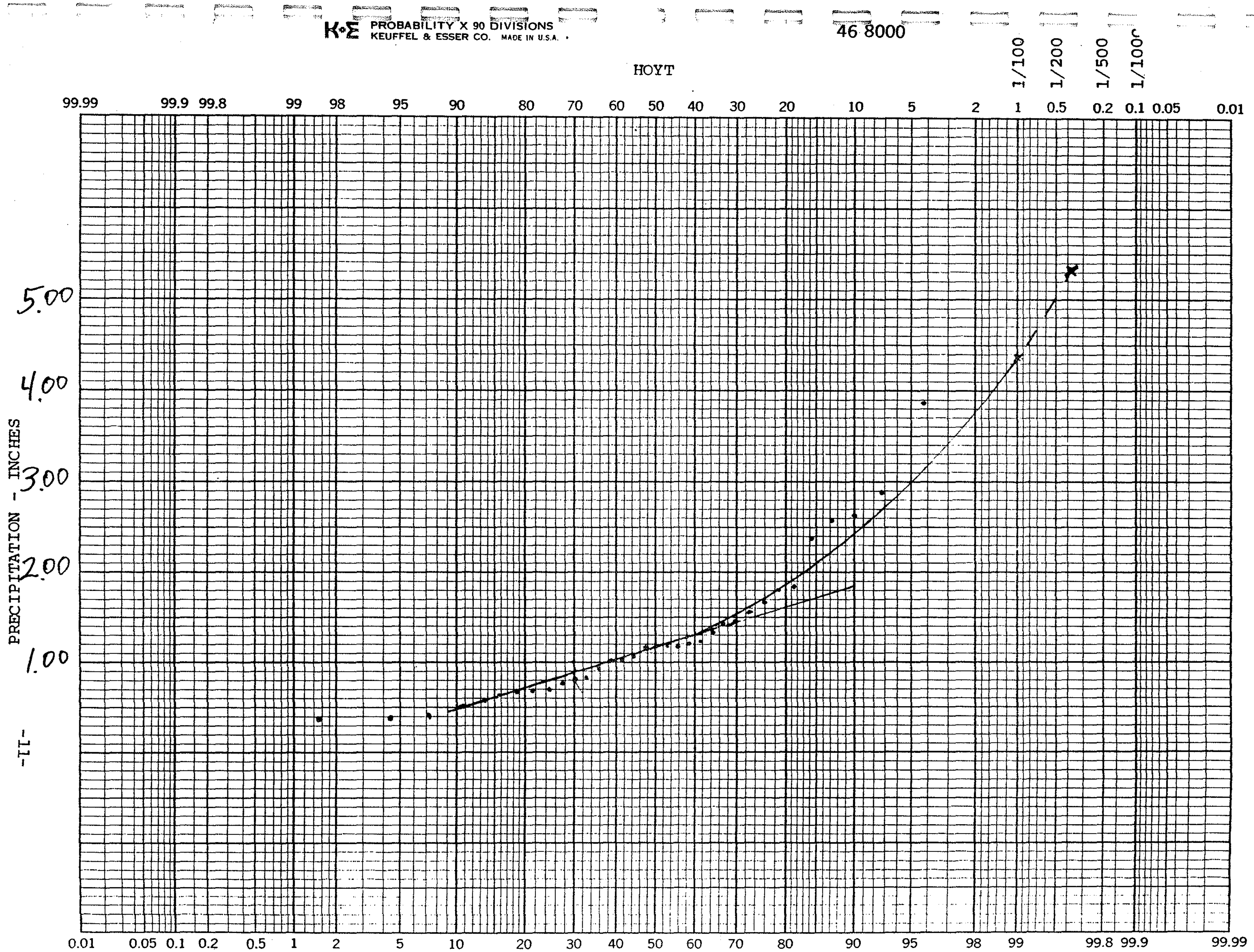


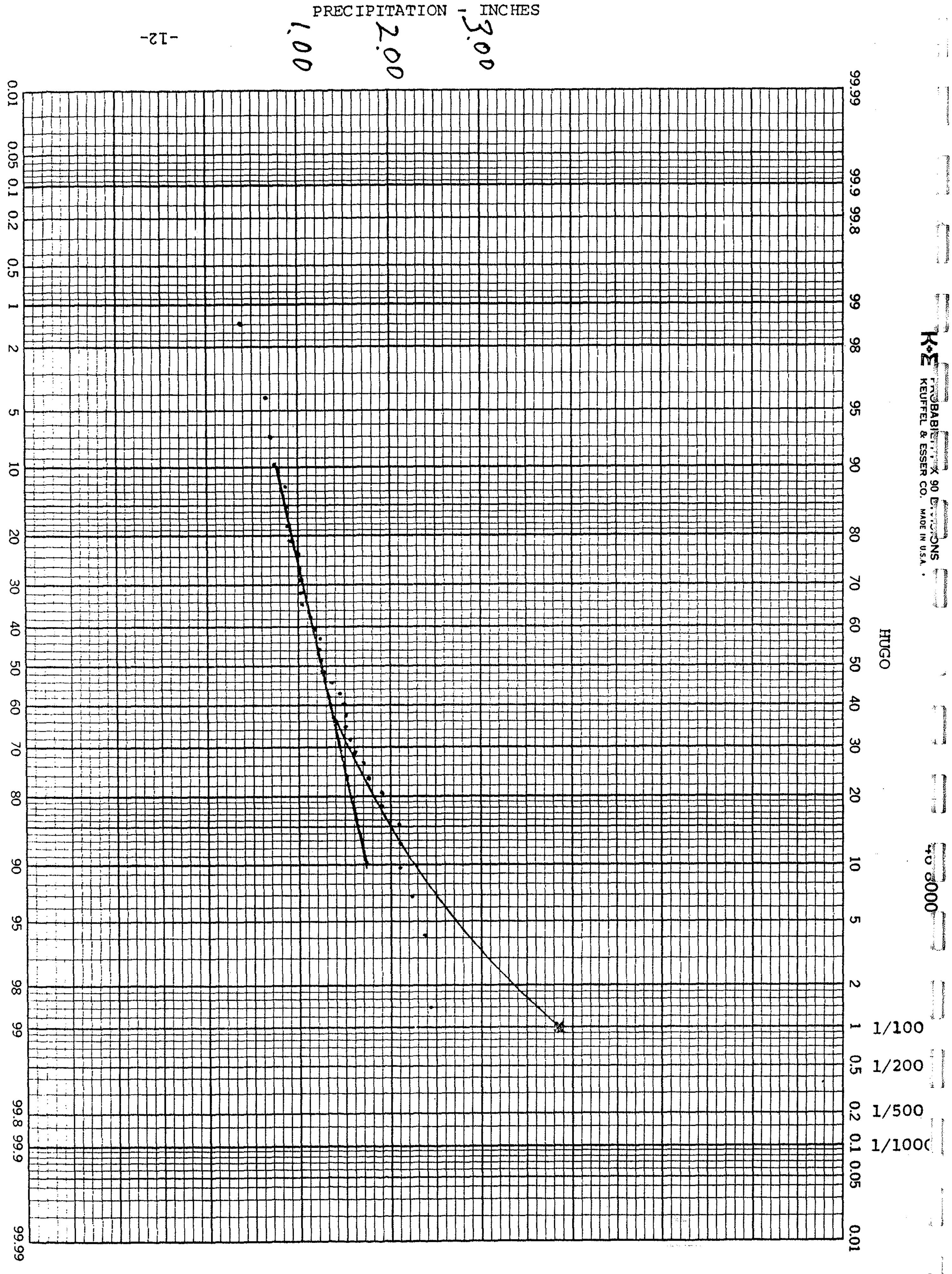

K•E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000
DEER TRAIL
PRECIPITATION - INCHES
1.00
2.00
3.00
4.00
1/100
1/200
1/500
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99

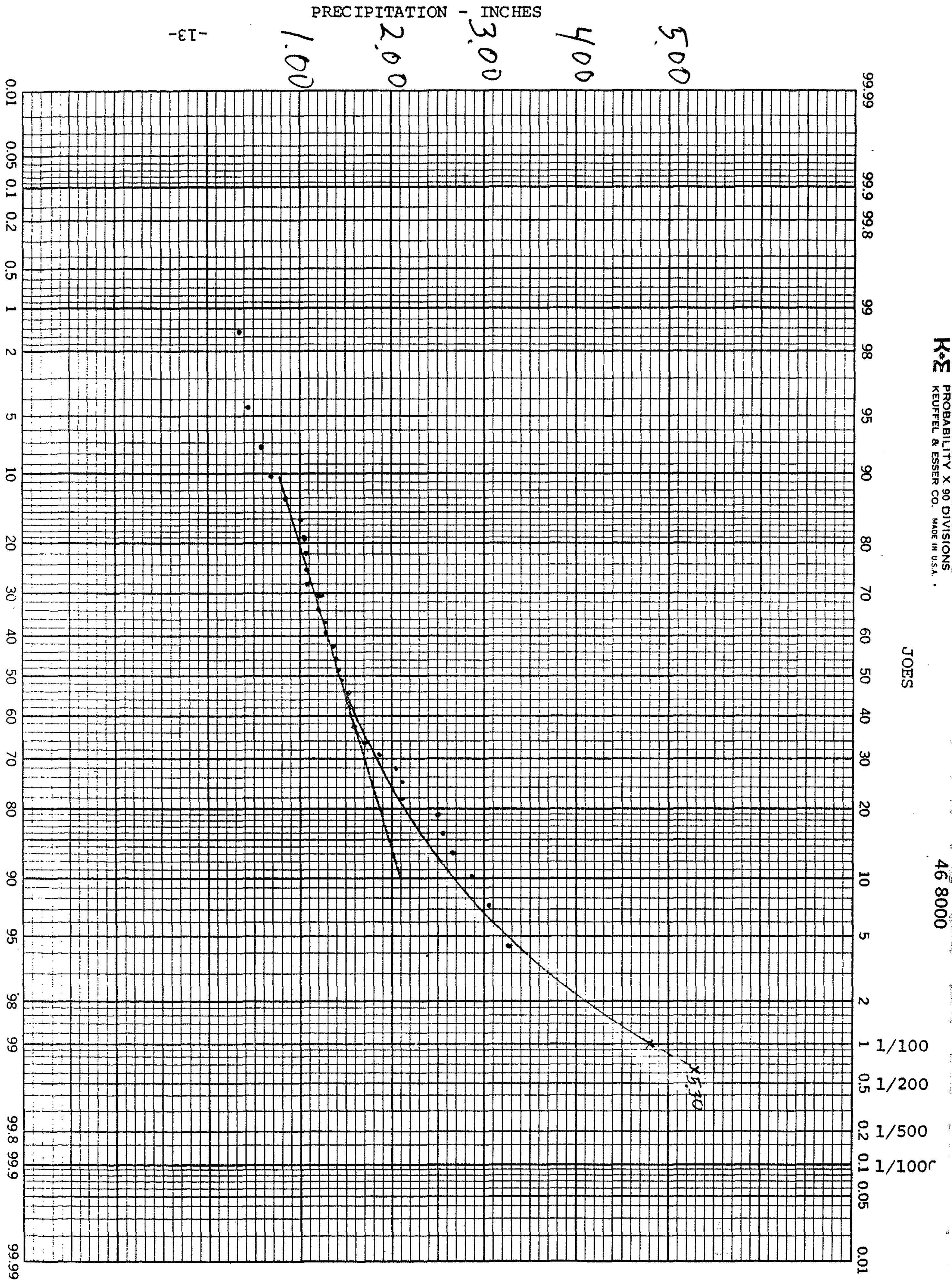

PRECIPITATION - INCHES
1.00
2.00
3.00
FLAGLER 2 NW
1/100
1/200
1/500
1/1000
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000


PRECIPITATION - INCHES
1.00"
2.00"
3.00"
FORT MORGAN
1/100
1/200
1/500
1/1000
K+E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000


PRECIPITATION - INCHES
1.00
2.00
3.00
GENOA 1 W
1/100
1/200
1/500
1/1000
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000


K·E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000
HOYT
1/100
1/200
1/500
1/1000
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
PRECIPITATION - INCHES
5.00
4.00
3.00
2.00
1.00
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99


PRECIPITATION - INCHES
1.00
2.00
3.00
HUGO
1/100
1/200
1/500
1/1000
K+E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8000


PRECIPITATION - INCHES
1.00
2.00
3.00
4.00
5.00
x5.30
1/100
1/200
1/500
1/1000
JOES
46 8000
K+E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

APPENDIX F

Segment of Final Report on Relationships between Hail and Rain in Kansas, Nebraska, and Eastern Colorado showing relationship between combined amounts of hail plus rain and crop damage.

Relationships between Hail and Rain In Kansas, Nebraska and Eastern Colorado

by

LOREN W. CROW

Denver, Colorado

Final Report

Contract No. NSF C-522

Sponsored by

NATIONAL SCIENCE FOUNDATION

Washington, D.C.

August 1969

LWC Report No. 76

There are several hundred cases in the three states which confirm the relatively low amount of coincident precipitation related to instances of hail damage. Some examples will be given. Fig. 7 shows the hail loss by townships and the coincident rainfall occurring on June 14, 1967, the largest hail loss day for Colorado in the ten-year period studied. The time of occurrence of the hail loss ranged from 1500 through 2400 with hail occurring coincidentally during the hours of 1500 and 1600 in at least five different areas separated by 30 miles or more in northeastern Colorado. The coincident precipitation for the 30 stations located inside the envelope line in Fig. 7 is shown in a portion of Table III.

TABLE III. NUMBERS OF CASES IN FIVE CLASSES OF DAILY AMOUNTS OF PRECIPITATION REPORTED AT STATIONS WITHIN OR NEAR THE HAIL-DAMAGED AREAS ON THE PEAK LOSS DAY DURING 1957-67 IN EACH STATE.

Precipitation Range	Colorado June 14, 1967 $354,390	Nebraska July 18, 1961 $1,127,706	Kansas June 7, 1966 $2,199,476
0	1	24	4
T. - .49	21	64	40
.50 - .99	7	15	40
1.00 - 1.99	1	1	32
2.00 +	0	0	18

There were at least three measurements made at Colorado stations within a six mile square township that suffered hail damage. The .37 inch recorded at Julesburg near the northeastern corner was in a township suffering a total hail loss between $5,000 and $19,999. The .44 inch measured at LeRoy 7WSW was in a township which sustained a loss in excess of $20,000.

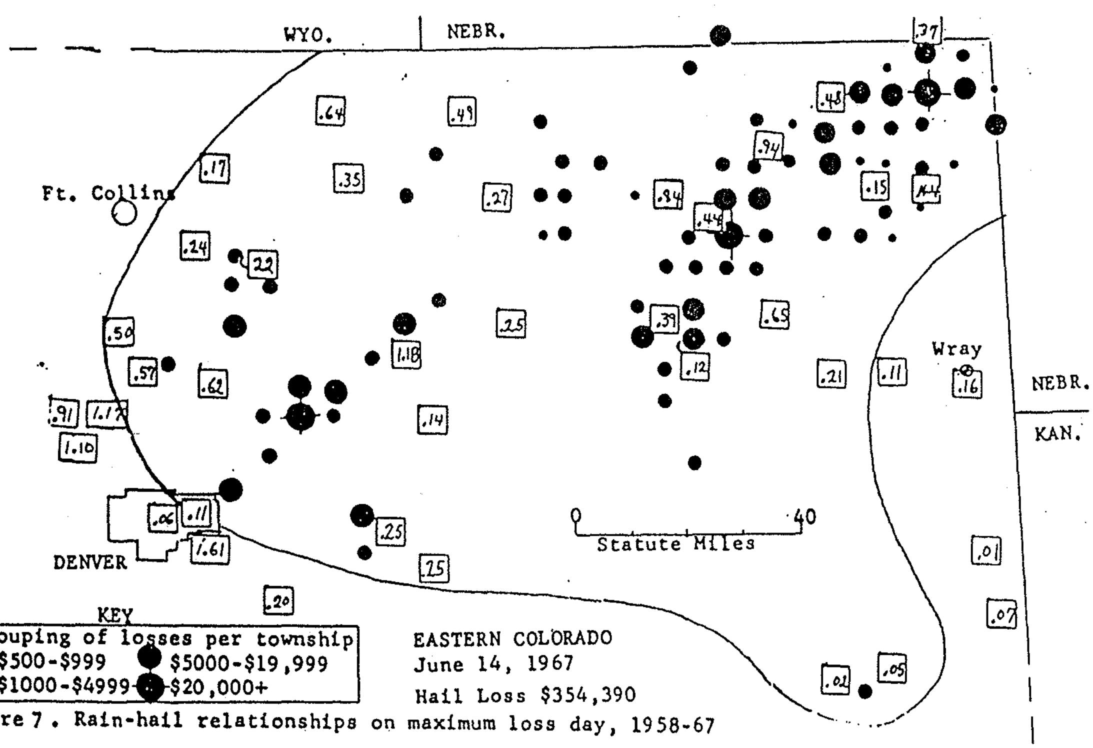


Figure 7. Rain-hail relationships on maximum loss day, 1958-67

Heavy hail damage sometimes is accompanied by heavy amounts of coincident rainfall, but most instances of heavy rainfall do not have hail associated therewith.

APPENDIX G

Segment of an ANALYSIS OF HMR-55 AND THE METEOROLOGICAL FACTORS RELATED TO THE GENERATION OF A PMP EVENT OVER SANTA FE, NEW MEXICO by George W. Wilkerson, North American Weather Consultants

ANALYSIS OF HMR-55 AND THE METEOROLOGICAL FACTORS RELATED TO THE GENERATION OF A PMP EVENT OVER SANTA FE, NEW MEXICO

NAWC Report AQ-86-11

Prepared for

Public Service of New Mexico

By

George W. Wilkerson

North American Weather Consultants

3761 South 700 East

Salt Lake City, Utah 84106

October 1986

4.5 Convective Storm Precipitation Data

Several convective storms play a major role in the determination of PMP values for Santa Fe in HMR-55. There are no limits set on the transposition of convective storms as they have occurred throughout the region. Two convective storm precipitation amounts were transposed even though the rainfall data associated with these storms is very questionable. Both of these storms play a major role in determining PMP amounts for both general and local storms. The two storms in question are Leadville, Colorado (general storm) and Masonville, Colorado (controlling case for local storms).

A study performed by Crow (1983) showed that precipitation measurements taken from 1919 to 1938 at Leadville, Colorado are very likely invalid. The storm in question occurred on July 27, 1937. During the period of 1919 to 1938 a Marvin type weighing gage was in place at Leadville (see Figure 4.5). Records show that a large percentage of the Leadville storm precipitation was in the form of hail. The shape of the Marvin gage is such that significant amounts of hail striking the surrounding snow shield are deflected into the gage resulting in abnormally high precipitation amounts to be recorded. A cumulative precipitation graph (Figure 4.6) shows that there was a significant increase in monthly precipitation corresponding to the years in which the Marvin type gage was installed. Furthermore there is no supporting precipitation data from surrounding gages for this storm. Finally, Crow showed that streamflow, a short distance downstream from Leadville, actually decreased on the day of the storm. It is unfortunate that this storm was considered to be a major controlling storm in light of the questionable precipitation data involved.

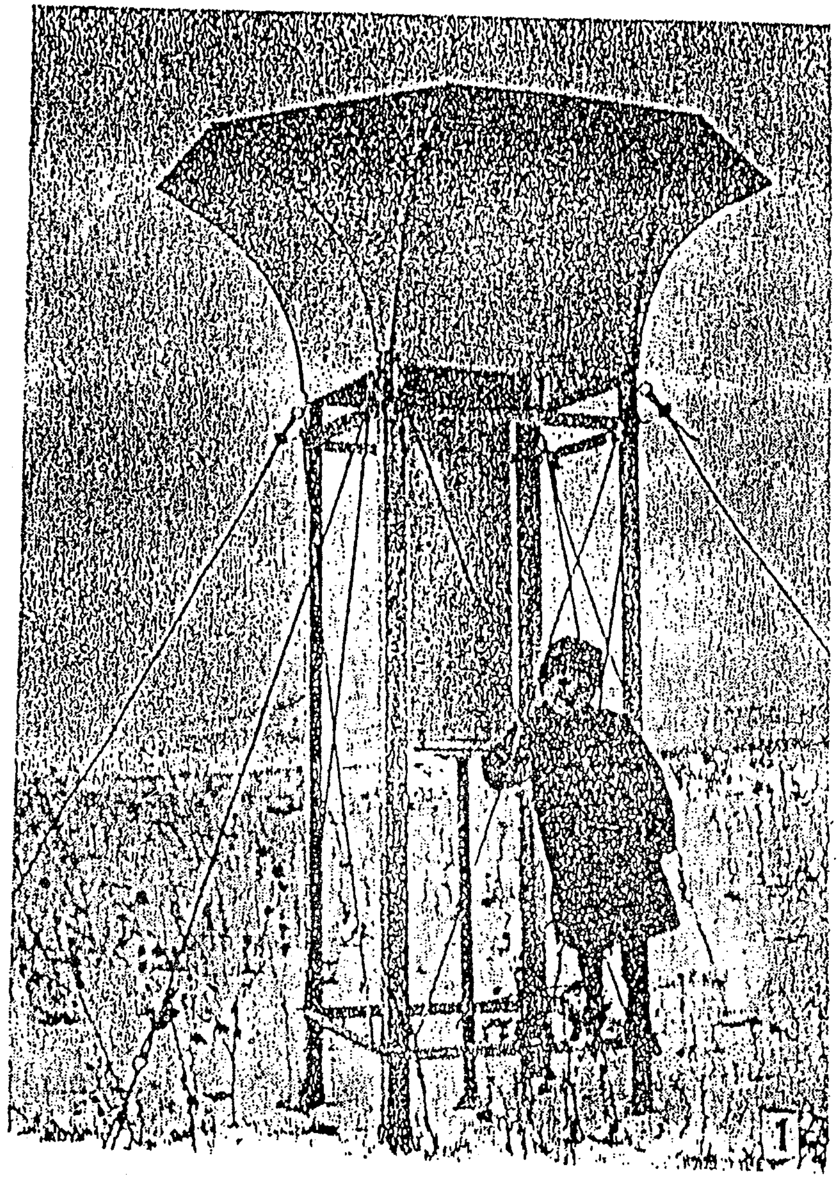


Figure 4.5 Marvin type weighing gage.

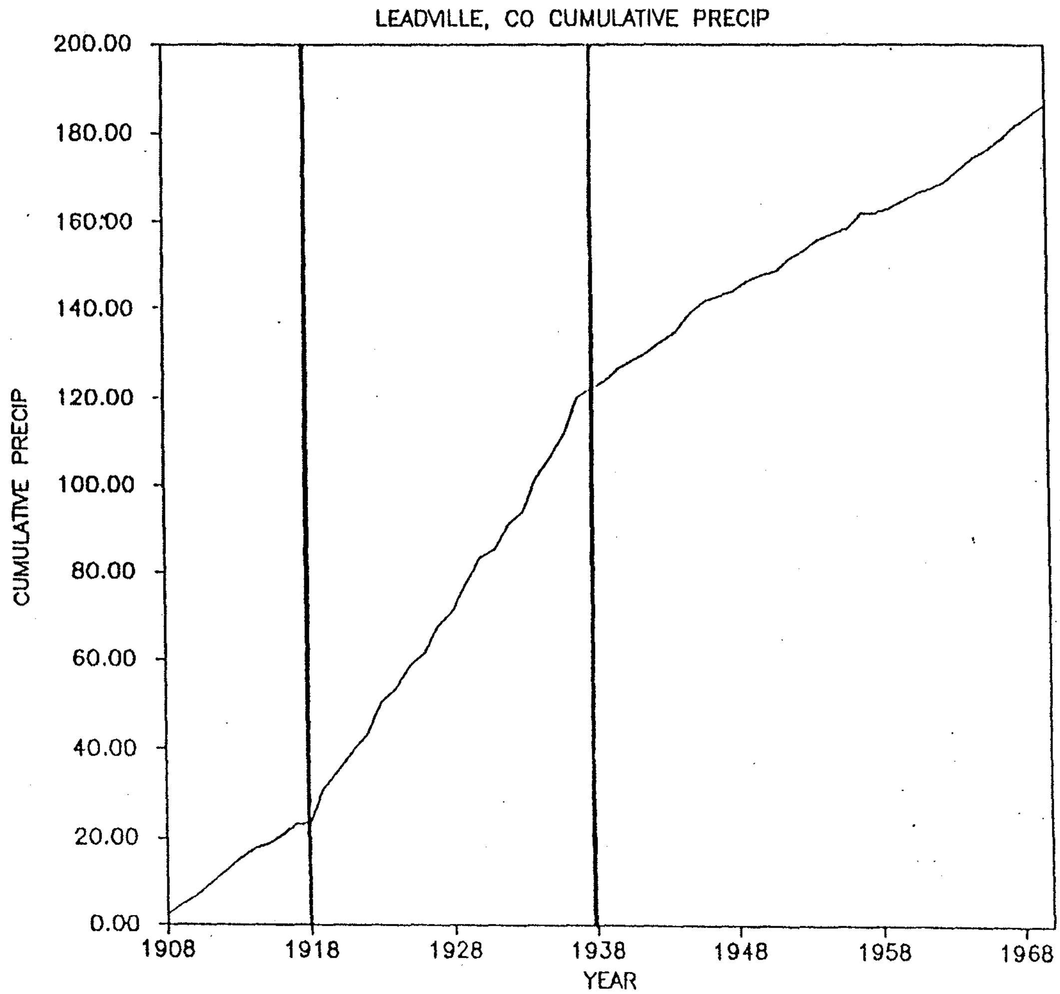


Figure 4.6 Leadville, Colorado cumulative precipitation 1908-1970.

The Masonville, Colorado storm was considered to be "the most important local storm in this study" by HMR-55 although the precipitation data used is very questionable. A direct quote from HMR-55 follows:

> "The only records of this storm come from a handful of ranchers in the area. Of these, one rancher reported... "about 7 in. within a half hour." Another rancher, approximately one-half mile from the first, reported ..."about 5 inches between 6 and 7 pm, most of it within 20 minutes..." (Follansbee and Sawyer, 1948). words such as "about" and "most" make evaluating these reports very difficult. In light of the fact that rain lasted approximately one hour only one-half mile from the 7 in report and the vagueness surrounding the 7 in amount, it was decided to accept the Masonville storm as 7 in in 1 hour."

Again, it seems unrealistic to put so much weight on rainfall observations taken by ranchers without instruments and use them in a report as critical as HMR-55.