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COMPARISON OF THE METHODS OF ESTIMATING MEAN AREAL RAINFALL

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A comparison of nine different methods of estimating mean areal rainfall is made. Five areas from three continents of the world are selected for application of the methods. The methods are utilized to estimate mean areal rainfall for daily, monthly and yearly values. It is shown that all methods generally yield comparable results, and that for most hydrologic problems simpler methods of estimating mean areal rainfall are sufficiently accurate-an observation contradicting the traditional belief.

Determination of the average amount of rain which falls on a watershed during a given storm is a fundamental requirement for many hydrologic studies. Of practical necessity rainfall is measured at a number of sample points, and the amounts recorded at these points are utilized to form an estimate of mean areal rainfall for the storm of interest. This estimate will, however, differ from the true mean areal rainfall for three reasons:

1. The sample points may be unrepresentative of the watershed in that no gauge may lie in the section of watershed having extreme rainfall.
2. The record may be constantly higher or lower than the true rainfall at that sample point.
3. Factors may combine to cause the rainfall amounts recorded at gauges to differ from their true values in an unsystematic manner.

It is, therefore, not surprising that little is known about the accuracy of the mean areal rainfall estimates; both the ease of making accurate point meas-

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Table 1.
Sources of information on methods of estimating mean areal rainfall.

Method	Source of information
UM	Whitmore et al. (1961); Rainbird (1967).
GAAM	Whitmore et al. (1961).
TP	Thiessen (1911); Whitmore et al. (1961); Bruce & Clark (1966); Rainbird (1967); Hutchinson (1969); Diskin (1969, 1970).
AAM	Whitmore et al. (1961).
TAM	Whitmore et al. (1961).
MYER	Myers (1959); Whitmore et al. (1961).
ISO	Reed & Kincer (1917); Butler (1957); Whitmore et al. (1961); Bruce & Clark (1966); Rainbird (1967); Diskin & Davis (1970).
TREN	Dawdy & Langbein (1960); Sutcliffe & Carpenter (1967); Unwin (1969); Chidley & Keys (1970); Shaw & Lynn (1972); Lee et al. (1974).
RDS	McGuiness & Harold (1965); Solomon et al. (1968); Pentland & Cuthbert (1971); Wei & McGuiness (1973).

urements of rainfall and the simplicity of determining the mean areal rainfall are indeed deceptive. Nevertheless, several techniques of estimating mean areal rainfall are available. Some of them are simple, but normally adequate for practical purposes, although they tend to be employed without sufficient appreciation of their limitations. Others are relatively new and demand the use of considerable skill, and even judgement in some cases, on the part of the user. The question arises: How do these techniques compare? Is one technique superior to the other? Are these techniques simply different alternatives to estimate mean arean rainfall or have they led to an increased understanding of spatial distributional characteristics of rainfall? These are the questions the present study attempts to answer.

METHODS OF ESTIMATING MEAN AREAL RAINFALL

The following methods were considered:

1. Unweighted mean (UM)
2. Grouped area aspect weighted mean (GAAM)
3. Individual area weighted mean, Thiessen polygon (TP)
4. Individual area altitude weighted mean (AAM)
5. Triangular area weighted mean (TAM)

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6. Myers method, grouped mean weighted for distance and altitude (MYER)
7. Isohyetal method (ISO)
8. Trend surface analysis (TREN)
   (a) Linear function (LIN), a simple TREN
   (b) Quadratic function (QUAD), a complex TREN
   (c) Cubic function (CUB), a more complex TREN
9. Recipropal distance squared method (RDS)

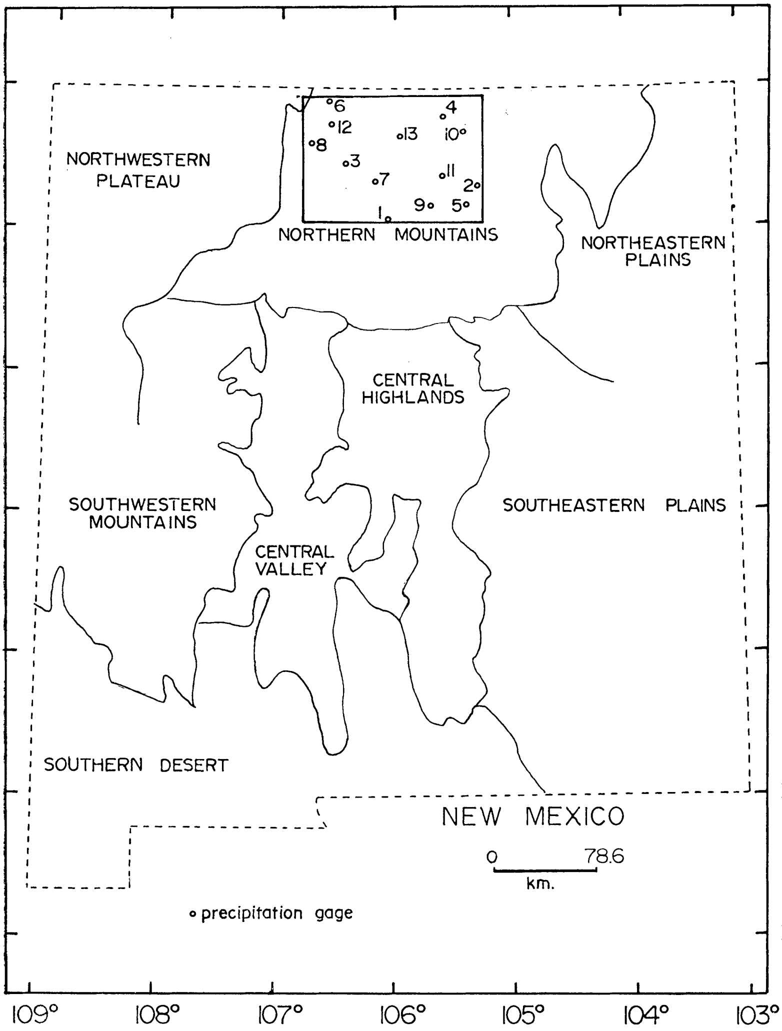

Fig. 1.
Study Area 1 in New Mexico, USA.

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These methods and their variants are well described in the literature, and no attempt will be made to repeat them here. Instead, we summarize the sources of information on these methods in Table 1. Henceforth, these methods will be referred to by their corresponding abbreviations.

DATA ANALYSIS AND DISCUSSION

Five application examples are cited to illustrate the comparative performance of these methods. Two of them are from New Mexico, one from South Africa, and two from Great Britain. It is noted that these areas have contrastingly different physiographic and climatological features. In order to arrive at a definitive conclusion we feel that these methods must be applied to a number of events in a number of areas. This will minimize the degree of fortuity arising in their performance.

Table 2.
General information on raingauge stations in Area 1 of New Mexico, USA.

Station Number	Station	County	Latitude Deg.	Latitude Min.	Longitude Deg.	Longitude Min.	Altitude (m)
1	Alcalde	Rio Arriba	36	06	106	04	1731
2	Black Lake	Colfax	36	18	105	17	2548
3	Canjilon	Rio Arriba	36	29	106	27	2386
4	Cerro	Taos	36	49	105	35	2342
5	Chacon	Mora	36	10	105	23	2591
6	Chama	Rio Arriba	36	55	106	35	2393
7	El Rito	Rio Arriba	36	20	106	11	2094
8	El Vado	Rio Arriba	36	36	106	44	2057
9	Penasco	Taos	36	10	105	41	2414
10	Red River	Taos	36	42	105	24	2644
11	Taos	Taos	36	22	105	37	2117
12	Tierra Amarilla	Rio Arriba	36	45	106	34	2263
13	Tres Piedras	Taos	36	40	105	59	2472

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Table 3.
Mean areal rainfall estimates by different methods.
Area 1 in New Mexico, daily totals (cm)

Date	UM	GAAM	TP	AAM	TAM	MYER	ISO	TREN			RDS
								LIN	QUAD	CUB	
1-1-1974	1.24	1.17	1.30	1.40	1.30	1.66	1.35	1.34	1.26	1.85	1.35
2-1-1974	0.91	0.91	0.91	0.81	0.81	1.18	0.89	.92	.79	1.07	0.79
3-29-1973	0.71	0.97	0.76	0.84	0.61	.92	0.66	.76	.80	1.05	0.74
3-30-1973	0.64	0.58	0.58	0.51	0.48	.85	0.56	.61	.62	.84	0.71
12-3-1964	1.27	1.22	1.24	1.22	1.19	1.47	1.27	1.26	1.18	1.50	1.35
$\bar{x}$	.95	.97	.96	.96	.88	1.22	.95	.98	.93	1.26	.99
σ^2	.09	.06	.10	.13	.13	.12	.13	.10	.08	.17	.11
σ	.29	.25	.31	.35	.36	.35	.35	.31	.28	.41	.33
C_v	.31	.26	.32	.37	.41	.29	.37	.32	.30	.32	.34

$\bar{x}$ = mean; σ^2 = unbiased variance; σ ≡ unbiased standard deviation; C_v ≡ coefficient of variation.

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Table 4.
Mean areal rainfall estimates by different methods.
Area 1 in New Mexico, of monthly totals (cm)

Month	UM	GAAM	TP	AAM	TAM	MYER	ISO	TREN			RDS
								LIN	QUAD	CUB	
Feb 1974	0.53	0.33	0.51	0.41	0.48	0.64	0.53	0.53	0.48	0.61	0.61
Jun 1974	5.00	4.75	4.78	4.65	4.78	6.30	4.80	5.06	4.58	5.91	4.72
March 1973	5.84	6.99	5.84	5.92	5.33	7.41	5.89	5.97	5.95	6.15	5.49
April 1973	2.06	3.33	2.13	2.31	1.60	2.54	2.21	2.23	2.63	2.37	1.50
Oct. 1973	2.36	2.36	2.41	2.41	2.39	2.83	2.41	2.31	2.58	1.96	2.34
$\bar{x}$	3.16	3.55	3.13	3.14	2.92	3.94	3.17	3.22	3.24	3.40	2.93
σ^2	4.83	6.28	4.61	4.67	4.31	7.92	4.63	5.00	4.39	6.20	4.38
σ	2.20	2.51	2.15	2.16	2.08	2.81	2.15	2.24	2.10	2.49	2.09
C_v	0.70	0.71	0.69	0.69	0.71	0.71	0.68	0.69	0.65	0.73	0.71

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Application – Example 1: Area 1 in New Mexico

An area, designated as Area 1, selected in New Mexico, USA, is shown in Fig. 1. It has an area of 16900 km^2, and is equipped with 13 raingauges of the usual standard U.S. Weather Bureau pattern. General information on the raingauge location including the latitude, longitude, and elevation is given in Table 2. From this table it is apparent that the area has mountainous topography varying in elevation from 1700 to 2500 m.

Five daily, five monthly and five yearly rainfall events were chosen. Computation of mean areal rainfall by different methods for these events is shown in the Tables 3–5. From these tables it is apparent that all methods yield comparable results except MYER. It is interesting to note that even those methods which do not explicitly account for altitudinal effects are comparable to those which do. An even more interesting observation is that UM and LIN, the easiest and fastest methods, provide comparable results. The general contention that such simple methods cannot provide adequate mean areal rainfall estimates is no longer valid here. The reason for the higher estimates given by MYER is its elevation factor. A considerable part (approximately 30 %) of the high elevation area is not covered by the raingauge network because of its uneven distribution. The elevation factor is, therefore, heavily biased by the ungaged high elevation area and turns out to be higher than it should be. Consequently it makes the estimates by MYER higher. It is not, however, plausible to argue whether these estimates are realistic. It has long been believed that the isohyetal method has higher capability to describe spatial distributional characteristics of rainfall, especially in higher altitude areas. If this is true, the estimates by MYER are then certainly biased.

Another interesting observation is that QUD and CUB, more complex TREN, do not have any particular advantage over LIN, a simpler TREN – an apparent contradiction to the traditional thinking (Mandeville & Rodda, 1970). For other methods also it can be argued that simple methods are just as good as complex ones, even in the physiographically complex area.

Application – Example 2: Area 2 in New Mexico

Another area selected in New Mexico, USA, designated as Area 2, is shown in Fig. 2. This area is much larger in size, about 155,400 km^2. It has 20 raingauges of the usual standard U.S. Weather Bureau pattern. General information on the raingauge location, including latitude, longitude, and elevation, is given in Table 6. It is clear from the table that the area has varying topography, mountainous in some parts while flat in the others.

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Table 5.
Mean areal rainfall estimates by different methods.
Area 1 in New Mexico, yearly totals (cm)

Year	UM	GAAM	TP	AAM	TAM	MYER	ISO	TREN			RDS
								LIN	QUAD	CUB	
1973	33.43	34.98	32.28	32.00	30.50	41.84	32.72	33.88	32.76	33.55	29.97
1958	34.06	34.37	33.45	33.60	32.59	42.08	32.72	34.32	32.68	34.67	32.60
1961	42.67	47.63	41.68	41.63	39.80	52.72	41.88	43.31	42.25	40.46	38.10
1964	34.77	38.00	34.43	35.13	32.89	41.48	34.34	35.15	35.17	35.80	29.54
1970	32.84	36.78	32.59	33.88	30.91	40.73	33.27	33.64	33.23	35.58	29.85
$\bar{x}$	35.55	38.35	34.89	35.25	33.34	43.77	34.99	36.06	35.22	36.01	31.99
σ^2	16.34	28.98	15.12	13.97	14.12	25.29	15.29	16.76	16.47	6.97	12.79
σ	4.04	5.38	3.89	3.74	3.76	5.03	3.91	4.09	4.06	2.64	3.58
C_v	0.11	0.14	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.07	0.11

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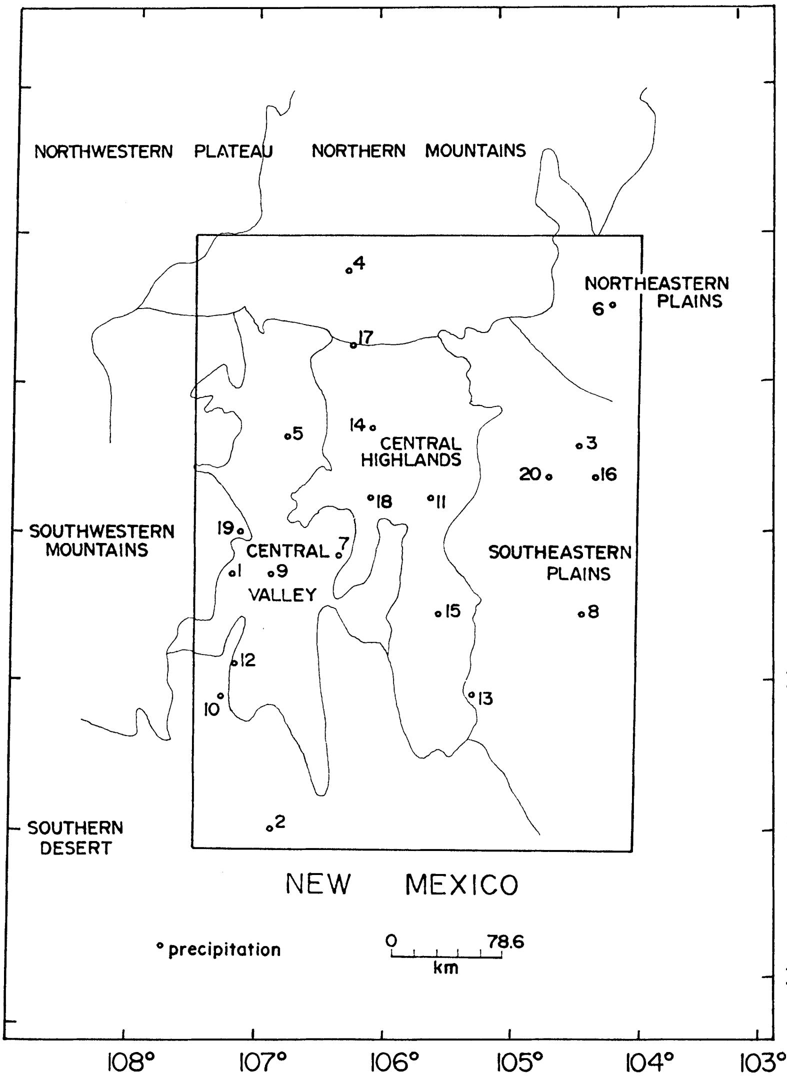

Fig. 2.
Study Area 2 in New Mexico, USA.

Twenty daily, twenty monthly and nineteen yearly rainfall events were chosen in this area. Computation of mean areal rainfall by the different methods in shown for these events in Tables 7–9. Statistical parameters were

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Table 6.
General information about raingauge stations in Area 2 of New Mexico, USA.

Station No.	Name of the Station	County	Latitude		Longitude		Elevation (m)
			Deg.	Min.	Deg.	Min.	
1	Reinhardt Ranch	Socorro	33	45	107	13	1661
2	Afton 5 ESE	Dona Ana	32	03	106	52	1280
3	Alamogordo Dam	De Baca	34	36	104	23	1312
4	Bandalier Nat. Mon.	San Doval	35	47	106	16	1847
5	Belen	Valencia	34	40	106	46	1463
6	Bell Ranch	San Miguel	35	32	104	06	1372
7	Bingham	Socorro	33	53	106	22	1662
8	Bitter Lake Wildlife Refuge	Chavez	33	29	104	24	1119
9	Bosque Del Apache	Socorro	33	46	106	54	1378
10	Caballo Dam	Sierra	32	54	107	18	1277
11	Corona	Lincoln	34	15	105	36	2031
12	Elephant Butte	Sierra	33	09	107	11	1395
13	Elk	Chavez	32	56	105	17	1737
14	Estancia	Torrance	34	45	106	04	1861
15	Fort Stanton	Lincoln	33	30	105	31	1899
16	Fort Summers 5S	De Baca	34	22	104	15	1234
17	Golden	Santa Fe	35	16	106	13	2042
18	Gran Quivira Nat. Mon.	Socorro	34	16	106	05	2018
19	Kelly Ranch	Socorro	34	02	107	08	2042
20	Yeso	De Baca	34	24	104	37	1478

computed for these events as shown in the tables. From these tables, again it is clear that all methods of estimating mean areal rainfall are comparable. MYER gives higher estimates. The reason appears to be the same as explained in the previous example. That same observation that one method does not have any particular advantage over the other as far as results are concerned holds true in this example as well. This observation cannot be attributed to chance because it is true for almost all events under study, and because a large number of events have been considered.

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Table 7.
Mean areal rainfall estimates by different methods.
Area 2 in New Mexico, daily totals (cm)

Date	UM	GAAM	TP	AAM	TAM	MYER	ISO	TREN			RDS
								LIN	QUAD	CUB	
May 17, 1952	.66	.58	.74	1.19	.74	.25	.99	.38	.97	.81	.53
June 17, 1953	.69	.91	.66	.51	.66	1.30	.71	.71	.63	.56	.71
Aug 7, 1954	1.07	.91	.94	.66	.97	1.55	.97	1.07	.79	.58	.94
Sep 25, 1955	.94	1.02	1.14	1.30	1.02	.89	1.17	.91	1.27	1.55	1.19
Aug 1, 1956	.38	.25	.43	.41	.38	.48	.53	.38	.38	.36	.36
Apr 29, 1957	.56	.43	.53	.48	.56	.84	.71	.51	.48	.58	.51
May 2 ,1958	.05	.05	.03	.03	.05	.08	.08	.05	.03	–.03	.03
July 8, 1959	.18	.28	.25	.33	.20	.23	.36	.23	.36	.46	.33
June 10, 1960	1.12	1.12	1.07	1.09	1.04	1.22	1.30	1.12	1.07	1.32	1.09
Sep 3, 1961	.13	.13	.13	.20	.13	.10	.23	.10	.15	.05	.10
Aug 21, 1962	.25	.25	.23	.28	.20	.25	.30	.25	.18	.05	.20
May 22, 1963	.15	.15	.18	.18	.18	.10	.25	.18	.13	.23	.23
Apr 4, 1964	.81	.71	.66	.58	.74	.86	.79	.69	.53	.86	.58
June 10, 1966	.36	.38	.33	.51	.36	.25	1.02	.28	.30	.10	.25
Aug 2, 1966	1.68	1.37	1.40	1.88	1.63	.89	1.80	1.75	1.73	.38	1.57
July 17, 1967	.46	.43	.53	.94	.51	.20	.84	.33	.63	.15	.38
May 12, 1968	.81	.89	.76	.97	.81	.58	.91	.76	.97	1.19	.84
Sep 8, 1969	.86	1.30	1.14	1.42	.91	1.27	1.14	1.14	1.52	1.85	1.50
Apr 18, 1970	.36	.51	.36	.23	.38	.58	.48	.43	.18	.10	.43
July 20, 1971	1.04	1.27	1.09	1.30	1.07	.76	1.14	.99	1.19	1.47	1.19
$\bar{x}$	.63	.65	.63	.72	.63	.63	.79	.61	.67	.63	.65
σ^2	.17	.18	.16	.26	.16	.21	.19	.19	.25	.32	.21
σ	.42	.42	.40	.51	.41	.46	.43	.44	.50	.57	.46
C_v	.67	.65	.63	.70	.65	.72	.55	.72	.73	.90	.71

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Table 8.
Mean areal rainfall estimates by different methods.
Area 2 in New Mexico, monthly total (cm)

Month	UM	GAAM	TP	AAM	TAM	MYER	ISO	TREN			RDS
								LIN	QUAD	CUB	
May 1952	1.55	1.30	1.93	2.18	1.70	1.30	2.01	1.32	2.06	2.41	1.63
Jun 1953	2.21	2.36	2.13	1.90	2.06	2.97	2.64	2.16	2.08	2.24	2.11
Aug 1954	6.10	5.77	6.35	5.74	5.97	7.75	6.38	6.27	6.30	6.45	6.22
Sep 1955	3.10	3.81	3.84	4.47	3.33	3.45	4.01	3.68	4.70	5.33	4.60
Aug 1956	2.97	2.57	2.95	2.92	2.95	3.02	3.23	2.97	2.84	3.25	2.84
Apr 1957	1.65	1.45	1.73	1.73	1.70	1.60	1.73	1.55	1.52	1.57	1.57
May 1958	1.83	1.47	2.06	2.41	2.01	2.18	2.31	1.90	2.03	1.24	1.93
Jul 1959	4.75	5.44	5.21	6.07	4.85	5.18	5.66	4.95	5.49	5.99	5.61
Jun 1960	4.65	4.60	4.52	4.22	4.55	5.21	4.72	4.67	3.81	4.78	4.72
Sep 1961	4.80	4.78	4.67	4.55	4.78	5.82	4.85	5.03	3.96	3.84	4.80
Aug 1962	0.97	1.09	0.94	0.99	0.91	1.14	1.19	0.99	0.99	1.27	1.02
May 1963	1.09	1.22	1.55	1.57	1.27	0.97	1.80	1.37	1.63	2.39	1.85
Apr. 1964	1.19	1.04	1.07	1.04	1.14	1.07	1.22	0.94	0.86	1.32	0.91
Jun 1966	6.48	6.07	6.93	6.63	6.40	7.44	6.63	6.60	6.98	5.97	6.65
Aug 1966	8.86	8.46	9.35	9.78	8.89	8.92	9.02	9.80	9.55	7.72	9.91
Jul 1967	5.16	4.83	5.51	5.84	5.23	4.34	5.49	5.03	4.88	5.21	5.26
May 1968	1.40	1.45	1.37	1.88	1.42	0.97	1.52	1.22	1.63	1.35	1.32
Sep 1969	5.54	5.99	5.66	6.12	5.69	6.45	5.74	6.20	6.38	4.98	6.65
Apr 1970	0.81	0.86	0.74	0.79	0.86	0.84	0.97	0.86	0.66	0.15	0.84
Jul 1971	5.51	5.74	5.84	6.30	5.46	4.67	5.87	5.38	5.77	7.54	5.98
$\bar{x}$	3.53	3.51	3.72	3.86	3.56	3.76	3.85	3.65	3.71	3.75	3.80
σ^2	5.33	5.24	5.85	6.11	5.23	6.61	5.28	6.23	6.09	5.40	6.41
σ	2.31	2.29	2.42	2.47	2.29	2.57	2.30	2.50	2.47	2.32	2.53
C_v	0.65	0.65	0.65	0.64	0.64	0.68	0.60	0.68	0.67	0.62	0.68

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Table 9.
Mean areal rainfall estimates by different methods.
Area 2 in New Mexico, yearly totals (cm)

Year	UM	GAAM	TP	AAM	TAM	MYER	ISO	TREN			RDS
								LIN	QUAD	CUB	
1952	25.83	24.87	26.90	28.22	25.96	26.03	27.48	25.53	26.42	25.53	26.16
1953	23.53	23.44	23.42	25.68	23.06	25.15	22.86	22.91	23.57	21.92	23.32
1954	23.70	23.16	23.85	25.17	23.37	26.72	23.95	24.05	24.18	21.18	24.03
1955	23.80	24.64	27.10	27.84	24.28	25.30	27.08	25.22	28.04	31.85	27.91
1956	13.84	12.12	14.88	14.50	13.82	14.66	14.48	14.17	13.36	15.11	14.43
1958	39.27	37.72	40.77	41.20	39.27	43.38	40.97	40.84	40.77	40.61	40.77
1959	30.91	30.99	32.11	35.20	31.37	30.28	32.44	30.66	31.06	30.43	31.93
1960	35.03	35.61	36.80	38.61	36.07	38.91	37.52	36.70	37.01	34.06	38.63
1961	30.53	29.44	30.48	31.32	30.40	31.85	31.98	30.38	28.37	29.46	30.12
1962	31.60	30.89	33.32	33.25	31.83	36.63	33.65	32.89	33.60	33.65	33.81
1963	24.49	24.23	26.64	26.85	24.99	24.66	27.79	24.89	26.49	27.33	26.57
1964	21.34	20.12	21.87	22.15	21.36	21.46	21.89	20.57	21.41	23.47	21.13
1965	33.27	31.93	34.44	37.62	33.40	31.78	34.14	31.58	34.04	34.01	32.82
1966	26.87	25.76	28.24	28.52	26.77	28.45	28.50	28.09	29.13	27.46	28.52
1967	30.68	30.63	30.73	33.53	30.61	32.03	31.88	30.00	31.14	31.11	30.48
1968	31.29	30.86	34.39	34.95	32.11	32.41	34.16	32.23	36.96	37.46	34.34
1969	40.31	39.45	41.96	43.92	40.79	37.59	40.61	40.03	41.50	43.05	42.19
1970	22.66	22.89	21.67	22.99	22.48	24.54	22.22	22.91	22.86	19.89	22.61
1971	29.41	29.16	30.56	32.79	29.16	28.02	30.48	29.11	30.66	31.90	30.28
$\bar{x}$	28.33	27.78	29.48	30.75	28.48	29.47	29.69	28.58	29.50	29.45	29.48
σ^2	41.63	42.16	46.29	52.08	43.74	45.36	45.87	43.91	49.02	51.71	48.24
σ	6.45	6.49	6.80	7.22	6.61	6.73	6.77	6.63	7.00	7.19	6.95
C_v	.23	.23	.23	.23	.23	.23	.23	.23	.24	.24	.24

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Application – Example 3: The River Ray Catchment, Great Britain

The River Ray catchment at Grendon operated by the Hydrological Research Unit, Wallingford, U.K. is relatively flat and dry. As shown in Fig. 3, it has an area of 18.6 km^2 and is sampled by 17 daily raingauges of the usual British Meteorological Office pattern (30.5 cm tall with an aperture of 123 cm^2). This example has been extracted from the work done by Mandeville & Rodda (1970). Four different methods of estimating mean areal rainfall were applied to daily and yearly values as shown in Tables 10 and 11. Lack of sufficient information did not permit computation by other methods. It is clear from these tables that all four methods yielded practically identical results. Despite identical performance of the methods, Mandeville & Rodda (1970) reached a conclusion that has little support; that is, they concluded that complex TREN performed better, but the truth of the matter is that it did not, as clearly evidenced by Tables 10 and 11. This observation is supported further by work done in New Mexico, USA, as elaborated previously. A complex TREN may be mathematically more attractive but its performance is no better than a simple TREN.

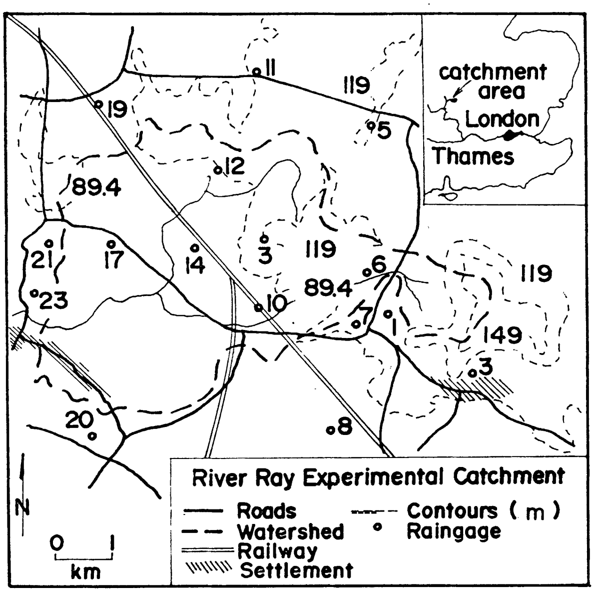

Fig. 3.
Location and instrumentation of the River Ray catchment.

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Table 10.
Mean areal rainfall estimates by different methods (after Mandeville & Rodda, 1970). River Ray catchment, daily totals (cm)

Date	UM	TP	ISO	TREN		
				LIN	QUAD	CUM
CONVECTIVE STORMS						
7–21–1964	5.87	6.30	6.60	5.87	6.81	6.25
7–14–1965	0.99	1.04	0.94	1.04	1.02	1.17
2–20–1966	0.94	0.94	0.94	0.94	0.94	0.97
6–16–1966	0.79	0.84	0.84	0.86	0.81	0.94
10–4–1968	0.61	0.64	0.64	0.64	0.64	0.58
3–21–1968	0.41	0.38	0.36	0.38	0.38	0.38
5–13–1968	0.56	0.56	0.53	0.53	0.56	0.58
8–9–1968	0.82	0.76	0.76	0.74	0.76	0.79
$\bar{x}$	1.37	1.43	1.45	1.37	1.49	1.48
σ^2	3.34	3.91	4.37	3.35	4.66	3.81
σ	1.83	1.98	2.09	1.83	2.16	1.95
C_v	1.33	1.38	1.44	1.33	1.45	1.34
FRONTAL STORMS						
6–1–1964	1.35	1.30	1.27	1.27	1.30	1.30
4–26–1965	0.81	0.84	0.84	0.86	0.84	0.86
9–17–1965	0.66	0.66	0.64	0.66	0.64	0.66
1–21–1965	0.64	0.69	0.71	0.66	0.69	0.74
4–18–1966	1.24	1.24	1.22	1.24	1.24	1.30
10–2–1966	1.30	1.32	1.32	1.30	1.32	1.27
12–9–1966	1.65	1.68	1.73	1.68	1.70	1.73
5–14–1967	2.26	2.31	2.31	2.31	2.29	2.34
$\bar{x}$	1.24	1.25	1.25	1.25	1.25	1.27
σ^2	0.30	.31	.31	.31	.31	.31
σ	.55	.55	.56	.56	.55	.56
C_v	.44	.44	.45	.45	.44	.44

Application – Example 4: River Rheidal Basin, Great Britain

This basin, as shown in Fig. 4, has an area of 146 km², and is equipped with 13 monthly storage gauges of the same dimensions as those in the Ray catchment. This example is also taken from the work done by Mandeville & Rodda

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(1970). By comparison with the Ray catchment, this basin is characterized by considerable rain and relief differences. In the absence of sufficient information, only four methods were applied to monthly rainfall values. The mean areal estimates of these methods are shown in Table 12. Statiscal parameters are also given there. The results of Table 12 support the same observations made previously.

Application – Example 5: Area in South Africa

This example is taken from the work done by Whitmore et al. (1961) for an area in South Africa. No information is available on physiographic features of the area, rainfall characteristics and observation, and raingauge network. The only quantitative information available is that seven different methods of estimating mean areal rainfall were applied to a yearly event, the results of which are as follows:

Annual totals (cm)

WM	GAAM	TP	AAM	TAM	MYER	ISO
65.7	59.6	61.0	61.0	63.3	65.6	61.3

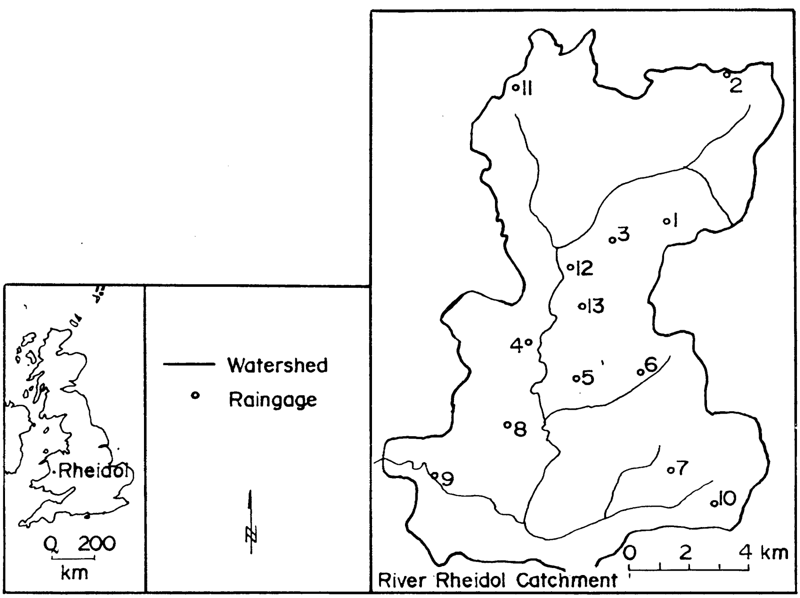

Fig. 4.
River Rheidol rain-gauge network.

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Table 11.
Mean areal rainfall estimates by different methods (after Mandeville & Rodda, 1970). River Ray catchment, annual totals (cm)

Year	UM	TP	ISO	TREN		
				LIN	QUAD	CUB
1963	60.20	59.54	62.56	59.64	59.46	60.17
1964	50.67	51.05	51.03	50.19	51.60	51.54
1965	70.10	69.72	69.27	69.16	69.32	69.88
1966	77.85	78.56	79.12	77.80	78.89	79.27
1967	69.99	68.83	68.43	68.94	68.66	68.76
$\bar{x}$	65.76	65.53	66.07	65.15	65.58	65.91
σ^2	110.38	110.94	106.16	108.38	108.38	110.45
σ	10.51	10.53	10.30	10.41	10.41	10.51
C_v	0.16	.16	.16	.16	.16	.16

This further indicates that results of all seven methods are comparable. WM and MYER, however, give slightly higher estimates. But on the basis of a single event a definitive conclusion cannot be reached.

In the wake of more or less identical performances of the methods one cannot make a strong argument for or against a given method. Nevertheless, all methods will not be equally suitable for all problems. For rapid computation of mean areal estimate, simple trend surface analysis may be preferable to time consuming graphical techniques. Unweighted mean method is simple, yields reasonable estimates if the raingage density is representative and if the spatial distributional characteristics of rainfall are close to homogeneous, and may be preferred to any other method. Simple graphical methods are useful when computer facilities are not available and when the use of unweighted mean is not advisable. The choice of a given method will be contingent upon the problem at hand. Nonetheless, a comparison criterion must consider: (a) accuracy of the method, (b) simplicity of the method, (c) data requirements of the method, (d) physiographic features of the area, (e) raingauge network characteristics, (f) types of data available, and (g) above all, the problem at hand. Although choosing among methods is a qualitative undertaking, it is not at all difficult to choose the right method for a given problem.

The identicality of performances of the different methods leads one to ask: Has the evolution of these methods led to our increased understanding of

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Table 12.
Mean areal rainfall estimates by different methods (after Mandeville & Rodda, 1970). River Rheidol basin, monthly totals (cm)

Month	UM	TP	ISO	TREN		
				LIN	QUAD	CUB
Feb 1966	15.54	15.98	16.69	15.37	15.70	18.69
Mar 1966	11.63	11.81	11.07	11.51	11.51	10.57
Apr 1966	12.01	12.07	11.30	11.89	12.75	10.00
May 1966	14.58	14.61	14.38	14.48	14.30	13.26
June 1966	22.76	22.83	21.74	22.56	22.63	21.92
July 1966	16.43	16.66	15.19	16.33	16.03	16.03
Aug 1966	9.63	9.32	9.91	9.58	9.88	8.20
Sept 1966	11.81	12.07	11.15	11.66	12.01	10.95
Oct 1966	17.25	16.99	16.36	17.25	16.56	16.76
Nov 1966	19.43	19.89	17.96	19.25	20.00	20.40
Dec 1966	40.84	40.67	40.82	40.54	39.40	37.03
Jan 1967	14.50	14.30	13.56	14.35	14.10	12.04
Feb 1967	16.56	16.48	15.67	16.38	16.33	14.20
Mar 1967	11.07	11.10	10.92	11.05	11.58	10.46
Apr 1967	8.94	8.61	7.75	8.86	8.56	6.73
May 1967	21.44	21.03	20.27	21.30	21.21	19.91
June 1967	8.28	7.98	7.92	8.26	8.20	6.25
July 1967	21.44	22.48	21.46	21.29	22.45	25.35
Aug 1967	18.00	17.81	17.70	17.83	17.20	18.82
Sept 1967	26.57	27.46	26.49	26.37	26.52	28.75
Oct 1967	39.57	40.08	39.42	39.17	38.89	38.35
$\bar{x}$	18.01	18.11	17.51	17.87	17.90	17.37
σ^2	77.66	102.88	104.96	99.20	95.57	104.48
σ	8.81	10.14	10.24	9.96	9.78	10.22
C_v	.49	.56	.59	.56	.55	.59

space-time distributional characteristics of rainfall, or are they simply different alternatives? Although this question is of fundamental significance, its answer is not encouraging. Judging the methods on the basis of their performance one is bound to conclude that our understanding of space-time distributional characteristics of rainfall has not advanced much: If it has, one is forced to conclude that evolution of these methods has remained divorced from our increased understanding, although it is very unlikely. Then these methods can only be labelled as different alternatives to meet the same end.

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CONCLUSIONS

Nine different methods of estimating mean areal rainfall have been compared in five different hydrologic environments. These methods perform more or less identically. There is no particular basis to claim that one method is superior to the other, although in a given situation one method may be preferable to another. The identicality of performances of the methods contradicts some of the beliefs advanced in the hydrologic literature.

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