GEOG 455 Exercise One
WATER BALANCE CALCULATION
15 points

Name:_____
Student#:_____

Purpose: To calculate the annual water balance for several stations, including Milwaukee.
Definitions:

T Monthly values of temperature, in °F
i Monthly values of the Thornthwaite heat index
I Annual heat index, the sum of the 12 monthly heat indices
P Precipitation, monthly average in inches
PE Potential evapotranspiration--the amount of water used by a mature ground cover of vegetation if soil were fully charged with water; roughly proportional to temperature
ST Soil moisture storage--for this exercise it will be assumed that a maximum of 4.0 inches of water may be stored in the root zone of plants, actually this varies considerably from place to place. The monthly values of ST gives the number of inches of water left in storage at the end of each month.
ΔST The change in soil moisture storage during the month--a negative value indicates removal of soil moisture; a positive value indicates recharge of soil moisture.
AE Actual evapotranspiration, the actual amount of water evaporated and transpired from the soil. If P > PE, then AE = PE. If P < PE, then AE will be limited to the amount of precipitation (P), plus any moisture remaining in storage (if any).
D Moisture deficit, occurring when P < PE *and* soil moisture storage has been depleted. In this case, D = PE - AE, and indicates the amount of water that would have to be supplied to the soil to maintain normal plant growth.
S Moisture surplus (runoff), occurring when P > PE *and* the soil moisture is fully recharged. In this case, any water received over the amount needed by plants becomes runoff, and S = P - PE.

Temperature and Precipitation Data for Selected Stations

	San Francisco (38°N)		New York (43°N)		Milwaukee (43°N)	
	T(°F)	P(In.)	T(°F)	P(In.)	T(°F)	P(In.)
Jan.	49.4	4.8	30.6	3.2	18.9	1.6
Feb.	51.4	3.6	30.5	3.3	23.0	1.5
Mar.	52.8	3.1	38.0	3.4	33.3	2.7
Apr.	54.3	1.6	48.5	3.3	44.4	3.5
May	55.5	0.7	59.4	3.5	54.6	2.8
June	57.2	0.1	68.5	3.5	65.0	3.2
July	57.3	0.0	73.5	4.1	70.9	3.5
Aug.	57.8	0.0	72.1	4.3	69.3	3.5
Sep.	59.9	0.3	66.4	3.4	61.7	3.4
Oct.	58.9	0.9	55.8	3.4	50.3	2.4
Nov.	55.5	2.4	44.1	3.4	37.7	2.5
Dec.	50.6	4.5	34.3	3.3	24.4	2.3
Annual	55.0	22.0	51.8	42.1	46.1	32.9

Procedure:

Part I: **Calculation of monthly values of PE for the stations (use the provided water balance sheets to record your data)**

1. From Table 1, using the monthly values of temperature (T), determine and record the monthly heat index (i) for each month.
2. Add the 12 monthly values of i for the station to determine the annual heat index (I).
3. From Figure 1, using the value of I and the individual monthly values of T, determine the unadjusted PE for each month. If T for a month is less than 32°F, then the unadjusted PE is 0.
4. From the station latitude, using Table 2, determine the proportion of mean duration of sunlight, and list the monthly values of this correction factor.
5. Multiply the unadjusted PE for each month by the correction factor for each month to produce the adjusted PE for each month. Sum the monthly PE factors to determine the total annual PE, and list all these values.

Part II: **Calculation of the water balance for a station**

1. List the monthly values of precipitation (P), as given, and the monthly values of PE, as determined in Part I.
2. For each month, determine the "net precipitation" (P - PE). If P - PE is positive, it indicates that there is more than enough precipitation to make up for evaporation losses. If P - PE is negative, it indicates that precipitation alone will not be sufficient to maintain evapotranspiration at the potential amount.
3. Before starting the monthly calculations, it is necessary to know the amount of storage (ST) in the soil for the first month (January). Check the sign of P - PE for January. If P - PE is positive for January, then check the values of P - PE for the months immediately preceding January, and see how many of these preceding months also had positive values of P - PE. If the sum of the P - PE for January plus the positive values of P - PE for the three months immediately preceding January is greater than 4.0 inches, then the soil will be fully recharged at the end of January, and ST for January will be 4.0 inches. If the sum of the January P - PE plus the immediately preceding P - PE monthly values is less than 4.0 inches, then the soil will not be fully recharged by the end of January, and the value of ST will generally be equal to the sum you just computed. If P - PE is negative, on the other hand, then ST for January will be less than 4.0. Check all the negative values of P - PE that immediately precede January. If the sum of the negative values for January and these preceding months is -4.0 or less, then ST for January will be 0. If this sum is between -4.0 and 0, then ST for January will be 4.0 minus this sum.

EXAMPLE: P - PE for January is 1.1. Values of P - PE for the months immediately preceding are: December (1.3), November (0.9), October (- 0.8). Because the October value is negative, only the November and December values will be considered. The sum of the positive values of P - PE is 1.1 + 1.3 + 0.9 = 3.3 inches. By the end of January, therefore, accumulated storage will total 3.3 inches. If the October value had been +0.8, then the sum of positive P - PE values would have exceeded 4.0, and ST in January would be 4.0.

4. Starting with January, determine the value of AE. If P > PE, then AE = PE. If P < PE, and the amount in storage (ST) exceeds PE - P, then AE = PE, ΔST is negative and equal to P - PE. (In other months ST is reduced by this amount, but ST for January is already calculated). If the amount in storage is less than PE - P, then AE will be limited to actual precipitation (P) plus all the remaining moisture in the soil, ΔST will be negative and equal to the total amount extracted, and ST at the end of the month will be zero (for January you will have already determined that ST is zero in this case).
5. Starting with January, determine ST and ΔST if not done already. If P < PE, then ST and ΔST are determined as described in #4 above. If P - PE is positive, and ST is already 4.0, then ST will remain 4.0 in January and ΔST will be zero. If P - PE is positive, but ST of the preceding month is less than 4.0, then recharge of soil moisture will occur (ST in December will need to be calculated before January can be done if this option is used, and then only ΔST will be determined, as ST for January is already calculated). In this case, add P - PE for the month to the value of ST for the preceding month--if this total is less than 4.0, then ST for the month will be equal to this sum, and ΔST will be equal to P - PE. If this total exceeds 4.0, the ST will be 4.0 for the month, ΔST will be the difference between 4.0 and ST for the preceding month, and any additional water will run off as surplus (S).
6. Determine the water deficit, if any. If P - PE is negative, and ST is zero by the end of the month, the D = PE - AE, the difference between potential and actual evapotranspiration. In all other cases, D = 0.
7. Determine the water surplus (S), if any. S will have a nonzero value only if P - PE is positive and the soil is fully recharged at the end of the month. If the soil was fully recharged at the end of the previous month, then S = P - PE. If the soil was not fully recharged in the previous month, but is by the end of the current month, then the surplus will be equal to P - PE minus ΔST for the current month.
8. Repeat steps 4-7 for each month until a complete water balance for the year is produced.
9. Compute the annual totals of P, PE, AE, S, and D.

NOTE

Table 4 has been included to give you an idea of how soil moisture holding capacity can vary with different soil and vegetation types. We have assumed a soil moisture capacity of 4.0 inches, but values from 2 - 16 inches are not uncommon, and could greatly change the yearly water balance.

TABLE 1

MONTHLY VALUES OF I CORRESPONDING TO MONTHLY MEAN TEMPERATURES (°F)

T °F	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
32	.00	.00	.00	.01	.01	.01	.02	.02	.03	.03
33	.04	.04	.05	.05	.06	.06	.07	.08	.09	.09
34	.10	.10	.11	.12	.13	.14	.15	.16	.17	.18
35	.19	.20	.21	.22	.23	.24	.25	.26	.27	.28
36	.29	.30	.32	.33	.34	.35	.36	.37	.39	.40
37	.41	.42	.43	.44	.46	.47	.48	.50	.51	.52
38	.54	.55	.56	.58	.59	.60	.62	.63	.65	.66
39	.68	.70	.71	.73	.74	.76	.77	.79	.80	.82
40	.83	.85	.86	.88	.90	.91	.93	.95	.96	.98
41	1.00	1.01	1.03	1.05	1.07	1.08	1.10	1.12	1.14	1.16
42	1.17	1.19	1.21	1.23	1.24	1.26	1.18	1.20	1.32	1.33
43	1.35	1.37	1.39	1.41	1.43	1.45	1.47	1.49	1.50	1.52
44	1.54	1.56	1.58	1.60	1.62	1.64	1.66	1.68	1.70	1.72
45	1.74	1.76	1.78	1.80	1.82	1.85	1.87	1.89	1.91	1.93
46	1.95	1.97	2.00	2.02	2.04	2.06	2.08	2.10	2.13	2.15
47	2.17	2.19	2.21	2.23	2.26	2.28	2.30	2.32	2.34	2.37
48	2.39	2.41	2.43	2.46	2.48	2.50	2.53	2.55	2.57	2.60
49	2.62	2.64	2.67	2.69	2.71	2.74	2.76	2.79	2.81	2.84
50	2.86	2.89	2.91	2.93	2.96	2.98	3.01	3.03	3.06	3.08
51	3.11	3.13	3.16	3.18	3.21	3.23	3.25	3.28	3.30	3.33
52	3.35	3.38	3.40	3.43	3.45	3.48	3.50	3.53	3.55	3.58
53	3.60	3.63	3.65	3.68	3.71	3.73	3.76	3.79	3.81	3.84
54	3.87	3.89	3.92	3.95	3.97	4.00	4.03	4.06	4.08	4.11
55	4.14	4.16	4.19	4.22	4.25	4.27	4.30	4.33.	4.35	4.38
56	4.41	4.44	4.47	4.50	4.52	4.55	4.57	4.60	4.63	4.66
57	4.69	4.72	4.75	4.77	4.80	4.83	4.86	4.89	4.92	4.95
58	4.98	5.01	5.04	5.07	5.10	5.13	5.15	5.19	5.22	5.25
59	5.28	5.31	5.34	5.37	5.40	5.43	5.46	5.49	5.52	5.55
60	5.58	5.61	5.64	5.67	5.70	5.73	5.76	5.79	5.82	5.85
61	5.88	5.91	5.94	5.97	6.00	6.03	6.06	6.10	6.13	6.16
62	6.19	6.22	6.25	6.28	6.31	6.34	6.38	6.41	6.44	6.47
63	6.50	6.53	6.56	6.59	6.62	6.66	6.69	6.72	6.75	6.79
64	6.82	6.85	6.88	6.92	6.95	6.98	7.02	7.05	7.08	7.12
65	7.15	7.18	7.22	7.25	7.28	7.32	7.35	7.38	7.42	7.45
66	7.48	7.52	7.55	7.58	7.62	7.65	7.68	7.72	7.75	7.78
67	7.82	7.85	7.89	7.92	7.95	7.99	8.02	8.05	8.09	8.12
68	8.16	8.19	8.23	8.26	8.30	8.33	8.37	8.40	8.44	8.47
69	8.51	8.54	8.57	8.61	8.64	8.68	8.71	8.75	8.78	8.82

Table 1 continued

70	8.85	8.89	8.92	8.96	8.99	9.03	9.05	9.10	9.13	9.17
71	9.20	9.24	9.27	9.31	9.34	9.38	9.42	9.45	9.49	9.53
72	9.57	9.60	9.64	9.67	9.71	9.75	9.78	9.82	9.85	9.89
73	9.93	9.97	10.01	10.04	10.08	10.12	10.15	10.19	10.22	10.26
74	10.30	10.34	10.37	10.41	10.45	10.48	10.52	10.56	10.60	10.64
75	10.67	10.71	10.75	10.78	10.82	10.86	10.89	10.93	10.97	11.01
76	11.05	11.09	11.13	11.17	11.20	11.24	11.28	11.31	11.35	11.39
77	11.43	11.47	11.51	11.54	11.58	11.62	11.66	11.70	11.74	11.76
78	11.82	11.85	11.89	11.93	11.97	12.01	12.05	12.09	12.13	12.17
79	12.21	12.25	12.29	12.33	12.37	12.41	12..45	12.49	12.53	12.57
80	12.61	12.65	12.69	12.73	12.77	12.81	12.85	12.89	12.93	12.97
81	13.01	13.05	13.09	13.13	13.17	13.21	13.15	13.29	13.33	13.37
82	13.41	13.45	13.49	13.53	13.57	13.61	13.65	13.69	13.73	13.77
83	13.81	13.85	13.89	13.94	13.98	14.02	14.06	14.10	14.14	14.18
84	14.22	14.26	14.31	14.35	14.39	14.43	14.47	14.52	14.56	14.60
85	14.64	14.69	14.73	14.77	14.81	14.85	14.90	14.94	14.98	15.02
86	15.07	15.11	15.15	15.19	15.23	15.28	15.32	15.36	15.40	15.45
87	15.49	15.53	15.58	15.62	15.66	15.71	15.75	15.79	15.84	15.88
88	15.92	15.97	16.01	16.05	16.10	16.14	16.18	16.23	16.27	16.31
89	16.36	16.40	16.44	16.49	16.53	16.57	16.62	16.66	16.70	16.75
90	16.79	16.83	16.88	16.92	16.98	17.01	17.05	17.09	17.14	17.18
91	17.23	17.27	17.32	17.36	17.41	17.45	17.49	17.54	17.58	17.63
92	17.67	17.72	17.76	17.81	17.85	17.89	17.94	17.98	18.03	18.07
93	18.12	18.16	18.21	18.25	18.30	18.34	18.39	18.43	18.48	18.52
94	18.57	18.62	18.66	18.71	18.75	18.80	18.84	18.89	18.93	18.98
95	19.03	19.07	19.12	19.16	19.21	19.25	19.30	19.34	19.39	19.44
96	19.48	19.53	19.58	19.62	19.67	19.71	19.76	19.81	19.86	19.90
97	19.95	20.00	20.04	20.09	20.14	20.18	20.23	20.28	20.32	20.37
98	20.42	20.46	20.51	20.56	20.60	20.65	20.70	20.74	20.79	20.84
99	20.88	20.93	20.98	21.03	21.08	21.13	21.17	21.22	21.27	21.32
100	21.36	21.41	21.46	21.51	21.56	21.60	21.65	21.70	21.75	21.79
101	21.84	21.89	21.94	21.99	22.03	22.08	22.13	22.18	22.23	22.28
102	22.33	22.38	22.42	22.47	22.52	22.57	22.62	22.67	22.71	22.76
103	22.81	22.85	22.91	22.96	23.00	23.05	23.10	23.15	23.20	23.25
104	23.30									

TABLE 2

MEAN POSSIBLE DURATION OF SUNLIGHT IN THE NORTHERN AND SOUTHERN HEMISPHERES EXPRESSED IN UNITS OF 30 DAYS OF 12 HOURS EACH

	J	F	M	A	M	J	J	A	S	O	N	D
N.Lat.												
0	1.04	.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
5	1.02	.93	1.03	1.02	1.06	1.03	1.06	1.05	1.01	1.03	.99	1.02
10	1.00	.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	.98	.99
15	.97	.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	.95	.97
20	.95	.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	.93	.94
25	.93	.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	.99	.91	.91
26	.92	.88	1.03	1.06	1.15	1.15	1.17	1.12	1.02	.99	.91	.91
27	.92	.88	1.03	1.07	1.16	1.15	1.18	1.13	1.02	.99	.90	.90
28	.91	.88	1.03	1.07	1.16	1.16	1.18	1.13	1.02	.98	.90	.90
29	.91	.87	1.03	1.07	1.17	1.16	1.19	1.13	1.03	.98	.90	.89
30	.90	.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	.98	.89	.88
31	.90	.87	1.03	1.08	1.18	1.18	1.20	1.14	1.03	.98	.89	.88
32	.89	.86	1.03	1.08	1.19	1.19	1.21	1.15	1.03	.98	.88	.87
33	.88	.86	1.03	1.09	1.19	1.20	1.22	1.15	1.03	.97	.88	.86
34	.88	.85	1.03	1.09	1.20	1.20	1.22	1.16	1.03	.97	.87	.86
35	.87	.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	.97	.86	.85
36	.87	.85	1.03	1.10	1.21	1.22	1.24	1.16	1.03	.97	.86	.84
37	.86	.84	1.03	1.10	1.22	1.23	1.25	1.17	1.03	.97	.85	.83
38	.85	.84	1.03	1.10	1.23	1.24	1.25	1.17	1.04	.96	.84	.83
39	.85	.84	1.03	1.11	1.23	1.24	1.26	1.18	1.04	.96	.84	.82
40	.84	.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	.96	.83	.81
41	.83	.83	1.03	1.11	1.25	1.26	1.27	1.19	1.04	.96	.82	.80
42	.82	.83	1.03	1.12	1.26	1.27	1.28	1.19	1.04	.95	.82	.79
43	.81	.82	1.02	1.12	1.26	1.28	1.29	1.20	1.04	.95	.81	.77
44	.81	.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	.95	.80	.76
45	.80	.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	.94	.79	.75
46	.79	.81	1.02	1.13	1.29	1.31	1.32	1.22	1.04	.94	.79	.74
47	.77	.80	1.02	1.14	1.30	1.32	1.33	1.22	1.04	.93	.78	.73
48	.76	.80	1.02	1.14	1.31	1.33	1.34	1.23	1.05	.93	.77	.72
49	.75	.79	1.02	1.14	1.32	1.34	1.35	1.24	1.05	.93	.76	.71
50	.74	.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	.92	.76	.70
S.Lat.												
5	1.06	.95	1.04	1.00	1.02	.99	1.02	1.03	1.00	1.05	1.03	1.06
10	1.08	.97	1.05	.99	1.01	.96	1.00	1.01	1.00	1.06	1.05	1.10
15	1.12	.98	1.05	.98	.98	.94	.97	1.00	1.00	1.07	1.07	1.12
20	1.14	1.00	1.05	.97	.96	.91	.95	.99	1.00	1.08	1.09	1.15
25	1.17	1.01	1.05	.96	.94	.88	.93	.98	1.00	1.10	1.11	1.18
30	1.20	1.03	1.06	.95	.92	.85	.90	.96	1.00	1.12	1.14	1.21
35	1.23	1.04	1.06	.94	.89	.82	.87	.94	1.00	1.13	1.17	1.25
40	1.27	1.06	1.07	.93	.86	.78	.84	.92	1.00	1.15	1.20	1.29
42	1.28	1.07	1.07	.92	.85	.76	.82	.92	1.00	1.16	1.22	1.31
44	1.30	1.08	1.07	.92	.83	.74	.81	.91	.99	1.17	1.23	1.33
46	1.32	1.10	1.07	.91	.82	.72	.79	.90	.99	1.17	1.25	1.35
48	1.34	1.11	1.08	.90	.80	.70	.76	.89	.99	1.18	1.27	1.37
50	1.37	1.12	1.08	.89	.77	.67	.74	.88	.99	1.19	1.29	1.41

TABLE 3

PROVISIONAL WATER HOLDING CAPACITIES WITH DIFFERENT COMBINATIONS OF SOIL AND VEGETATION

SOIL TYPE	*AVAILABLE WATER*		*ROOT ZONE*		*APPLICABLE SOIL MOISTURE* RETENTION TABLE	
	MM/M	IN/FT	M	FT	MM	IN
SHALLOW-ROOTED CROPS (SPINACH, PEAS, BEANS, BEETS, CARROTS, ETC.)						
FINE SAND	100	1.2	.50	1.67	50	2.0
FINE SANDY LOAM	150	1.8	.50	1.67	75	3.0
SILT LOAM	200	2.4	.62	2.08	125	5.0
CLAY LOAM	250	3.0	.40	1.33	100	4.0
CLAY	300	3.6	.25	.83	75	3.0
MODERATELY DEEP-ROOTED CROPS (CORN, COTTON TOBACCO, CEREAL GRAINS)						
FINE SAND	100	1.2	.75	2.50	75	3.0
FINE SANDY LOAM	150	1.8	1.00	3.33	150	6.0
SILT LOAM	200	2.4	1.00	3.33	200	8.0
CLAY LOAM	250	3.0	.80	2.67	200	8.0
CLAY	300	3.6	.50	1.67	50	6.0
DEEP-ROOTED CROPS (ALFALFA, PASTURES, SHRUBS)						
FINE SAND	100	1.2	1.00	3.33	100	4.0
FINE SANDY LOAM	150	1.8	1.00	3.33	150	6.0
SILT LOAM	200	2.4	1.25	4.17	250	10.0
CLAY LOAM	250	3.0	1.00	3.33	250	10.0
CLAY	300	3.6	.67	2.22	200	8.0
ORCHARDS						
FINE SAND	100	1.2	1.50	5.00	150	6.0
FINE SANDY LOAM	150	1.8	1.67	5.55	250	10.0
SILT LOAM	200	2.4	1.50	5.00	300	12.0
CLAY LOAM	250	3.0	1.00	3.33	250	10.0
CLAY	300	3.6	.67	2.22	200	8.0
CLOSED NATURE FOREST						
FINE SAND	100	1.2	2.50	8.33	250	10.0
FINE SANDY LOAM	150	1.8	2.00	6.66	300	12.0
SILT LOAM	200	2.4	2.00	6.66	400	16.0
CLAY LOAM	250	3.0	1.60	5.33	400	16.0
CLAY	300	3.6	1.17	3.90	350	14.0

THESE FIGURES ARE FOR MATURE VEGETATION. YOUNG CULTIVATED CROPS, SEEDLINGS, AND OTHER IMMATURE VEGETATION WILL HAVE SHALLOWER ROOT ZONES AND, HENCE, HAVE LESS WATER AVAILABLE FOR THE USE OF THE VEGETATION. AS THE PLANT DEVELOPS FROM A SEED OR A YOUNG SPROUT TO THE MATURE FORM, THE ROOT ZONE WILL INCREASE PROGRESSIVELY FROM ONLY A FEW INCHES TO THE VALUES LISTED ABOVE. USE OF A SERIES OF SOIL MOISTURE RETENTION TABLES WITH SUCCESSIVELY INCREASING VALUES OF AVAILABLE MOISTURE PERMITS THE SOIL MOISTURE TO BE DETERMINED THROUGHOUT THE GROWING SEASON.

Water Balance for _____
Latitude _____

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
T													
i													I=
unadj. PE													XXXX XXXX
sun. correct.													XXXX XXXX
adjusted PE													
P													
PE													
P-PE													XXXX
ΔST													XXXX
ST													XXXX
AE													
D													
S													

Figure 1

Nomograph for computing unadjusted potential evaporation (in inches) from the annual heat index (I), and from the mean monthly temperature in degrees Fahrenheit. According to C.W. Thornthwaite.