UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
WASHINGTON

August 11, 1961

IN REPLY, PLEASE ADDRESS
CHIEF, U. S. WEATHER BUREAU
WASHINGTON 25, D. C.
AND REFER TO

C-3.1

FILE: 922 MEMO (Climatological Services Memorandum No. 89) WASHINGTON, D. C. 8-11-61

MEMORANDUM

TO : Area and State Climatologists, Field Aides (HC), Field Aides, WRPCs, River Forecast Centers, River District Offices, and Area Engineers (with copies to Regional Offices for information)

FROM : Director, Climatology

SUBJECT : Climatological Services Memorandum No. 89

1. Fitting of Climatological Extreme Value Data *

On occasion, a State Climatologist may be confronted with a problem which should be handled with proper application of extreme value statistics. Since some may not be familiar with the theory, two examples are presented here which may be used as guides to the use of Lieblein's fitting procedure to extreme value data.

Gumbel (1) and others have written extensively on order statistics and on statistical distributions of extreme values. "Order statistics" deals with extreme and near-extreme values, and, therefore, extreme value distributions are a special case of order statistics. There is more than one kind of extreme value distribution, but only the Fisher-Tippett Type I is discussed here since it is the one of most general interest in climatology. Other types may be applicable when there is a known upper or lower bound in the data; e.g. Thom (2) has shown that the Fisher-Tippett Type II distribution fits extreme wind speed data.

Various graph papers have been designed to give a straight line fit to extreme value data. W.B. Form 811-2 (used in the following examples) is a reproduction of one of these and is intended for use with data that can be fitted by the Fisher-Tippett Type I distribution. It is possible to plot the extreme values on this paper (using the methods described later) and draw by eye a straight line of best fit to the plotted points. However, this is relatively inaccurate and, in fact, usually wastes a great deal of the data. If one is dealing with annual extremes, for instance, (and that is the case with the two examples shown here) it takes 30 years of record to obtain the 30 annual extremes which form the body of data. One cannot afford to discard any part of such a small data sample. There are other much more efficient ways of fitting the straight line, and, of those, the most efficient method known today is due to Lieblein.

The Fisher-Tippett Type I distribution, in its cumulative probability form, is expressed by the double exponential equation:

$$F(x) = \exp\left[-e^{-(x-\alpha)/\beta} \right]$$

where F(x) is the probability that a selected x value will not be reached. ("exp" means e raised to the power of the expression in the bracket.) Of course 1 - F(x) is the probability that the same x value will be exceeded. The two parameters α and β must be estimated from the data, and Thom in (3) and (4) describes Lieblein's procedure for doing this. At this point the reader would be well to consult pp. 30-35 of (3) or pp. 57-59 in (4) before proceeding further.

There are two minor changes which should be made in Thom's description. First, the equation should appear as written above with a negative sign before the second exponent, viz. $-(x - \alpha)/\beta$, regardless of whether the equation is being applied to extreme maximum or to extreme minimum data; Lieblein's procedure automatically delivers a negative β for extreme minimum data and a positive β for extreme maximum data, and this in turn produces the correct final sign for the second exponent. Secondly, when ordering the data preparatory to plotting the points on the graph, extreme minimum data should be arrayed in descending order of magnitude and extreme maximum data should be arrayed in ascending order of magnitude, as shown here in the following examples, before the m/(n + 1) computations are made.

Lieblein's method involves the use of certain weights which differ according to sample size as shown on p. 31 of (3) and p. 58 of (4). Unfortunately, calculating these weights is such a terrific job that Lieblein was able to obtain them only for samples up to size six. Naturally, most climatological data samples are much larger, and it becomes necessary to divide the larger sample into sub-samples in order to make use of Lieblein's parameter estimation procedure. Since the sub-sample size should be as large as possible, sub-sample size six was selected for the following examples. The 30 year data sample for the first example and the 42 year record for the second example were arrayed in chronological order, and then divided into 5 and 7 sub-samples, respectively, still in chronological order. Note that the samples, 30 and 42, are evenly divisible by six which is the desired sub-sample size; this avoids the additional work otherwise necessary, as described in (3) and (4). If, for some reason, it is not possible to obtain the original data in chronological order, sub-samples must be produced by drawing at random from the data according to a table of random numbers. After the sub-samples are created, each sub-sample is arranged within itself in ascending order for extreme maximum data and in descending order for extreme minimum data and made the body of a table as shown in each example.

Some readers may not be familiar with the subscript notation used in the tables on pages 31 and 32 of (3) and on page 58 of (4). Such notation uses x_{ij} to mean the x value appearing in the table in the i th row and the j th column. If the i is replaced with a dot, e.g. $x_{.j}$, it means that the rows are summed along the j th column. Thus, $S_{.2}$ means all rows are summed along the second column, and in simpler language merely indicates the sum of the second column of figures. Similar reasoning applies if the j is replaced with a dot to indicate summation of columns along a row.

To plot the data points on the graph, the entire sample is ordered (ascending for maximum and descending for minimum data) and the $m/(n + 1)$ calculations made; m is the order number from the top and n is the period of record, 30 and 42 in this case. The values thus obtained are the abscissa values on the probability scale at the bottom of the graph, and, of course, the ordinates are the corresponding extreme values.

After α * and β * are obtained (the asterisk indicates they are estimated values) using Lieblein's procedure, the line of best fit is drawn by evaluating the reduced variate $(x - \alpha)/\beta$ for two values of x fairly far apart. The results are plotted (using the reduced variate scale at the bottom, below the probability scale) against the two x values used, which are the ordinates. A line drawn through these two points (circled in these examples) becomes the line of best fit. In the first example, temperatures of 40 and 20 were picked; α * and β * were 37.05 and -5.36, respectively. The reduced variate values then became $(40 - 37.05)/-5.36 = -0.55$ and $(20 - 37.05)/-5.36 = 3.18$. The 40 and -0.55 values determine the first point, and the 20 and 3.18, the second.

It is convenient at this point to introduce the concept of the return period T as used in extreme value theory. T is defined as the average time distance between successive rare events, each one of which is at least as large as the first. For example, a 100 year flood is said to be one that happens, on the average, once every 100 years; therefore, it has a 100 year return period.

This extreme value distribution has some very interesting peculiarities. The median is considerably smaller than the mean, and, in fact, is 0.69 T. This means that there is a 50-50 chance that the 100 year flood will occur within 69 years. On the other hand, the probability that the event will happen within its return period is only 0.63. The 100 year flood, therefore, has only a 63% chance of happening at all within 100 years even though, on the average, it occurs once every 100 years. Finally, the probability W(v) that an event will happen within v years is

$$W(v) = 1 - q^v$$

where $q = 1 - p$, and p is the event's probability $(1/p = T)$. If p is less than about 0.1 and T greater than about 10, the above equation can be approximated by

$$W(v) \approx 1 - \exp(-v/T)$$

All of this is discussed in detail by Gumbel (1).

The last equation above is used now to examine the two greatest 24 hourly rainfall amounts, 8.81 and 9.57, shown in the second example. Both of these points appear to be well away from the line, and some may wonder if something is wrong. To find out, the return period of each event is determined by moving horizontally from the points to the fitted line and then reading the return period from the scale at the top of the graph. The 8.81 event is found to have approximately an 83 year return period, and the 9.57 event to have one of about 175 years. Next, the probability is found that each of these has of occurring in 42 years, which is the data period of record. For the 8.81 event

$$W(42) = 1 - \exp(-42/83) = 1 - e^{-0.51} = 1 - 0.60 = 0.40$$

Thus, there is a 40% chance that this event can occur in this period, which is a good chance, indeed. For the second case

$$W(42) = 1 - \exp(-42/175) = 1 - e^{-0.24} = 1 - 0.79 = 0.21$$

Therefore, there is a 21% chance that 9.57 event might happen within the same 42 year period, and the odds are only about 4 to 1 against it happening. Again, these are not prohibitive odds at all.

From such analysis, one can see that some rare events may have a much greater chance of happening than most people believe possible.

If, for some reason, one should want to make a probability determination directly from the distribution function, instead of using the extreme probability paper, he should proceed as follows. The distribution function is

$$F(x) = \exp\left[-e^{-(x - \alpha)/\beta} \right]$$

which becomes, after taking natural logarithms of both sides,

$$\ln F(x) = -e^{-(x - \alpha)/\beta}$$

Using a change of variable, let $z = (x - \alpha)/\beta$. This equation then becomes

$$e^{-z} = -\ln F(x)$$

Again using the first example, where α * and β * have been determined to be 37.05 and -5.36, find, for instance, the extreme minimum temperature that will not be exceeded in 90% of the years (i.e., a lower temperature will not occur in 90% of the years). Then,

$$e^{-z} = -\ln(0.90) = -(-0.10536)$$

With the help of a table of exponential functions or of natural logarithms, we find

$$z = 2.25$$

Therefore, $(x - \alpha)/\beta = 2.25$

and $$x = 37.05 + (2.25)(-5.36) = 37.05 - 12.06 = 25.0$$

Therefore, in 90% of the years Brownsville will not experience a January extreme minimum temperature lower than 25 degrees. Also, a lower than 25° temperature will occur in 10% of the years.

Before undertaking any type of data analysis, one should always determine that the data series is homogeneous. The station location history and instrumentation history should be examined to see if a change in station location or instrumentation might cause part of the record to be incompatible with other parts. If this is suspected, the data should be tested for homogeneity. There are many statistical tests suitable for this, and Thom describes several of them on pp. 6-16 of (3) and on pp. 48-53 of (4).

Bibliography

1. Gumbel, Statistics of Extremes, Columbia University Press, New York, 1958.
2. Thom, H. C. S., "Distributions of Extreme Winds in the United States", Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. ST 4, April 1960.
3. Thom, H. C. S., "Three Chapters on Climatological Analysis", printed manuscript of U. S. Weather Bureau, August 1960.
4. Barger, Gerald L. (editor), Climatology at Work, U. S. Weather Bureau, October 1960.

*This article was prepared by C. K. Vestal, Southeastern Area Climatologist, Ft. Worth, Texas.

Brownsville, Texas
January Extreme Minimum Temperatures
(1930-59)

Year	Temp.	m	Temps. in Order	m/(n+1)
1930	24	1	46	.032
31	41	2	42	.065
32	40	3	42	.097
33	38	4	41	.129
34	42	5	40	.161
35	25	6	39	.194
36	32	7	39	.226
37	37	8	38	.258
38	34	9	38	.290
39	46	10	38	.323
40	25	11	37	.355
41	35	12	37	.387
42	33	13	36	.419
43	27	14	36	.452
44	32	15	35	.484
45	39	16	35	.516
46	36	17	34	.548
47	30	18	33	.581
48	28	19	33	.613
49	23	20	32	.645
50	39	21	32	.677
51	25	22	31	.710
52	42	23	30	.742
53	38	24	28	.774
54	35	25	27	.806
55	36	26	25	.839
56	37	27	25	.871
57	33	28	25	.903
58	38	29	24	.935
1959	31	30	23	.968

Brownsville, Texas

Lieblein fitting procedure as applied to January extreme minimum temperatures for 1930-59

n = 30 = number of values
m = 6 = size of sub-groups
k = 5 = number of sub-groups

Arranging data within sub-groups in order of decreasing magnitude, we get:

	42	41	40	38	25	24
	46	37	35	34	32	25
	39	36	33	32	30	27
	42	39	38	28	25	23
	38	37	36	35	33	31
$S_{.j}$ =	207	190	182	167	145	130
$a_{.j}$ =	0.35545	0.22549	0.16562	0.12105	0.08352	0.04887
$a_{.j}S_{.j}$ =	73.57815	42.84310	30.14284	20.21535	12.11040	6.35310

and $\Sigma\ a_{.j}S_{.j} = 185.24294$

$b_{.j}$ =	-0.45928	-0.03599	0.07319	0.12673	0.14953	0.14581
$b_{.j}S_{.j}$ =	-95.07096	-6.83810	13.32058	21.16391	21.68185	18.95530

and $\Sigma\ b_{.j}S_{.j} = -26.78742$

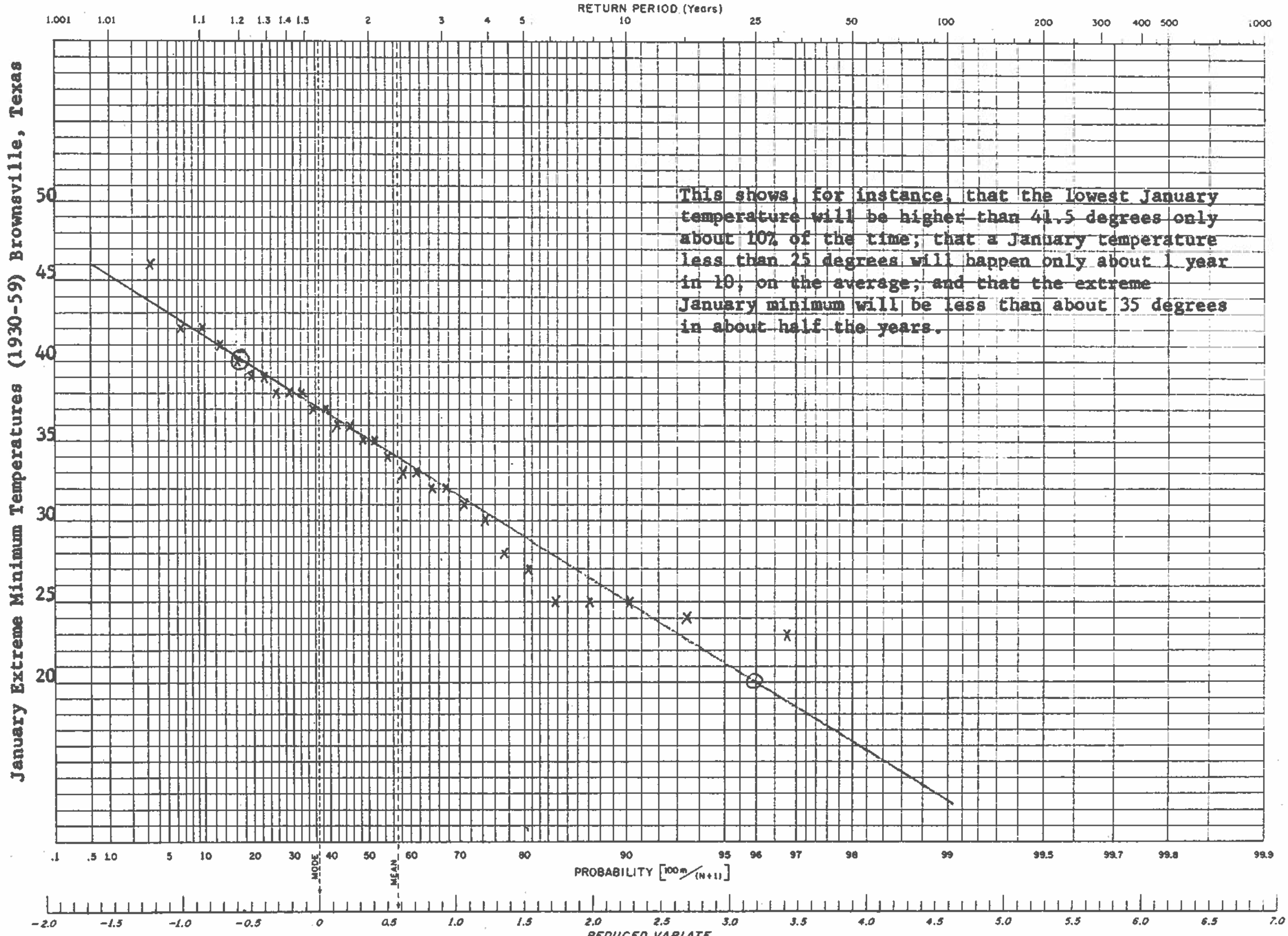
$\alpha * = (\Sigma\ a_{.j}S_{.j})/k = 185.24294/5 = 37.04859$ or 37.05

$\beta * = (\Sigma\ b_{.j}S_{.j})/k = -26.78742/5 = -5.35748$ or -5.36

W. B. FORM 611-2
(1-56)

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

EXTREME PROBABILITY PAPER



USCOMM-WB-DC

Fort Worth, Texas
Maximum Annual 24-hour Precipitation
(1919-1960)

Year	Amt. Inches	m	Ordered Data	m/(n+1)
1919	3.24	1	1.61	.023
20	4.33	2	1.80	.047
21	1.87	3	1.82	.070
22	8.81	4	1.87	.093
23	4.00	5	1.87	.116
24	2.68	6	2.05	.140
25	4.00	7	2.18	.163
26	2.26	8	2.26	.186
27	3.41	9	2.35	.209
28	4.14	10	2.38	.233
29	1.61	11	2.40	.256
1930	4.56	12	2.61	.279
31	1.82	13	2.66	.302
32	9.57	14	2.68	.326
33	5.27	15	2.75	.349
34	2.89	16	2.79	.372
35	3.74	17	2.80	.395
36	4.12	18	2.89	.419
37	3.06	19	2.99	.442
38	3.30	20	3.06	.465
39	2.18	21	3.24	.488
1940	3.33	22	3.30	.512
41	2.05	23	3.33	.535
42	5.08	24	3.41	.558
43	5.85	25	3.67	.582
44	2.79	26	3.74	.605
45	2.61	27	3.83	.628
46	5.04	28	4.00	.651
47	3.83	29	4.00	.675
48	2.38	30	4.12	.698
49	6.03	31	4.14	.721
1950	2.99	32	4.33	.744
51	1.87	33	4.55	.768
52	2.40	34	4.56	.791
53	2.35	35	5.04	.814
54	2.66	36	5.08	.837
55	2.80	37	5.27	.861
56	2.75	38	5.85	.884
57	4.55	39	5.91	.907
58	3.67	40	6.03	.930
59	5.91	41	8.81	.954
1960	1.80	42	9.57	.978

Fort Worth, Texas
Lieblein fitting procedure as applied to annual maximum 24-hour precipitation
(1919-1960)

n = 42 = number of values
m = 6 = size of sub-groups
k = 7 = number of sub-groups

Arranging data within each sub-group in order of increasing magnitude, we get:

	1.87	2.68	3.24	4.00	4.33	8.81
	1.61	2.26	3.41	4.00	4.14	4.56
	1.82	2.89	3.74	4.12	5.27	9.57
	2.05	2.18	3.06	3.30	3.33	5.08
	2.38	2.61	2.79	3.83	5.04	5.85
	1.87	2.35	2.40	2.66	2.99	6.03
	1.80	2.75	2.80	3.67	4.55	5.91
$S_{.j}$ =	13.40	17.72	21.44	25.58	29.65	45.81
$a_{.j}$ =	0.35545	0.22549	0.16562	0.12105	0.08352	0.04887
$S_{.j}a_{.j}$ =	4.76303	3.99568	3.55089	3.09646	2.47637	2.23873

and $\Sigma a_{.j}S_{.j} = 20.12116$

$b_{.j}$ =	-0.45928	-0.03599	0.07319	0.12673	0.14953	0.14581
$S_{.j}b_{.j}$ =	-6.15435	-0.63774	1.56919	3.24175	4.43356	6.67956

and $\Sigma b_{.j}S_{.j} = 9.13197$

$\alpha * = (\Sigma a_{.j}S_{.j})/k = 20.12116/7 = 2.87445$ or 2.87

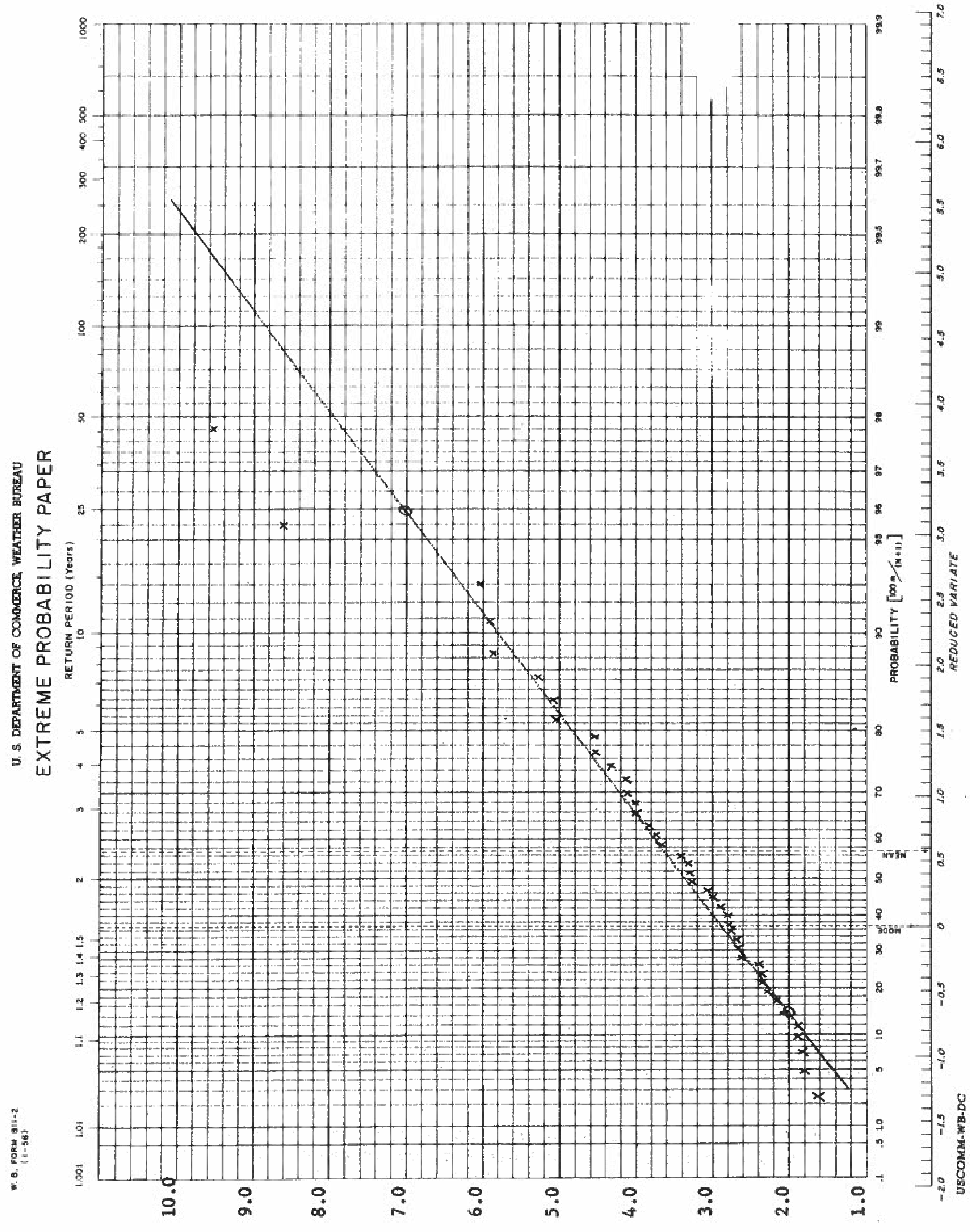
$\beta * = (\Sigma b_{.j}S_{.j})/k = 9.13197/7 = 1.30457$ or 1.30

$(x - \alpha)/\beta$ = the reduced variate

Let x assume two values, say, 2.00 and 7.00

Then: $(2.00 - 2.87)/1.30 = -0.669$ or -0.67

and $(7.00 - 2.87)/1.30 = 4.13/1.30 = 3.18$



Maximum Annual 24-hour Precipitation, Fort Worth, Texas (1919-1960)

2. Advisory Committee on Climatology

Dr. J. H. Longwell, former chairman of this Committee, and Dr. E. Wendell Hewson have retired. The Committee now is composed of the following members:

Dr. William E. Reifsnyder (Chairman of Committee)
School of Forestry
Yale University
New Haven, Connecticut

Dr. George S. Benton
Department of Civil Engineering
Johns Hopkins University
Baltimore 18, Maryland

Dr. Douglas B. Carter
Department of Geography
Syracuse University
Syracuse, New York

Dr. John R. Mather
Laboratory of Climatology
Elmer, New Jersey

Dr. David H. Miller
Pacific Southwest Forest & Range Experiment Station
Box 245
Berkeley 1, California

Dr. Norman J. Volk, Director
Agricultural Experiment Station
Purdue University
Lafayette, Indiana

3. Evapotranspiration

As indicated in CSM 81, the USDA Soil Conservation Service Soil Survey Group has been interested in developing a system for determining certain climatic factors which will apply to soil and land classification. In early 1960, the Western Group adopted the recommendation that each State make evapotranspiration computations using the Thornthwaite method. During the past year Mr. Marvin D. Magnuson, AC/NW, participated in several SCS workshops to help explain the concept of evapotranspiration and to assist SCS personnel in making these computations. As a result of these contacts, the AC/NW has prepared an information series, a bibliography and glossary, and work outlines on this topic. Although this information has had prior distribution to all western SC offices and to some SCS offices, it is now reproduced for information of all SC's.

"The sun is the source of all the energy that is required and utilized in the transformation of liquid water to water vapor. Regardless of whether this transformation involves the simple process of evaporation from a water surface, or the complex evaporation from a soil surface, or the transpiration processes of plants, the sum total or evapotranspiration is dependent upon (and also limited by) the amount of solar energy available. Thus, evapotranspiration, like precipitation or temperature, becomes an important and basic climatological factor. It can be shown that the rate of evapotranspiration is dependent upon four things with the first two listed being the most important: the climate, the soil moisture supply (the varying water capacities of soil), the plant cover and the land management.

"There are three different approaches to the problem of determining evapotranspiration. These are moisture indices or ratios, the development of instruments and the theoretical approach.

"Over 100 years ago, climatologists proposed the ratio of P/E (precipitation divided by pan evaporation) as a moisture index or precipitation effectiveness index. Because of the lack of data on evaporation, the index was modified to some form of P/T (precipitation divided by temperature). Many variations of this ratio followed, varying from 8P/5T+120 (Köppen) to $115(P/T-10)^{10/9}$ (Thornthwaite 1931). But these ratios lack universal application and for this reason, each investigator must change the constants as he changes from one area of study to another. Another deficiency is that identical ratios can result from different combinations of temperature and precipitation.

"In regard to the instrumentation approach, there has been no instrument perfected to measure satisfactorily and simply the water movement from the earth to the atmosphere--the reverse of precipitation. First are the instruments which measure the evapotranspiration indirectly. These include the expensive neutron meters as well as soil moisture meters or blocks which measure the soil moisture at spot locations and levels. The evapotranspiration can be computed from day-to-day or week-to-week changes of these readings after taking into account infiltration of precipitation and irrigation. Here we have the difficult problems of calibration of instruments, sampling, representativeness, etc. Then there are a number of small instruments which attempt to measure the evaporation directly, such as the Piche' evaporimeter, the Livingston atmometer, the small evaporation pan, etc. Here, the rate of water loss is dependent in varying degrees upon the size and other characteristics of the instrument (the evaporating surface) and a correction or conversion factor is needed to determine the evapotranspiration. Third are the large tanks and lysimeters with soil and growing plants which are constructed with the intent of measuring the actual water loss. These evapotranspirometers--as they are called--can provide good measurements, but there are many operational and physical problems including maintenance of a homogeneous plant cover, a proper water level and correct tension on the lower free water surface. Also one must guard against the 'oasis' effect, etc.

"The third method is the theoretical approach. Using several energy budget equations, Penman derived a method for computing evapotranspiration. In spite of its strong theoretical base, there are a number of empirical constants in his complicated formulas. Furthermore, the required climatic variables of wind, humidity and sunshine are available for only a few locations in each state. Another set of equations was developed by Thornthwaite in 1948. Although the concept in this development can be considered as 'energy budget', the equations of Thornthwaite are primarily empirical. Air temperature, which is a reflection of the amount of solar energy in a given location, is the basic climatic variable in this formula and is thus widely available over all states. The computations have been greatly simplified by Palmer and Havens who have developed diagrams to facilitate rapid computations of potential evapotranspiration and 'actual'evapotranspiration.

"The 1948 Thronthwaite method, as simplified by Palmer and Havens, was used to make computations at about 100 locations in the State of Washington (computations have also been completed for California and are underway in a number of other western states). The Weather Bureau normals of monthly precipitation and temperature were used. The following items were computed for each location: (1) the potential (or maximum) evapotranspiration for annual, 32° freeze-free season and 28° freeze-free season, (2) the 'actual' evapotranspiration--assuming a 2-inch available water capacity--for annual, 32° freeze-free season, and 28° freeze-free season and (3) the 'actual' evapotranspiration--assuming a 6-inch available water capacity--for annual, 32° freeze-free season, and 28° freeze-free season. These data were mapped for the State of Washington and discussed in some detail. A by-product of this water budget method is that information on water surplus and water deficiency is produced. However, when working with only 'normal' values, both quantities, water surplus and water deficiency, tend to be underestimated.

"A nomogram, a computation sheet, and a work outline were distributed to show the relative simplicity and the relative speed for converting weather data into estimates of evapotranspiration.

"To derive the maximum use of these new data, one should select actual daily weather data (temperature and precipitation) rather than the normal values. Then information on variability of all parameters, frequencies or probabilities can be computed, etc. Also the best estimates of water deficiency and water surplus would be secured. In doing this then, a regular bookkeeping procedure can be set up and the water balance determined at daily intervals. The moisture in the soil may be regarded as a bank account. Precipitation adds to the account and evapotranspiration withdraws from it. Controls can be set up for varying amounts of 'available water capacities'. This procedure thus lends itself to machine programming and computing. An abbreviated bibliography was distributed which included references to such machine programming, as well as other pertinent information."

EVAPOTRANSPIRATION FORMULAS

1. Precipitation Effectiveness Index - Thornthwaite, 1931.

$$\text{P-E Index} = \frac{P}{E} = \sum_{n=1}^{12} 115\,[P/(T-10)]^{10/9}$$

where P=precipitation, inches

E=evaporation, inches

T=temperature, °F.

A close approximation would be $100 \cdot \frac{9P}{T-10}$

2. Potential Evapotranspiration, PET - Thornthwaite, 1948.

$PET = 1.6\ (10T/I)^a$

where T = temperature, °C

I = heat index = $\sum_{n=1}^{12} i$

$i = (T/5)^{1.514}$

a = empirical exponent

$= 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} I + .49$

3. Penman Method.

$E_o = (\Delta H + .27\ E_a)/(\Delta + .27)$

where E_o = open water evaporation (mm day^{-1})

Δ = slope of the vapor pressure curve at mean air temperature

E_a = auxiliary quantity related to wind and vapor pressure difference

H = complex term relating to radiation. (H is actually the net radiation.)

$H = R_a(1-r)(.18+.55S) - \sigma\ T_a^{\ 4}(.56-.092\ \sqrt{e_d})(.1+.9S)$

where R_a = mean extraterrestrial radiation (mm day^{-1})

r = reflection coefficient (albedo of open water)

S = sunshine percentage

$\sigma\ T_a^{\ 4}$ = black body radiation at air temperature T_a

e_d = actual vapor pressure, mm Hg

and $E_a = .35\ (e_a - e_d)(0.5+.0098u)$

where e_a = saturation vapor pressure, mm Hg

u = wind speed at 2m, miles day^{-1}

Then $PET = fE_o$

where PET = potential evapotranspiration
f = empirical factor (depends primarily on day length)
(Penman used .6 for winter months to .8 for summer

months.)

4. Blaney-Criddle Method

$u = kf$

where u = mo. consumptive use

k = mo. empirical coefficient

f = water use factor

$f = Tq$

where T = monthly temperature, °F

q = monthly percent of daytime hours of the year

then $U = KF$

where U = consumptive use (or potential evapotranspiration)

K = empirical coefficient, period or annual

F = sum of f factors

ABBREVIATED BIBLIOGRAPHY - EVAPOTRANSPIRATION

1. Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data, H. F. Blaney & W. D. Criddle, Technical Paper 96, USDA, Washington, D. C. 1950.

2. Water Loss Investigations: Vol. I - Lake Hefner Studies, Geological Survey Circular 229, USGS, Washington, D. C. 1952.

3. Evapo-Transpiration: Excerpts from Selected References, Compiled by H. W. Lull, Occasional Paper 131, Southern Forest Experiment Station, Vicksburg, Mississippi. Aug. 1953.

4. The Measurement of Potential Evapotranspiration, edited by John R. Mather, Publications in Climatology, Vol. VII, No. 1, Johns Hopkins University, Seabrook, New Jersey. 1954.

5. The Water Balance, C. W. Thornthwaite and J. R. Mather, Publications in Climatology, Vol. VIII, No. 1, Drexel Institute of Technology, Centerton, New Jersey. 1955.

6. Does Transpiration Decrease as the Soil Moisture Decreases? F. J. Veihmeyer and A. H. Hendrickson, Transactions, AGU, Vol. 36, No. 3, pp. 425-448, June 1955.

7. Estimating Evaporation, H. L. Penman, Transactions, AGU, Vol. 37, No. 1, pp. 43-50, Feb. 1956.

8. Estimating Soil Moisture Conditions and Time for Irrigation with the Evapotranspiration Method, C. H. M. van Bavel, ARS, USDA, North Carolina Ag. Exp. Sta., Raleigh, North Carolina, Aug. 1956.

9. Evaporation and Evapo-Transpiration Research in the United States & Other Countries, John R. Davis, Purdue Univ., Lafayette, Indiana, Dec. 1956.

10. A Graphical Technique for Determining Evapotranspiration by the Thornthwaite Method, W. C. Palmer & A. V. Havens, Monthly Weather Review, April 1958.

11. Evaporation Maps for U. S., Technical Paper 37, U. S. Weather Bureau, Washington, D. C. 1959.

12. Transpiration and Evapotranspiration as Related to Meteorological Factors, R. H. Shaw, Iowa State College, Ames, Iowa, April 1959.

13. Water Deficits and Irrigation Requirements in the Southern United States, C. H. M. van Bavel, Journal of Geophysical Research, Vol. 64, No. 10, October 1959.

14. The Application of High-Speed Computers in Irrigation Research, H. W. Engelbrecht, Bulletin of the American Met'l Society, Vol. 40, No. 11, November 1959.

15. Graphical Solution of the Penman Equation for Potential Evapotranspiration, J. C. Purvis, Monthly Weather Review, June 1961.

TERMINOLOGY IN EVAPOTRANSPIRATION

1. Evapotranspiration. The combined evaporation from soil surface and transpiration from plants.

2. Potential Evapotranspiration. This is the water loss which will occur from an area which is fully covered by actively growing vegetation if there is no deficiency of water in the soil for the use of the vegetation. This would be the maximum amount of evapotranspiration for a given area and under these conditions (no moisture stress), it would be independent of precipitation. The Palmer-Havens Diagram makes these computations in a quick and simple manner. Variously called PET, PE, or even E in the literature.

3. Actual Evapotranspiration. This is the water loss that actually occurs in a given location under specified temperatures and precipitation and moisture storage capacity of the soil. This quantity approaches the potential amount in rainy climates; whereas, in arid climates, the quantity is only a fraction of the potential amount. Called E_a, ET or even modified PE in the literature.

4. Heat Index. An empirical constant in Thornthwaite's equation for evapotranspiration. (See formula sheet.) This constant varies from place to place and shows small location variations in cold climates and larger

variations in warm climates.

5. Langley. In meteorology, this is a unit of energy per unit area and by definition, it is equal to one gram-calorie per square centimeter. In Penman's formula, these radiation units have been converted into evaporation equivalent (1 gram of water equals 590 calories) and expressed in inches or millimeters of water.

6. Field Capacity. The amount of water held in soil which has been saturated and then allowed to drain freely. At field capacity, the soil contains no surplus of gravitational water and no deficit of capillary water.

7. Wilting Point. The amount of water held in soil, when plants growing in that soil first show permanent wilting. This point is obtained in the laboratory by subjecting soil samples to a 15-atmosphere pressure over a suitable membrane. Rough approximation is field capacity times .543.

8. Available Water Capacity. The amount of moisture available to vegetation growing in a soil which is at field capacity. This is the difference between field capacity and wilting point. Called AWC in our computation sheet.

9. Soil Dryness Correction. Evaporation from a moist soil begins immediately to lower the moisture content of the soil. As the soil dries, the rate of evapotranspiration diminishes. Thornthwaite and many other investigators assume that the evapotranspiration rate decreases linearly with the water loss. That is, when one-half of the available water is gone, the evapotranspiration rate falls to one-half of the potential rate. A soil dryness correction curve based on AWC (instead of field capacity) is carried on the Palmer-Havens Diagram which simplifies the computation for actual evapotranspiration.

10. Water Balance. This term refers to the balance between the income of water from precipitation and the outflow of water by evapotranspiration. It is a climatic balance since both precipitation and evapotranspiration are active factors of climate.

11. Moisture Surplus and Moisture Deficiency. In setting up a bookkeeping comparison of the seasonal march of precipitation with the evapotranspiration, it is possible to determine other related moisture parameters, such as the moisture surplus and moisture deficiency. During a wet spell or a rainy season, precipitation in excess of the water holding capacity of the soil is called moisture/or water surplus. The moisture or water deficiency is the difference between the actual evapotranspiration and the potential evapotranspiration. This difference is small in cool marine climates and very large in hot arid climates. In working with normals of both temperature and precipitation, the estimates of moisture surplus and moisture deficiency are both underestimated. Daily data of both temperature and precipitation for a period of years are necessary in order to arrive at good estimates of these quantities of surplus and

deficiency.

WORK OUTLINE FOR COMPUTATION SHEET

1. Enter the temperature normals.

2. Determine from Table 1 on nomogram sheet. "I" equals the annual value of "i's.

3. Determine from nomogram following procedures thereon from 1-9. Potential evapotranspiration is also abbreviated as PE.

4. Enter precipitation normals.

5. From freeze bulletin or Climates of the States, enter freeze data at top of sheet. Prorate monthly amounts for selected freeze months and add for seasonal PET.

6. Same as 5.

7. As indicated.

8. To determine Δs, the soil dryness curve should be used with each selected AWC value (Available Water Capacity). Follow example on nomogram. The computed loss will be Δs. Start computations in fall when (P-PET) becomes positive.

9. Accumulate Δs's beginning in fall month and carry forward until "s" reaches AWC. Show Δs as either positive (+) or negative (-) as it is critical for Step 11.

10. Any amount which accumulates in excess of AWC is arbitrarily called runoff or water surplus.

11. Actual evapotranspiration. $E_a = P - \Delta s - RO$. Actual evapotranspiration is also abbreviated as ET.

12. D_1 can be called the moisture deficiency or water deficit (for a given AWC). List only the negative values.

13. Prorate and compute in similar fashion as 5.

14. Prorate and compute in similar fashion as 6.

15-21. Repeat same steps as 8-14 except change the basic AWC to 6 inches.

CSM 89 - 20

COMPUTATION SHEET FOR EVAPOTRANSPIRATION

Town ____________________ County ____________________ State _________________

Elev.___________ft. Lat.___________ Long.__________

Frost free season (32°)__________ to _________=__________days;

(28°)__________ to _________=__________days

	J	F	M	A	M	J	J	A	S	O	N	D	Seasonal Annual
1. Temp. (Normal)													
2. i values													
3. P. E. T.													
4. Precip. (Normal)													
5. P. E. T. (32°)													
6. P. E. T. (28°)													
7. P-PET (4-3)													
A.W.C. (2 inches)													
8. Change in S(ΔS)													
9. Storage S													
10. Runoff (RO)(Surplus)													
11. Ea (Actual)													
12. D_1 (Ea-PET)(Defic.)													
13. Ea (32°)													
14. Ea (28°)													
A.W.C. (6 inches)													
15. Change in S(ΔS)													
16. Storage S													
17. Runoff (RO)(Surplus)													
18. Ea (Actual)													
19. D_1 (Ea-PET)(Defic.)													
20. Ea (32°)													
21. Ea (28°)													

TOWN____________________

Month		Unadj. P.E.T.		Month		Unadj. P.E.T.	
Jan	( )	( )	(4.4286)=	Jul	( )	( )	(4.4286)=
Feb	( )	( )	(4.0000)=	Aug	( )	( )	(4.4286)=
Mar	( )	( )	(4.4286)=	Sep	( )	( )	(4.2857)=
Apr	( )	( )	(4.2857)=	Oct	( )	( )	(4.4286)=
May	( )	( )	(4.4286)=	Nov	( )	( )	(4.2857)=
Jun	( )	( )	(4.2857)=	Dec	( )	( )	(4.4286)=

	2" AWC			6" AWC		
Month	P.E.T.-P/AWC = %	$(\%)_c$	(S)=ΔS	P.E.T.-P/AWC = %	$(\%)_c$	(S) = ΔS
Jan	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Feb	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Mar	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Apr	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
May	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Jun	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Jul	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Aug	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Sep	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Oct	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Nov	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=
Dec	( )/2.0=	( )	( )=	( )/6.0=	( )	( )=

Frost-free season computations:

4. Correction To Page 41, CSM 87

The last sentence on Page 41 should be changed to "A study of prolonged rainy periods and of periods without rain was made for central New Jersey."

5. State and Area Climatologists on Leave

Will each State and Area Climatologist please inform the Office of Climatology on those occasions when he plans to be absent on leave or travel for more than a week? Such information is very helpful in planning.

6. State Climatologists Travel Reports

In planning travel, the SC should use WB Form 274-1 (Trip Authorization), to inform the appropriate RAO that travel money is actually being obligated. Copies of Form 274-1 should also go to AC offices. Form 274-2, Trip Report, is not needed since it is addressed to the Central Office which has no particular interest in individual trips.

Narrative travel reports are no longer a requirement of the WB Manual. Those matters handled or encountered during travel which should be reported on should be written up in memorandum form. Such memoranda should be addressed to appropriate offices or divisions and usually with copies to the AC and the RAO. Some account or summary of travel should appear in non-periodic activity reports of SC's so that all offices concerned, i.e., RAO, AC, O/C, can be kept informed of the nature and scope of travel.

7. Decals for Substation Observers

An attractive 4" x 4" decal will soon be furnished to each substation observer to identify his home as a cooperative weather station.

8. RAO Conferences with Representatives of Office of Climatology

The recent meeting of Climatology representatives with Regional Administrative Officers was not designed to arrive at any decisions. Discussions were held on segments of the climatological program in order to obtain reaction and opinions of the RAO's. Subjects discussed follow:

1. State Climatologist Prospects. Although every state is covered for climatology many states are covered by dual capacity positions. It was made clear that addition of bona fide state climatologists will have to await appropriations. Addition of not more than one per year is all that could be expected.

2. Considerable discussion revolved around the question of public service functions at state climatologist offices. There was general agreement that the function belongs with the Weather Bureau Office and not the state climatologist. However, this is a "weaning away" process and will be done gradually as the public becomes aware of the delineation of functions.

3. Office help for the state climatologist was discussed. Considera-

tion was given to hiring a met. technician, who can type, instead of a typist. This could possibly give a relief for sick and annual leave. The RAO's advice was that the calibre of employee in Met. Technician 4 or 5 would not meet our expectations. Further discussion was deferred for consideration of other possible solutions.

4. City vs. Commercial Airport Space for state climatologists was discussed. It was reiterated that there is no immediate need to pay premium space rates at airports for state climatologists since their functions are distinct. Mention was made of the "free space" offers from Experiment Stations and Universities. Since there is no immediate operational requirement in the state climatologist functions his office need not be contiguous to the operational aspects of the Weather Bureau particularly if it requires premium rates on space.

5. Centralized meetings of state climatologists such as have just been inaugurated were discussed and endorsed wholeheartedly. Annual or biannual meetings were considered very worth while from both technical and administrative viewpoints.

6. The problem of Urban Weather Stations was discussed at length and considered to be a move in the right direction. With more and more weather stations going to remote airports the needs of the urban community for heating, air conditioning, etc., are in need of Weather Bureau assistance. The need for urban stations was recognized and endorsed by the RAO's.

9. Surplus CSM Copies

The Office of Climatology has some surplus copies of CSM 85 containing Dr. Landsberg's talk on "Government Careers in Meteorology" which may be obtained on request.

10. Climatological Substation Summaries

A milestone has been reached with the publication of the 500th summary. We have now raised our sights and the new target is 750 summaries. A list of summaries by states follows:

Alaska	15	Maine	1	Ohio	8
Arizona	113	Massachusetts	3	Oklahoma	10
Arkansas	6	Michigan	28	Oregon	18
California	18	Minnesota	11	Pennsylvania	2
Colorado	9	Mississippi	2	South Carolina	18
Connecticut	1	Missouri	1	South Dakota	4
Florida	8	Montana	11	Tennessee	2
Georgia	37	Nebraska	2	Texas	9
Illinois	3	New Hampshire	4	Utah	24
Indiana	11	New Mexico	36	Washington	32
Iowa	3	New York	5	Wisconsin	39
Louisiana	1	North Carolina	18	Wyoming	3

The State Climatologist should inspect the final copy before it goes to press to see that there are no obvious errors or discrepancies in it.

11. Correction to CSM 86

On Page 20, the name of the State Climatologist for North Carolina should be changed from Charles F. Carney to Albert V. Hardy.

12. Publications furnished State and Area Climatologists Since CSM 88

"Presenting Information with 2 x 2 Slides" by Henry W. Smith: reprinted from the Agronomy Journal, Vol. 49: 109-113, 1957.

FOR WRPC

13. Instructions for Monthly Summary of Surface Data for Climatological Data Table of CDNS

The following instructions have been issued to the WRPCs to be effective with data for June 1961:

1130.51 Punching data for Climatological Data table of CDNS.

1130.511 Data will be punched for each Weather Bureau first-order observing station into a card deck or decks in accordance with punching instructions to be issued by the NWRC.

1130.512 Punching pressures, dew point, and relative humidity data.

1130.5121 For all stations, obtain monthly average station pressure from Form 733-1.

1130.5122 Procedures for stations included in the LCD Supplement program.

1130.51221 Obtain monthly average sea level pressure, dew point and relative humidity by taking sums of the appropriate total fields in the Summary by Day - WBAN Surface (Card No. 2) summary cards and dividing by the total number of observations in the month.

1130.5123 Procedures for stations not included in the LCD Supplement program.

1130.51231 If data are available for 4 synoptic observations daily, compute monthly averages of dew point and relative humidity from the monthly sums of the synoptic observations of these data.

1130.5124 Convert monthly average station pressure to millibars and tenths before punching. Conversion may be done mechanically by first punching the data in inches and thousandths in an unused field of the card.

1130.513 Punching wind data.

1130.5131 Punch average speed and prevailing direction from the Wind Direction and Speed Occurrences table of LCD Supplement, if available.

1130.5132 Punch average speed from Form 733-1 if the LCD Supplement is not available. The prevailing direction may be omitted unless it is entered on Form 733-1.

1130.5133 Punch fastest mile, direction, and date as recorded in Form 733-1. If fastest mile data are not available, highest observed wind speed, peak gust, or maximum hourly average may be substituted if available in Form 733-1.

1130.514 Punch all other required data as entered in Form 733-1.

1130.52 Print-out of data.

1130.521 List all cards on 2-part paper to review the punching.

1130.522 Correct all cards and listings.

1130.53 Mail all cards and the originals of the listings separately to the National Weather Records Center, Asheville, N. C., Attn: Climatography Section, by the 25th of the month following the data month. Mark all packages and envelopes: "Climatological Data Table for CDNS".

1130.531 Retain carbon copies of the listings until the appropriate issues of CDNS have been published, and then discard.

H. E. Landsberg
Director, Climatology

GUIDE TO CLIMATOLOGICAL SERVICES MEMORANDUM NO. 89