FREQUENCY OF MOISTURE DEFICIENCIES IN THE LOWER PENINSULA OF MICHIGAN

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Robert J. Moraniec

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E H Kidder
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FREQUENCY OF MOISTURE DEFICIENCIES IN THE LOWER PENINSULA OF MICHIGAN

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Robert J. Moraniec

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INTRODUCTION

Moisture deficiency in the root zone of the soil during the crop production season, is a major problem confronting Michigan farmers. With an erratic rainfall distribution pattern, the amount of moisture available for the plant may often be less than the amount required for maximum plant development and yield. The soil is like a large reservoir where water is added by rainfall, irrigation, or capillary action, and removed by evapotranspiration, deep percolation, or surface runoff. With good agricultural practices through-out the growing season on non-irrigated soil the movement of water by capillary action, deep percolation, and surface runoff will be negligible. When the balance between rainfall and evapotranspiration indicates the reservoir is empty, plant growth is retarded. Evapotranspiration is computed by finding the amount of water that can be evaporated with the energy received from the sun. The energy received from the sun is assumed to be proportional to the energy used for the evapotranspiration of moisture from the soil.

The use of supplemental irrigation has been increasing in recent years where rainfall through the growing season is inadequate. Farmers having irrigation systems could use an individual bookkeeping system, where the rainfall is added and evapotranspiration is subtracted to obtain their soil reserve for each day of the season. Other farmers contemplating buying irrigation equipment need information on how many times each year, and the number of years in ten they can expect to use the equipment.

The objective of this study was to determine evapotranspiration rates and to compute the frequency of moisture deficient days through-out the growing season from the Michigan climatological data.

REVIEW OF LITERATURE

Cahow (3), studied the precipitation in Michigan and classified a drought as a "period constituting seven days or more in which less than 0.25 inches of precipitation has occurred in 24 hours." He then calculated the frequency of one, two, three, four, and five week droughts for the lower peninsula of Michigan.

Van Bavel, (16), developed a method for using daily precipitation and daily moisture loss to estimate the supply of available moisture in the soil. This method assumes that crops have a moisture reservoir in the soil to the depth of the effective root zone. The capacity of this reservoir varies directly with the root depth of the crop and the water holding capacity of the soil. If the root depth is two feet and the water holding capacity is one inch per foot then the crop has a two inch moisture reservoir. In computing his daily moisture loss Van Bavel takes into account the moisture removed by evaporation from the soil and transpiration from the leaves. This is commonly refered to as evapotranspiration.

Empirical Formula Based on Experimental Data

Thornthwaite, (12), assumes that the relationship between temperature and evapotranspiration is exponential.

In other words, when temperature and evapotranspiration are plotted on log-log paper they form a straight line.

Thornthwaite's (12) assumption is based on experience with watersheds in central and eastern United States and is therefore of limited value. Where temperature and radiation are strongly correlated this method works well. In southern latitudes or locations where the land is effected by large bodies of water as in Michigan, the air temperature lags behind radiation by three to four weeks giving evapotranspiration values which are questionable.

Blaney and Criddle (2) developed an empirical formula in which $u = \frac{t \times p}{100} \times f$.

$u =$ monthly evapotranspiration in inches.
$t =$ average monthly temperature in $^{\circ}$F.
$f =$ empirical consumptive use factor.
$p =$ percent of annual daytime hours occuring that month.

Values of f are obtained by growing various crops in large vats or lysimeters that can be weighted without destroying the crop. The daily change in weight is then given the value of f which is similar for most crops. The value of f often varies from one location to another.

The Blaney Criddle formula is based on temperature and length of day which implies the use of radiation energy. Good results are obtained where radiation is closely related to temperature. Estimates of seasonal requirements are generally better than the shorter monthly periods.

Theoretical Vapor Transfer Method

Thornthwaite and Holzman (13), developed a vapor transfer formula in which $E = \frac{K_o^2 (x_1 - x_2)(u_2 - u_1)}{(\text{Log } z_2/z_1)^2}$

E = rate of evaporation.
K_a = universal constant.
z_1 = height 1.
x_1 = vapor density at height 1.
u_1 = wind speed at height 1.

Formulas of this nature have not been thoroughly tested and the neccessary data is not available.

Theoretical Energy Balance Method

This method is based on the fact that the energy received by the earths surface through radiation must be equal to the energy used for evaporation plus that used to heat both the soil and the air. The energy used for heating the soil and air can be neglected for daily balances, and if an error of 5 percent is acceptable they can be neglected on the monthly balances.

Penman (10) first published a method of estimating the amount of radiative energy gained by the surface and expressed this in mm of evaporated water. The method was slightly modified by Van Bavel (18) giving the following equation for evapotranspiration.

$$E_T = \frac{\Delta H + .27\, E_a}{\Delta + .27}$$

E_T = evapotranspiration in mm/day.
Δ = slope of the saturated vapor pressure curve. at air temperature. (See appendix II, A.)
H = net radiation.
E_a = $.35\,(e_a - e_d)(1 + .0098\, u_2 0$ mm/day.
e_a = saturation vapor pressure at mean air temperature in mm Hg. (See appendix II, B.)

e_d = saturation vapor pressure at mean dew point.
or actual vapor pressure of air in mm Hg.
also equal to e_a x (percent relative humidity).

u_2 = wind speed at 2 meters in miles per day which
is equal to $u_h \times \left(\frac{\log 6.6}{\log h}\right)$

u_h = wind speed in miles per day at height h in feet.

Van Bavel (18), states that the experimental evidence so far lends the most support to the Penman formula for determining evapotranspiration values.

PROCEDURE

Temperature in Michigan lags behind radiation by approximately four weeks. Any method of calculating evapotranspiration without using radiation as one of the variables would give questionable results. Experimental evidence so far show more favorable results with the Penman formula as a universal method (18). Therefore the Penman(10) method was used for calculating evapotranspiration. This method indicated the potential evapotranspiration that can take place on vegetation. It was then modified by a factor of .75 to obtain actual evapotranspiration. Tests in the Netherlands indicate that .75 was the best correction factor for obtaining actual evapotranspiration from potential evapotranspiration.

Calculating Evapotranspiration

Penman's formula is $E_t = \dfrac{\Delta H_t + .27\, E_a}{\Delta + .27/SD}$

E_t = potential evapotranspiration in mm/day.
Δ = slope of saturated vapor pressure curve. (see appendix II, A.)
H_t = net radiation.
E_a = auxiliary quantity.
S = factor denoting influence of diffusion resistance.
D = factor denoting influence of length of day.

Net radiation values were calculated from:

$$H_t = Ra\ (1-r)(0.18 + 0.55\ n/N) - \sigma T_a^4\ (0.56 - 0.092\sqrt{e_d})(0.10 + 0.90\ n/N)$$

R_a = mean monthly extraterrestrial radiation.
r = 0.20 radiation reflection coefficient for vegetation.
n/N = ratio actual to possible hours of sunshine.
σ = Stefan Boltzman constant 2.01 x 10^{-9} mm/day.
T_a = absolute temperature of air °R.
e_d = saturation vapor pressure at mean dew point.

Values of E_a were calculated from:

$$E_a = 0.35\ (e_a - e_d)(1 + 0.0098\ u_2)\ \text{mm/day.}$$

e_a = saturation vapor pressure at mean air temperature.
u_2 = windspeed at two meters.

Values of S were calculated from:

$$S = La/(La + 0.16)$$

La = effective diffusion lenght of air which is equal to .65 (1 0.0098 u_2)

Values of D were calculated from:

$$D = N/24 + 1/\pi \sin N\pi/24$$

N = hours from sunrise to sunset.

The wind speed was given in miles per hour at a height 60 feet in East Lansing, 64 feet in Detroit, 81 feet in Grand Rapids, and 89 feet in Alpena. The formula Penman (10) uses to convert this to a two meter elevation is:

$$u_2 = u_h \times \left(\frac{\log 6.6}{\log h}\right)$$

u_h = wind speed at height h in miles per day.

No further corrections were made to this value because it was felt that even though the tower was located in town on top of a building, the figure obtained for 2 meters would still represent the rural wind speed.

The average air temperatures in cities has been about 1 to 2½ degrees °F higher in the summer time because of higher night time temperatures brought about by the slow cooling rate for buildings and roads (5).

East Lansing Temperature

	June	July	Sept.
City Temperature	68.9	72.8	68.8
Rural Temperature	67.0	70.4	67.1
Difference	1.9 °F	2.4 °F	1.7 °F

A correction was made on average air temperature by subtracting 2 °F so that the values would represent average rural air temperatures.

Average values for relative humidity were about 5 percent lower in cities because the soil is covered with roads and buildings causing less evapotranspiration (5).

East Lansing Relative Humidity

	June	July	Sept.
Rural RH	64	54	61
City RH	54	49	50
Difference	10%	5%	11%

To prevent overcorrecting the relative humdity, 5 percent was added to the average city value to give a representative rural value.

Appendix 1 shows an example of the calculation procedure for finding evapotranspiration rates. Monthly calculatings were made for Grand Rapids, Detroit, East Lansing, and Alpena with the data listed in Appendix IV.

Results of these calculations when modified by multiplying by .75 are shown in table 1. Because of the small difference between the values (table 1) for the various locations through out the state, (figure 1) the value for Lower Michigan (table 1) assumed to represent daily evapotranspiration for the Lower Peninsula of Michigan.

Calculation of Moisture Deficient Days

In calculating moisture deficient days only the crop production months, May through September, were used. The moisture reservoir of the soil was assumed to be full on the 1st. of May each year. The reservoir amounts used were 1, 2, 3, 4, 5, and 7-inches, from which the Lower Michigan daily evapotranspiration values were subtracted and daily rainfall added, never allowing the total to go over the individual reservoir amounts or to go below zero. (See table 2.) By not allowing the total to go above the reservoir amount, water could be removed by runoff or deep percolation. This happened when heavy rainfall was received in May or June. Later in the season under good agricultural practices very little runoff occurs and the soil reservoir will normally hold all the rainfall.

A moisture deficient day occured each time the calculated soil moisture was zero as shown in table 2. The number of moisture deficient days occuring each month were counted and recorded for the six moisture reservoirs. This was accomplished by using the IBM equipment in the tabulating department of Michigan State University.

TABLE 1 ACTUAL AVERAGE DAILY EVAPOTRANSPIRATION

	May	June	July	Aug.	Sept.
Grand Rapids	.09	.12	.13	.10	.07
East Lansing	.08	.12	.12	.10	.07
Detroit	.09	.12	.13	.10	.07
Alpena	.08	.11	.12	.10	.06
Lower Michigan	.09	.12	.13	.10	.07

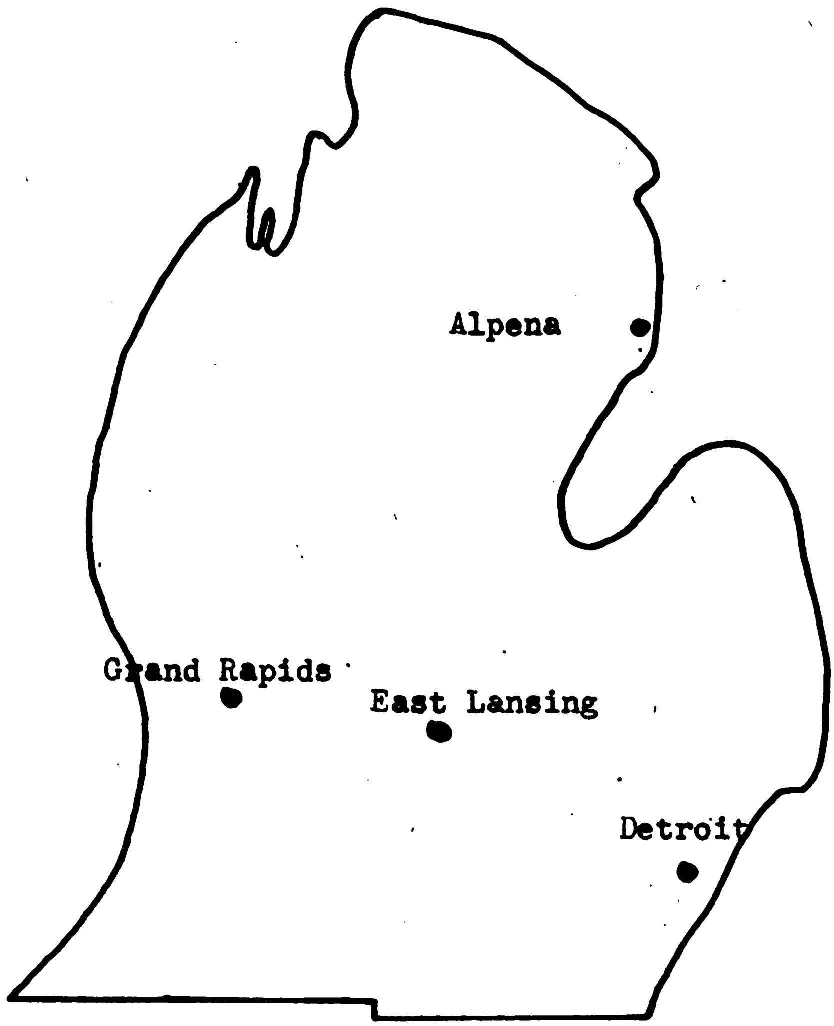


Figure 1. Location of weather stations used to determine evapotranspiration.

TABLE 2 EXAMPLE OF COMPUTATION FOR DETERMINING NUMBER OF MOISTURE DEFICIENT DAYS FOR VARYING SOIL MOISTURE RESERVOIRS

Date	Evapotranspiration inches	Precipitation inches	Moisture Reservoir 1 inch inches	3 inch inches	5 inch inches
Amount from previous months			0.33	0.55	2.75
1	0.25		0.08	0.30	2.50
2	0.25		0.00	0.05	2.25
3	0.25		0.00	0.00	2.00
4	0.25	0.75	0.50	0.50	2.50
5	0.25	1.25	1.00	1.50	3.50
6	0.25		.75	1.25	3.25
Total number of moisture deficient days			2	1	0

Weather information for the stations shown in figure 2 were used for the calculation of moisture deficient days. This eliminated punching daily rainfall on cards. The values calculated for Lower Michigan evapotranspiration given in table 1 were punched in columns 75 and 76 for all stations except East Lansing, where columns 73 and 74 were used.

The No. 604 calculating punch did the computing and a trailer card inserted at the end of each month was punched with the actual number of moisture deficient days for the given month. After running the cards through three times for six moisture reservoirs, the No. 120 sorter removed the trailer cards. The accounting machine printed the information from the trailer cards and it was compiled in tables 3 through 10. For easier reading of the tables 3 through 10, all zero's were omitted. The bottom two lines of tables 3 through 10 give the actual number of moisture deficient days occuring once in ten years and five times in ten years. In this paper the probability of .1 is refered to as 1 year in 10 and the probability of .5 is refered to as 5 years in 10. This is based on the actual number occuring over a thirty year period and may change slightly with a longer period of time.

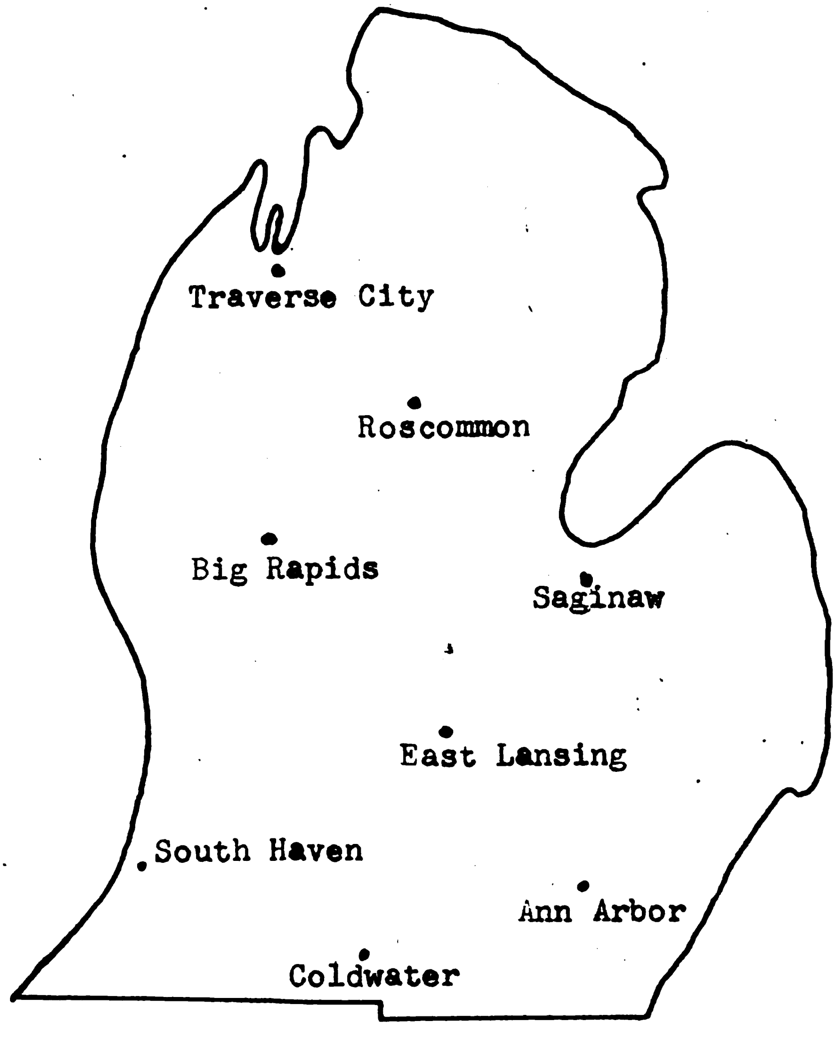


Figure 2. Location of weather stations used in calculation of moisture deficient days.

TABLE 3 MOISTURE DEFICIENT DAYS FOR SOUTH HAVEN, MICHIGAN FOR 1, 2, 3, 4, 5, AND 7-INCH SOIL MOISTURE RESERVOIRS

Years	May (31 days)						June (30 days)						July (31 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27							10						23	23	14	5		
28	5						7						8					
29	2						11	3					24	24	15	7		
30							17	6					17	13	11	3		
31							7						20	14	6			
32	2						17	8					13	11	9	1		
33							13	4					14	6				
34	7						21	18	12	8	1		25	25	25	25	25	1
35	2						8						13	5				
36	8						16	7					27	27	26	17	9	
37							4						18	11	1			
38							7						13	10	1			
39	7												13	5				
40							7						21	13	5			
41							13	4					23	23	19	9	1	
42	3						2						15	5				
43							11						8	4				
44							8						20	13	4			
45													20	11	3			
46							16	7					30	30	28	20	12	
47							10						22	21	13	4		
48	6						16	12					16	15	14	7		
49	4						11	3					11					
50	14	1					1	1					10					
51							11	2					9					
52													9	1				
53	6						13	7					7					
54	8						7						15	5				
55	6						11	5					23	23	20	12	4	
56	1						23	16	7				15	14	14	11	2	
1 yr. in 10.	7						17	12					25	25	25	12	9	
5 yrs. in 10	1						11	1					16	11	4			

TABLE 3 CONTINUED: SOUTH HAVEN, MICHIGAN

Years	August (31 days)						September (30 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	21	21	21	21	17		9	9	9	9	9	2
28	10	10										
29	22	22	22	22	22		17	1	1	1	1	
30	22	19	19	19	12		12	12	12	12	12	
31	21	21	21	17	6		2					
32	4	3	3	3			14	14	14	14		
33	19	11	6				10	10	10	4		
34	5	5	5	5	5	5						
35	4	1					8	6				
36	12	12	12	12	12	2						
37	13	12	12	1			3					
38	5	5	5				3	1	1			
39	8	8					10	7	7			
40	1	1	1				3					
41	9	9	9	9	9		2	2	2	2	2	
42	4											
43	3	3										
44	18	18	18	12	2							
45	5	5	5									
46	24	24	24	24	24	20	16	16	16	16	16	16
47	29	29	29	29	24	4						
48	20	20	20	20	17		11	11	5	5	5	3
49	17	5										
50	31	24	14	2			14	14	14	14		
51	5						6					
52	5						9					
53	12	2					2	2				
54	8	8	1				16	16	16			
55	16	16	16	16	16		10					
56	11	11	11	11	11		14	14	14	14	14	
1 yr. in 10	24	24	22	22	22	4	16	14	14	14	12	2
5 yrs. in 10	12	10	6	2			8	1				

TABLE 4 MOISTURE DEFICIENT DAYS FOR EAST LANSING, MICHIGAN FOR 1, 2, 3, 4, 5, AND 7-INCH SOIL MOISTURE RESERVOIRS

Years	May (31 days)						June (30 days)						July (31 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	4						17	6					17	17	14	5		
28							3						18	12	2			
29	1						20	11					17	17	16	5		
30							4						28	22	14	5		
31							9	1					20	20	10	2		
32	2						17	8					11	8	5			
33							24	14	4				16	9	9	3		
34	6						18	14	5				20	16	16	10	2	
35	3						3						8					
36	16	4					18	12	6				23	21	18	14	6	
37													18	9				
38							8						17	16	6			
39	2						4						21	12	4			
40													15	4				
41							5						26	21	12	3		
42	1						1						8					
43							12	3					7					
44							8						25	23	15	7		
45							1						17	7				
46							8						31	25	16	8		
47							5						8	1				
48							13	4					17	8				
49	6						11	2					6					
50	9						2						10	3				
51	1						4						22	17	7			
52							12	5					17	17	12	2		
53							11	1					10	3				
54	15	3					2						14	6				
55	8						11						11	4				
56							14	5					17	15	8			
1 yr. in 10	9						18	12	4				26	22	16	8		
5 yrs. in 10							8						17	12	5			

TABLE 4 CONTINUED: EAST LANSING, MICHIGAN

Year	August (31 days)						September (30 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	27	30	30	30	26	5	7	7	7	7	7	7
28	15	15	15	5								
29	31	31	31	31	27	4	19	19	19	19	19	19
30	30	30	30	30	27	6	15	15	15	15	15	15
31	15	15	15	15	7		2	2	2	2	2	
32	18	18	18	13	2		3					
33	22	22	22	22	15		9	9	9	9	9	
34	19	19	19	19	19							
35	7	5					12	12				
36	17	17	17	17	17	5						
37	6	5	5				15					
38	5	5	5	1			7					
39	14	14	14	8			13	13	13	13	6	
40	9	9	3				3					
41	12	10	10	10	4		5					
42	2						7					
43	6											
44	22	22	22	22	19							
45	4	4	2									
46	27	27	27	27	27	2	7	7	7	7	7	7
47	13	13	3									
48	18	14	12	1								
49	10											
50	10											
51	8	6	6	4			7					
52	4	4	4	4			19	17	2			
53	9						12	12	12	7		
54	15	15	8				6	4	3			
55	12	7					13					
56												
1 yr. in 10.	30	30	30	30	27	5	15	15	13	13	9	7
5 yrs. in 10.	14	13	6	4			7					

TABLE 5 MOISTURE DEFICIENT DAYS FOR ANN ARBOR, MICHIGAN FOR 1, 2, 3, 4, 5, AND 7-INCH SOIL MOISTURE RESERVOIRS

Years	May (31 days)						June (30 days)						July (31 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27							3						5					
28	2						9						7	4				
29	1						12	5					13	13	9			
30	3						7						19	14	6			
31							11	2					16	16	9	1		
32	1						12	3					6	6				
33	1						18	8					12	4				
34	12						25	25	15	5			25	25	25	25	21	5
35	3						10						16	14	6			
36	17	6					15	11	5				26	26	26	22	15	
37													6					
38							9						5	2				
39	13	2					4	4					15	12	7			
40													12					
41	2						3						17	10	1			
42	3						3						10	4				
43							2						7					
44							4						19	11	2			
45							3						15	2				
46							10						25	19	11	3		
47							11	3					27	27	21	10	1	
48	4						9	3					12	12	5			
49	7						12	4					11	6				
50	5						5						17	10	2			
51							13	3					10	8	2			
52							20	11	1				22	22	22	13	4	
53	4						13	7					8					
54	13	2											29	20	12	3		
55	20	9					24	24	23	14	5		12	7	7	7	7	
56							6						11	7	2			
1 yr. in 10	13	2					20	11	5				26	26	22	13	7	
5 yrs. in 10	1						9						13	10	2			

TABLE 5 CONTINUED: ANN ARBOR, MICHIGAN

Years	August (31 days)						September (30 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	27	17	5				3	3	3			
28	10											
29	28	28	28	26	14		11	11	11	11	11	
30	31	31	31	29	18		16	16	16	16	16	11
31	11	11	11	11	1		5	5	5	5	5	
32	7						1					
33	20	15	15	4			16	16	16	16	6	
34	27	27	27	27	27	27	2	2	2	2	2	2
35	8	1	1				13	5	5	1		
36	24	24	24	24	24	22						
37	1						18	3				
38	9	9					8	8	7			
39	24	24	24	22	11		3	3	3	3	3	
40	5	5					6					
41	12	12	12				3					
42	7	1					1	1				
43	13	1					6	3				
44	10	10	10	2			15	15	15	15	2	
45	12	11	3				4	4	4			
46	3	3	3	3			9	4	4	4		
47	15	15	15	15	15		6					
48	24	23	23	18	7		12	12	12	12	12	
49	6	3	3									
50	19	4	4				2					
51	12	2					13	13	3			
52	26	26	26	26	26	5	6					
53	15	9					2	2	1			
54	13	13	13	13	2		13	13	13	13	13	
55	31	29	29	29	29	22	30	30	30	30	30	30
56	5	3	3				25	16	16	5		
1 yr. in 10	28	28	28	27	26	22	18	16	16	16	13	2
5 yrs. in 10	13	11	5				6	3	3			

TABLE 6 MOISTURE DEFICIENT DAYS FOR BIG RAPIDS, MICHIGAN FOR 1, 2, 3, 4, 5, AND 7-INCH SOIL MOISTURE RESERVOIRS

Years	May (31 days)						June (30 days)						July (31 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27							11	1					15	15	8			
28	2						3						16	8				
29							8						9					
30	11						6	3					21	15	10			
31							11	1					18	12	4			
32	3						12	2					12	3				
33							17	8					11	6	4			
34	8						14	11	3				28	23	23	16	8	
35	7						15	11	2				14	6	6			
36	7						20	15	7				25	25	25	23	15	
37	1						15	5					20	20	17	7		
38	3						7						21	19	12	1		
39	7						4						21	11	4			
40							3						21	14	6			
41	5						20	14	5				25	25	25	23	12	
42							1						12	5				
43													12	4				
44							3						14	6				
45							12	1					16	16	7			
46							10						23	19	11	4		
47							9						8	7				
48	7						6	3					16	5				
49	8						7	3					9					
50	3						11	2					7	7				
51	3						10	3					13	12	4			
52							13	3					9	9	3			
53							3						7	1				
54	10						3						20	11	2			
55	5						11	2					22	22	15	6		
56	1						20	11	1				6	6	6			
1 yr. in 10	8						20	11	3				25	23	23	16	8	
5 yrs. in 10	2						11	2					16	11	4			

TABLE 6 CONTINUED: BIG RAPIDS, MICHIGAN

Years	August (31 days)						September (30 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	30	30	30	28	18		4	4	4	4	4	
28	5	2					1					
29	21	19	7				8	8	8	3		
30	23	23	23	23	11		16	16	16	16	16	
31	12	5	5				4	4	4	1		
32	18	18	8				12	12	12	4		
33	15	13	13	6			19	19	19	19	14	
34	5	1	1	1	1							
35	5	1	1				15	15	15	13		
36	17	17	17	17	17	14						
37	19	19	19	19	17		8	8	8	8	8	1
38	5	5	5	5			4					
39	3	3	3									
40	5	5	5	1								
41	15	12	12	12	12	5	5	5	5	5	5	5
42	15	4										
43	15	15	6									
44	13	12	9									
45	7	6	6	3								
46	15	15	15	15	8		9	9	9	9	9	
47	26	26	22	12								
48	24	24	22	11	1		11	11	11	11	11	
49	6											
50	21	11	1				3	3	3			
51	7	7	7	2			4					
52	9						10	6				
53	10						7	7				
54	15	12	12	5			11	11	11	11	1	
55	20	20	20	20	18		5					
56	4						18	4	4			
1 yr. in 10	23	23	22	20	17		16	15	15	13	11	
5 yrs. in 10	15	12	7	1			4	4				

TABLE 7 MOISTURE DEFICIENT DAYS FOR COLD WATER, MICHIGAN FOR 1, 2, 3, 4, 5, AND 7-INCH SOIL MOISTURE RESERVOIRS

Years	May (31 days)						June (30 days)						July (31 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27							8						9	7				
28							8						12	5				
29	4						9	3					15	10	5			
30	2						19	11	2				29	22	17	11	2	
31							8						21	11	3			
32	3						13	4					10	7	1			
33							18	8					15	7				
34							18	9					21	21	20	11	3	
35	3						1						12	3				
36	7						16	9	1				19	18	18	11	2	
37							1						10					
38							1						2					
39	1						8						11	1				
40	1												16	7				
41							3											
42	4						4						15	10	2			
43							6						10					
44							7						25	19	10	2		
45							3						10	2				
46							1						28	20	12	4		
47													16	8				
48	1						7						14	9				
49	5						9	1					5					
50	16	4					2	1					12					
51							5						6					
52							5						7					
53							15	6					12	12	8			
54	12						1						16	6				
55	6						11	2					7	6				
56							13	5					7	5				
1 yr. in 10	7						18	8					25	20	17	11	2	
5 yrs in 10							7						12	7				

TABLE 7 CONTINUED: COLDWATER, MICHIGAN

Years	August (31 days)						September (30 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	19	18	16	4			8	8	8	8		
28	11						1					
29	29	29	29	23	13		15	15	15	15	15	3
30	26	26	26	26	26	5	13	13	13	13	13	13
31	4	3	3				3	3	3			
32	8						5					
33	19	18	15	4			9	9	9	9	1	
34	12	9	9	9	9							
35	5	1					13	5				
36	19	19	19	19	19		3	3	3	3	3	2
37	12											
38	9						8	3				
39	2						7					
40	3						12					
41	30	28	25	17	6		13	13	13	13	13	
42	2						8					
43	15	13	1									
44	22	22	22	22	14		5	5	5	5	5	
45	5	2										
46	13	13	13	13	6		5	5	5	5	5	
47	18	18	17	7								
48	12	10	8				5	5	5			
49	13											
50	27	19	7									
51	5						5					
52	19	7					2					
53	12	7	7	6			5	5	5	5		
54	10	10	5				5					
55	5						11					
56	17	6					19	19	11			
1 yr. in 10	27	26	25	22	14		13	13	13	13	13	2
5 yrs. in 10	12	7	3				5					

TABLE 8 MOISTURE DEFICIENT DAYS FOR SAGINAW, MICHIGAN FOR 1, 2, 3, 4, 5, AND 7-INCH SOIL MOISTURE RESERVOIRS

Years	May (31 days)						June (30 days)						July (31 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27							16	7					16	16	14	5		
28							3						4					
29							18	9	1				22	22	22	12	4	
30							3						30	24	16	8		
31							9						19	14	6			
32							16	8					9					
33							18	9	1				20	15	15	6		
34	13						19	19	11	1			23	23	23	23	14	
35	4						6						25	17	8			
36	10						21	20	11	2			20	20	20	20	14	
37	7						11	8					12	10	8			
38	2						14	2					22	22	15	8		
39	18	4					10	8					21	18	18	10	2	
40							2						17	8				
41	7						27	23	13	5			19	17	17	17	13	
42							2						17	11	2			
43							2						11	2				
44							15	4					23	23	19	10	1	
45							6						21	16	5			
46	1						6						25	20	12	4		
47							6						12	10	2			
48	7						4	1					23	17	8			
49	9						14	9					12					
50	7						15	11	1				3					
51	7						10	5					17	6				
52	1						21	11	3				11	11	11	5		
53	6						14	9					15	15	14	5		
54	15	4					6						25	16	7			
55	8						6						14	10	3			
56							22	12	2				10	9	9	2		
1 yr in 10.	13						21	19	11	1			25	23	20	17	13	
5 yrs. in 10.	1						11	5					19	15	8			

TABLE 8 CONTINUED: SAGINAW, MICHIGAN

Years	August (31 days)						September (30 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	31	31	31	31	26	4	5	5	5	5	5	5
28	5						1					
29	23	23	23	23	23	6	9	9	9	9	9	9
30	27	27	27	27	25	3	14	14	14	14	14	14
31	18	14	14	9			7	7	7	7	5	
32	11	11	7									
33	21	21	21	21	17		8	8	8	8	8	3
34	19	19	19	19	19	16	2	2	2	2	2	2
35	24	24	24	24	11		14	14	14	14	14	
36	14	14	14	14	14	11						
37	5	5	5	4			9					
38	3	3	3	3			9					
39	13	13	13	13	13		2	2	2	2	2	
40	4	4	4									
41	14	12	12	12	12	7	1	1	1	1	1	1
42	4						3					
43	1	1					3					
44	11	11	11	11	11							
45	12	12	12	7								
46	16	16	16	16	7		10	10	10	10	10	
47	14	4										
48	19	18	18	17	6		21	21	21	21	21	
49	12	8	1									
50	16	5					4	4				
51	14	14	12	2								
52	9											
53	16	5	3	3			6	6	3	3		
54	23	23	23	22	11		9	9	9	9	9	
55	11	11	11	3								
56	3	3	3	3			14					
1 yr. in 10	24	24	24	24	23	7	14	14	14	14	14	5
5 yrs. in 10	14	12	12	7			3					

TABLE 9 MOISTURE DEFICIENT DAYS FOR TRAVERSE CITY, MICHIGAN FOR 1, 2, 3, 4, 5, AND 7-INCH SOIL MOISTURE RESERVOIRS

Years	May (31 days)						June (30 days)						July (31 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27							16	7					15	12	11	2		
28	4						16	10					12	12	11	2		
29							5						9	1				
30	4						11	3					23	23	16	9	1	
31							17	8					24	24	23	15	7	
32							17	8					14	14	12	5		
33	3						12	5					20	20	15	7		
34	8						11	3					22	21	15	7		
35	15	3					14	13	7				22	22	22	18	9	
36							18	7					21	20	18	11	3	
37	8						20	16	6				7	7	7	5		
38							21	12	4				21	21	21	17	9	
39							7						16	14	6			
40							7						17	10				
41	5						19	13	4				28	28	28	24	15	
42							6						16	12	3			
43	8												19	11	3			
44	6						5						24	17	8			
45							17	8					19	19	17	7		
46							5						18	8				
47							11	2					24	24	17	8		
48	7						16	12	3				16	16	16	9		
49	4						12	6					7					
50	7						14	10	1				8	8	8			
51	10						14	7					10	8	3			
52	6						20	15	6				1					
53	9						11	9					7					
54	9						2						26	17	9	1		
55	6						12	4					12	5				
56	4						13	4					2					
1 yr. in 10	9						20	13	6				24	24	22	17	9	
5 yrs. in 10	4						13	7					17	14	9	2		

TABLE 9 CONTINUED: TRAVERSE CITY, MICHIGAN

Years	August (31 days)						September (30 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	25	25	25	25	15		10	10	10	10	10	
28	10	4	4	4			10	10	10	10	2	
29	22	22	12	2			10	10	10	10		
30	28	28	28	28	28	8	12	12	12	12	12	12
31	14	13	13	13	13							
32	4						1					
33	17	17	17	17	12		8	8	8	8	8	
34	12	9	9	9	7							
35	5	5	5	5	5							
36	17	17	17	17	17							
37	8						2					
38	3	3	3	3	3							
39												
40	6	4	3									
41	19	19	19	19	19	14						
42	16	16	16	9			5	5	5	5	2	
43	15	11	11	2			13	13	13	13		
44	24	24	24	23	12							
45	6	6	6	6	3							
46	24	24	24	11								
47	17	17	17	17	16		6	6	6	6	6	
48	11						16	13	6	6	5	
49	23	20	15	5								
50	7											
51	18	18	18	10			7	7	7	7	3	
52	7						6					
53	8											
54	27	27	27	27	17		8	8	8	8	8	2
55	21	20	16	6			6	2	2	2		
56	2											
1 yr. in 10	25	25	25	25	17		12	12	10	10	8	
5 yrs. in 10	15	13	12	6			1					

TABLE 10 MOISTURE DEFICIENT DAYS FOR ROSCOMMON, MICHIGAN FOR 1, 2, 3, 4, 5, AND 7-INCH SOIL MOISTURE RESERVOIRS

Years	May (31 days)						June (30 days)						July (31 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27							16	7					15	10	8			
28	3						16	7					17	12	9			
29							18	8					6					
30	6						6						15	9	1			
31							15	7					27	27	25	17	7	
32	1						12	2					6	6				
33	8						12	7					15	14	12	5		
34	10						16	14	3				18	18	18	11	3	
35	16	5					16	15	9	1			25	19	19	19	11	
36	4						29	23	14	5			22	21	21	21	17	1
37							19	7					9	9	7			
38							19	11	2				11	10	10	2		
39													20	12	2			
40							4						13	4				
41	4						20	14	4				14	14	14	10	1	
42							4						15	6				
43	1												5					
44							4						17	9				
45							12	1					11	11	1			
46							7						11	2				
47							10	1					12	11	2			
48	5						5						10	2				
49	8						12	8					7					
50	12						14	14	4				3					
51	2						5						10					
52	6						14	8					6	6	4			
53							7						8					
54	9						1						27	18	10	2		
55	7						19	14	4				16	14	14	10	2	
56							14	5					2					
1 yr. in 10	10						19	14	4				25	19	19	17	7	
5 yrs. in 10	1						12	7					13	9	2			

TABLE 10 CONTINUED: ROSCOMMON, MICHIGAN

Year	August (31 days)						September (30 days)					
1927-56	1"	2"	3"	4"	5"	7"	1"	2"	3"	4"	5"	7"
27	25	24	24	23	13		2	2	2	2	2	
28	13	1					2	2				
29	19	19	15	4			12	12	12	12	3	
30	31	31	31	21	10		20	20	20	20	20	3
31	20	20	20	20	20	9	3	3	3	3	3	3
32	16	3					7	2				
33	27	19	19	19	13		8	8	8	8	8	
34	14	14	14	14	14							
35	3	3	3	3	3							
36	19	10	10	10	10	10						
37	1											
38	3	3	3	3								
39												
40												
41	8	4	4	4	4							
42	13	5					1					
43	13	6					9	9	1			
44	6	1	1									
45												
46	12	5					5	5				
47	19	10	8				3					
48	17	5					26	26	16	2		
49	13	7										
50	9											
51	12	9					1	1				
52	8						11					
53	3						10	8				
54	23	23	23	23	15		7	7	7	7	7	
55	25	24	24	24	24	3	22	22	22	22	22	22
56	3											
1 yr. in 10	25	24	24	23	15	3	20	20	16	12	8	3
5 yrs. in 10	13	5					2					

DISCUSSION OF RESULTS

A series of maps were made to illustrate the number of moisture deficient days listed on the bottom of tables 3 through 10. The number of moisture deficient days occuring once in ten years were shown on map A and five times in ten years on map B, of each figure. One figure was used for each 1, 2, 3, 4, 5, and 7-inch moisture reservoir, or six figures per month for the months May through September. This gave a total of 30 figures with sixty maps, illustrated in figures 3 through 32.

Discussion of Moisture Deficient Days Occuring Once in Ten Years For Each Moisture Reservoir

1-inch Reservoir (Maps A, figures 3, 9, 15, 21, 27)

The number of moisture deficient days for May ranged from 7 in the south west to 13 in the eastern part of the state. In June there were lows of 17 in the south west and 19 in the north central, and a high of 21 in the eastern part of the state. July ranged from 24 in the north to 26 in the Lansing, Ann Arbor area. August had a low of 23 across the central part going to a high of 25 in the north and 29 in the south central part of the state. In September the pattern of moisture deficient days showed some decrease of intensity with lows of 12 in the north, 13 in the south and 14 across the center along with highs of 18 near Ann Arbor and 20 near Roscommon.

<u>2-inch Reservoir</u> (Maps A, figures 4, 10, 16, 22, 28)

The number of moisture deficient days for May was zero north west of the Coldwater, Lansing, Saginaw area and 2 in the Ann Arbor area. In June the minimum was 8 at the south edge and the maximum was 19 in the north eastern part of the state. July went from 20 moisture deficient days in the north central and south central to 26 in the eastern part of the state. August had a low of 23 across the central part and highs of 25 in the north and 29 in the south central part of the state. September had lows of 12 in the north, 13 in the south west and 14 in the "thumb" along with highs of 16 near Ann Arbor and 20 near Roscommon.

<u>3-inch Reservoir</u> (Maps A, figures 5, 11, 17, 23, 29)

There were zero moisture deficient days for May. In June the minimum was still zero in the south west and the maximum was 11 in the north east part of the state. July had lows of 16 near Lansing and 19 near Roscommon along with a high of 22 across the central and into the northern, western and eastern part of the state. August had a low of 22 in the west central with a high of 25 in the north and 29 in the Lansing area. September had lows of 10 in the north and 13 in the Saginaw, Lansing, Coldwater area increasing to highs of 6 near Roscommon and Detroit.

<u>4-inch</u> <u>Reservoir</u> (Maps A, figures 6, 12, 18, 24, 30)

There are zero moisture deficient days for May. In June the minimum was still zero except for 1 moisture deficient day near Saginaw. July had a low of 8 near Lansing increasing to a high of 17 in the north and northeastern part of the state. August had a low of 20 on the west central edge with a high of 25 in the northern and 30 in the south central part of the state. September had 10 moisture deficient days in the north, 13 near Coldwater, and Lansing with a high of 16 in the Detroit area.

<u>5-inch</u> <u>Reservoir</u> (Maps A, figures 7, 13, 19, 25, 31)

There were zero moisture deficient days in May and June. July had 2 moisture deficient days in the south central part and 13 in the north east part of the state. August had a low of 14 near Coldwater and 15 near Roscommon, increasing to a high of 26 in the Lansing, Ann Arbor area. September had lows of 8 in the north and 9 near Lansing, along with a high of 14 in the "thumb" area.

<u>7-inch</u> <u>Reservoir</u> (Maps A, figure 8, 14, 20, 26, 32)

There were zero moisture deficient days in May, June and July. In August there were lows of zero near Coldwater and the west central area with a high of 22 in the Ann Arbor area. September had lows of zero in the west and 2 in the south east along with a high of 7 in the Lansing area.

Discussion of Moisture Deficient Days Occurring Five Times in Ten Years For Each Moisture Reservoir

1-inch Reservoir (Maps B, figures 3, 8, 15, 21, 27)

The number of moisture deficient days for May ranged from zero in the south central to 4 in the northwest part of the state. The intensity of drought was greater in June with 7 days in the Coldwater area and 13 in the northern part of the state. In July there were lows of 12 at Coldwater and 13 at Roscommon with a high of 19 in the "thumb" area. August had lows of 12 in the southwest and 13 in the Roscommon area, and a high of 15 in the Traverse City, Grand Rapids area. September had a low of 1 in the northern part and a high of 8 moisture deficient days in the south western part of the state.

2-inch Reservoir (Maps B, figures 4, 10, 16, 22, 28)

There were zero moisture deficient days for May. In June the low was zero in the southern part with a high of 7 in the northern part of the state. July had a low of 7 near Coldwater and 9 near Roscommon increasing to a high of 15 in the "thumb" area. August had lows of 12 across the central part and 13 in the northern part of the state. September had zero moisture deficient days in Roscommon, Saginaw, Coldwater area increasing to highs of 3 near Ann Arbor and 4 near Big Rapids.

<u>3-inch</u> <u>Reservoir</u> (Maps B, figures 5, 11, 17, 23, 29)

There were zero moisture deficient days in May and June. July had a low of zero in the south and another low of 2 near Roscommon, along with a high of 8 in the north and northeast. August had a low of zero near Roscommon and 3 near Coldwater increasing to a high of 12 in the northern and north eastern part of the state. September had zero moisture deficient days west of the Saginaw, Coldwater area and 3 days in the Detroit area.

<u>4-inch</u> <u>Reservoir</u> (Maps B, figures 6, 12, 18, 24, 30)

There were zero moisture deficient days in May and June. July had zero moisture deficient days over most of the state except for 2 in the northern part. August had a low of zero in the southern and north central part with a high of 5 in the northern and north eastern part of the state. September had zero moisture deficient days.

<u>5-inch</u> <u>Reservoir</u> (Maps B, figures 7, 13, 19, 25, 31)

There were zero moisture deficient days in the months of May, June, July, August and September.

<u>7-inch</u> <u>Reservoir</u> (Maps B, figures 8, 14, 20, 26, 32)

There were zero moisture deficient days for the months May, June, July, August and September.

APPLICATION OF RESULTS

When irrigation is frequent, the amount of additional water needed each month for a 1, 2, 3, 4, 5, or 7-inch moisture reservoir can be computed for any location in Lower Michigan by multiplying the number of moisture deficient days given in figures 3 through 32, by the amount of evapotranspiration per day given in table 2 for Lower Michigan.

Farmers can compute daily, the average moisture reserve of their soil reservoir by adding rainfall and subtracting evapotranspiration. Values of rainfall can be obtained from the daily weather report or preferably a rain gage on the farm. The calculated evapotranspiration rates are given in figure 2. Knowing the amount of moisture in reserve would be especially helpful in scheduling the time of irrigation for various crops and soils.

Farmers contemplating buying irrigation equipment can refer to the discussion of moisture deficient days for the particular soil moisture reservoir in which they are interested. Then for an illustrated distribution of moisture deficient days per month, the figures 3 through 32 can be consulted. Each figure has the number of moisture deficient days that can be expected once in ten years and five times in ten years. The figures can then be used as an indication of the probable number of days in which supplemental irrigation water would be needed on a particular farm throughout Lower Michigan.

CONCLUSIONS

Using the Penman method of calculating potential evapotranspiration on vegetation and modifying it by .75 to obtain actual evapotranspiration, the following observations are found in the Lower Peninsula of Michigan.

1. More moisture deficient days occur in the eastern part of the lower peninsula than in the western part.

2. More moisture deficient days generally occur in the northern part of the lower peninsula than in the southern part.

3. The smaller soil moisture reservoir has a greater number of moisture deficient days.

4. In the month of May, water is needed 5 years out of 10 for a 1-inch soil moisture reservoir.

5. In the month of June water is needed 5 years out of 10 for a 1 and 2-inch soil moisture reservoir.

6. The months of July and August have the greatest number of moisture deficient days.

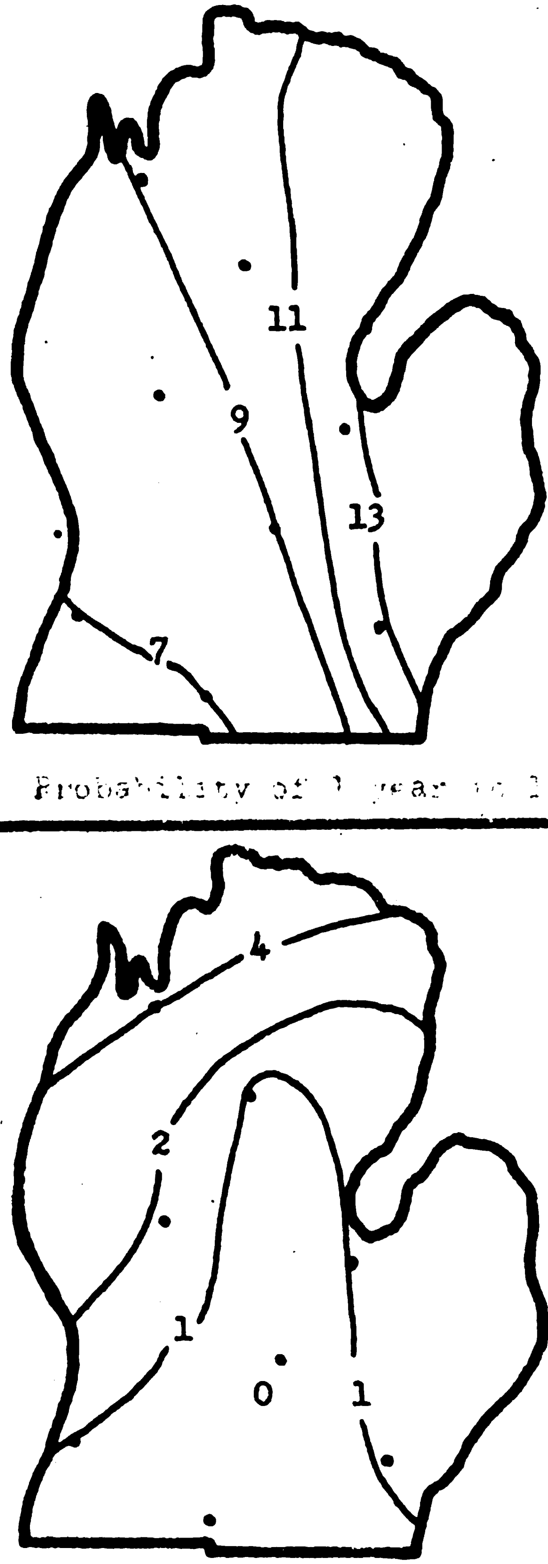
7. The 5 and 7-inch moisture reservoirs do not need additional water 5 years out of 10.

SUGGESTIONS FOR FUTURE STUDIES

1. A study could be made with weighing Lysimeters to determine the correction factor which should be applied to potential evapotranspiration to determine actual evapotranspiration in Michigan. Possibly .75 will change slightly in Michigan.

2. A study on the frequency of use, of irrigation equipment, in various part of the state through-out the growing season on given soil moisture reservoirs.

3. A current soil moisture study could be made by subtracting present evapotranspiration values and adding in the rainfall for various soil moisture reservoirs. Eventually this might be included in a daily farm weather report that would be helpful in scheduling irrigation.



a. Probability of 1 year in 10

b. Probability of 5 years in 10

Figure 3. Moisture deficient days in May for a 1 - inch reservoir.

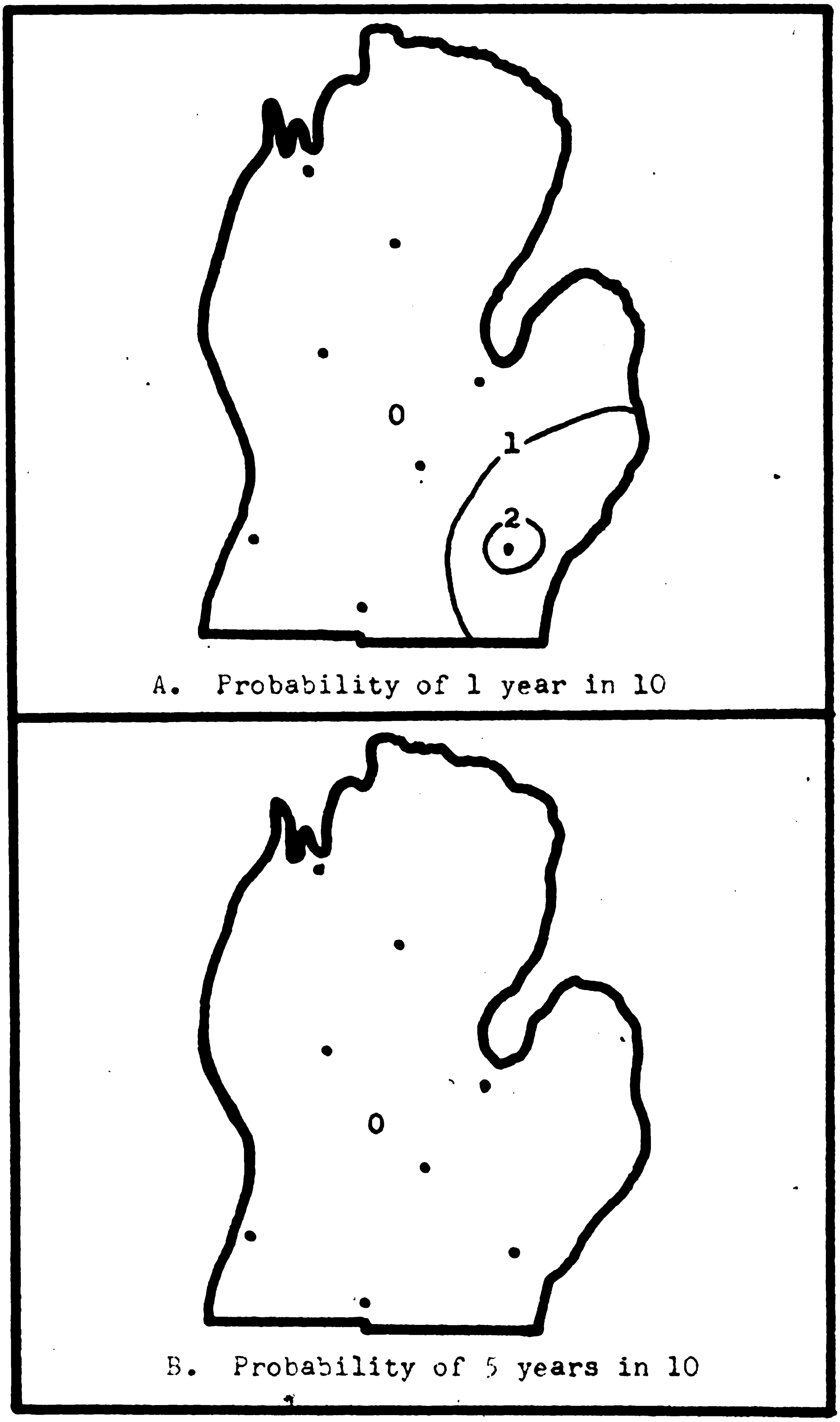
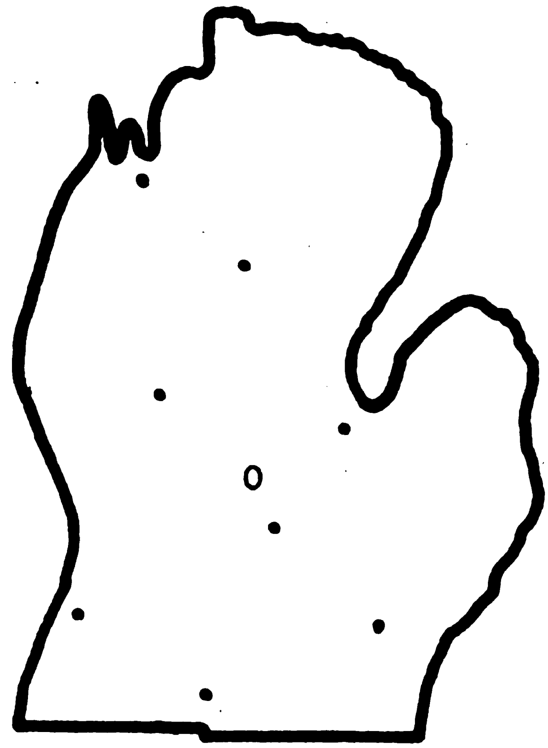
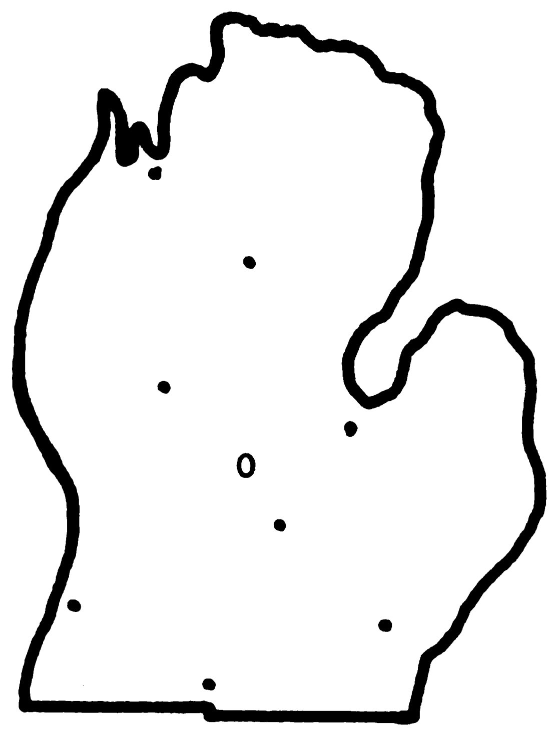


Figure 4. Moisture deficient days in May for a 2 - inch reservoir.

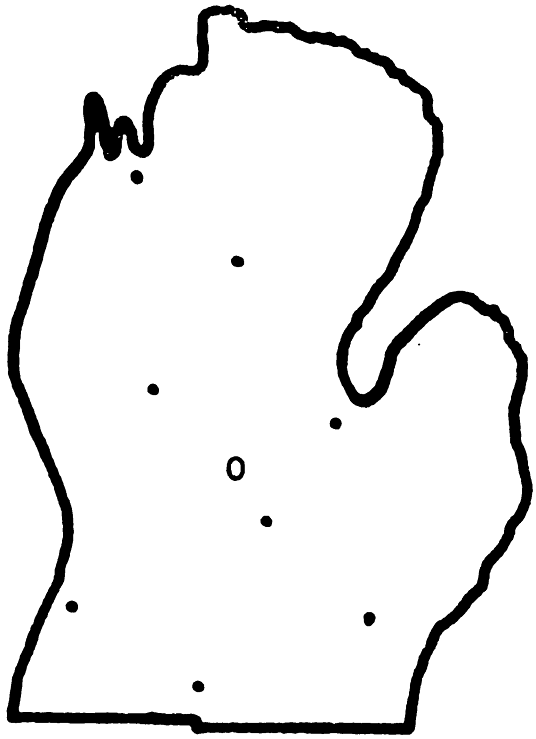


A. Probability of 1 year in 10

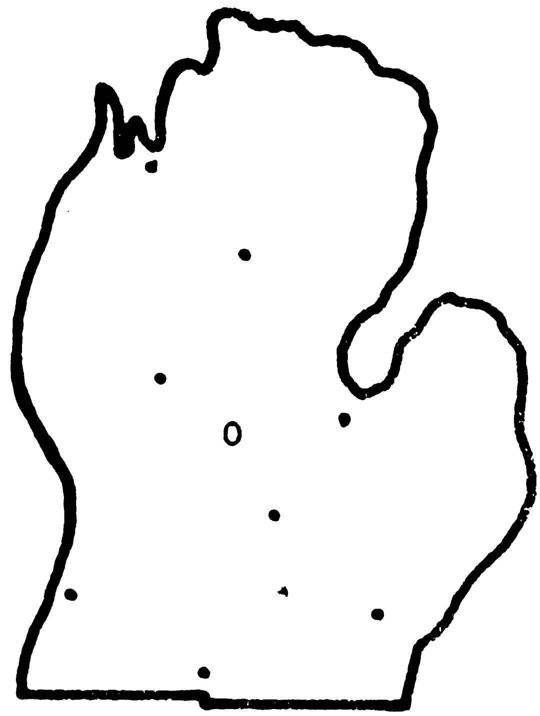


B. Probability of 5 years in 10

Figure 5. Moisture deficient days in **May** for a 3 - inch reservoir.

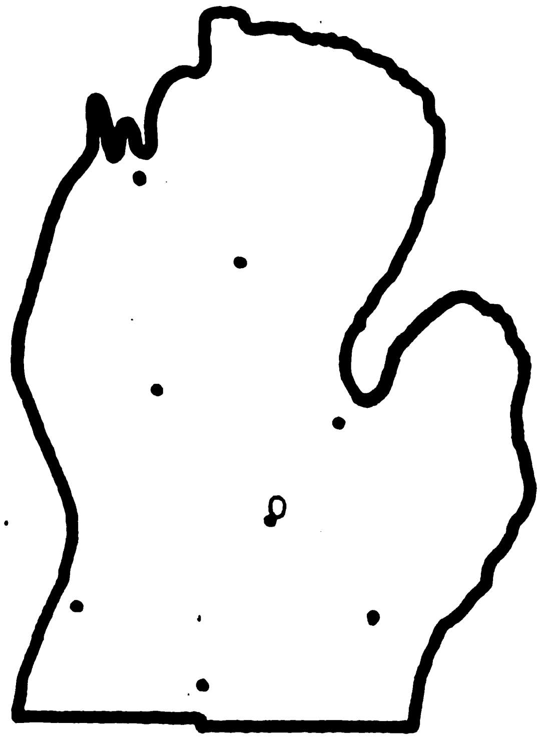


A. Probability of 1 year in [illegible]

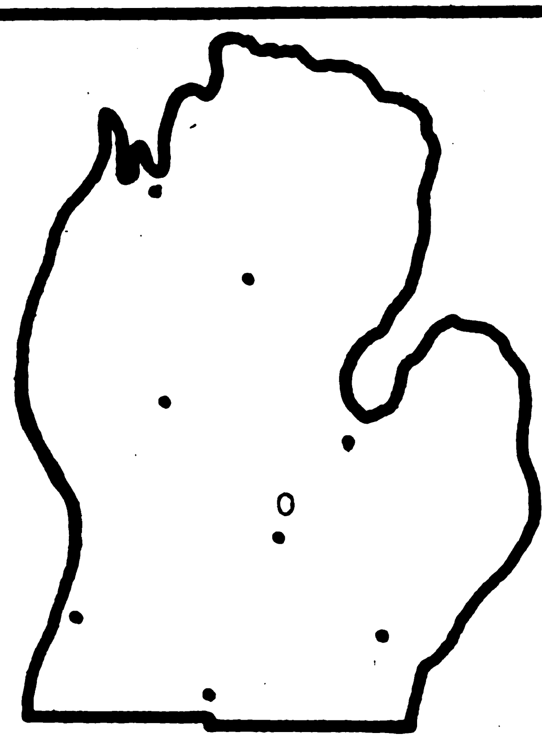


B. Probability of [illegible] years [illegible]

Figure **6.** [illegible]oisture deficient [illegible] in **May** [illegible]
a **4** - inch reser[illegible]

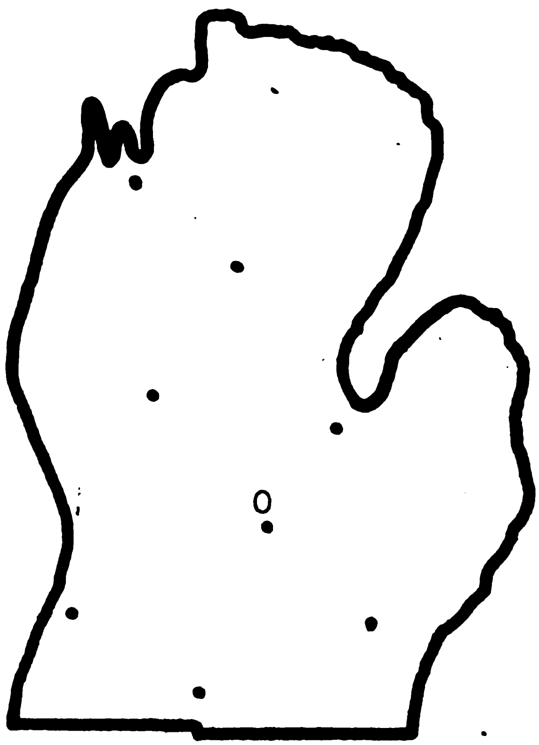


A. Probability of 1 year in 10

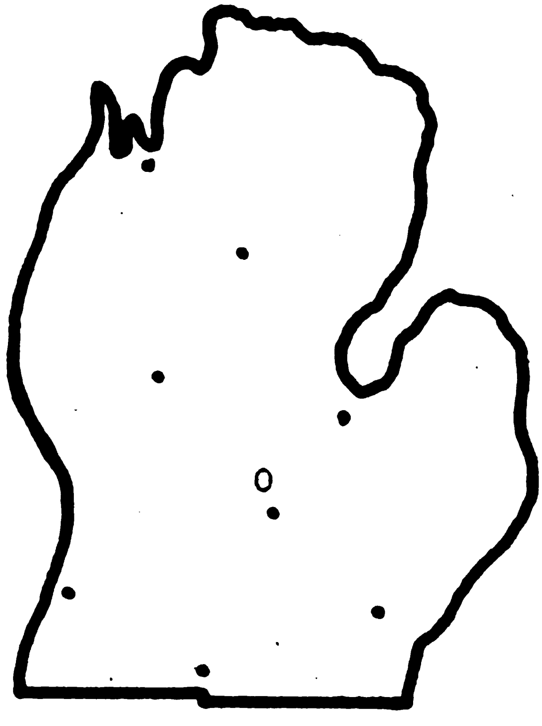


B. Probability of 5 years in 10

Figure 7. Moisture deficient days in May for a 5- inch reservoir.

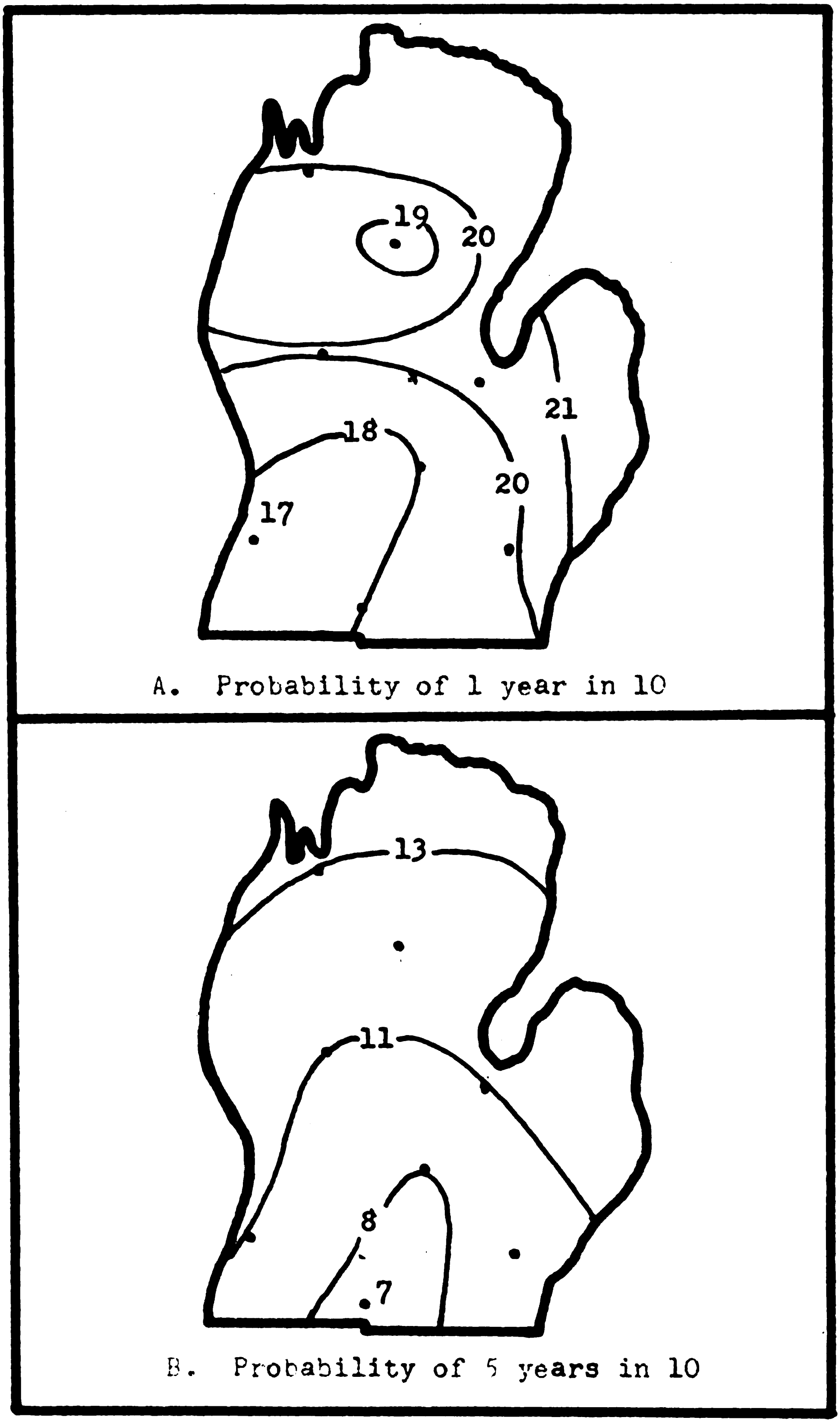


A. Probability of 1 year in 10



B. Probability of 5 years in 10

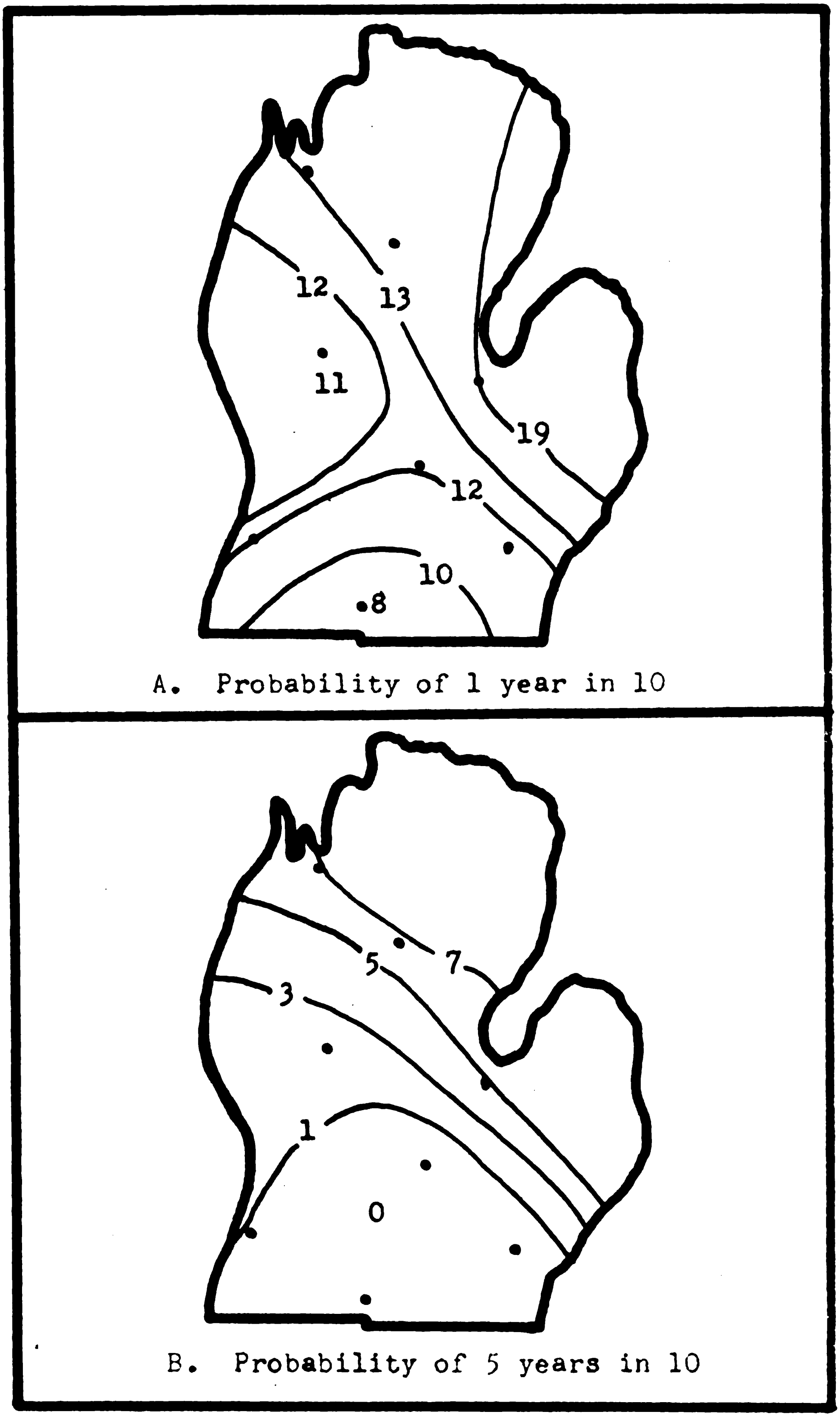
Figure 8. Moisture deficient days in May for a 7 - inch reservoir.



A. Probability of 1 year in 10

B. Probability of 5 years in 10

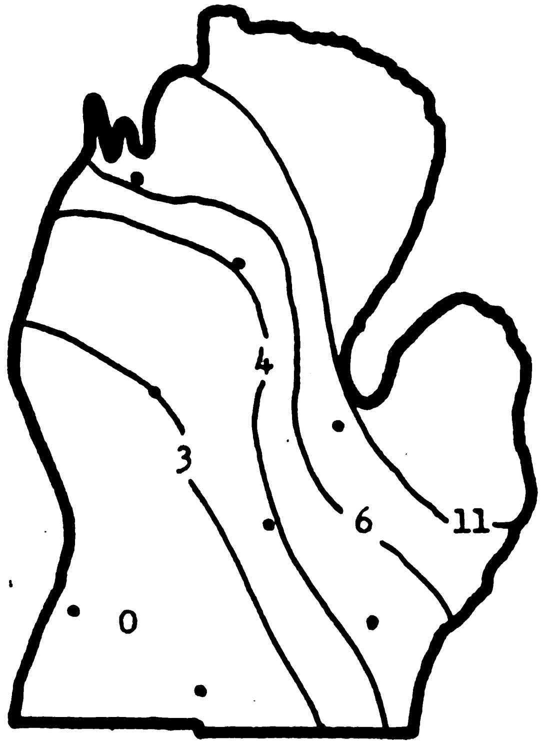
Figure 9. Moisture deficient days in June for a 1 - inch reservoir.



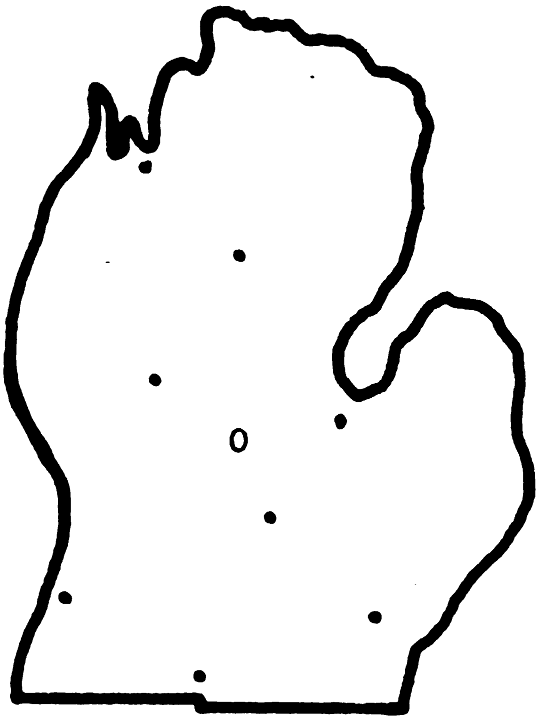
A. Probability of 1 year in 10

B. Probability of 5 years in 10

Figure 10. Moisture deficient days in June for a 2 - inch reservoir.



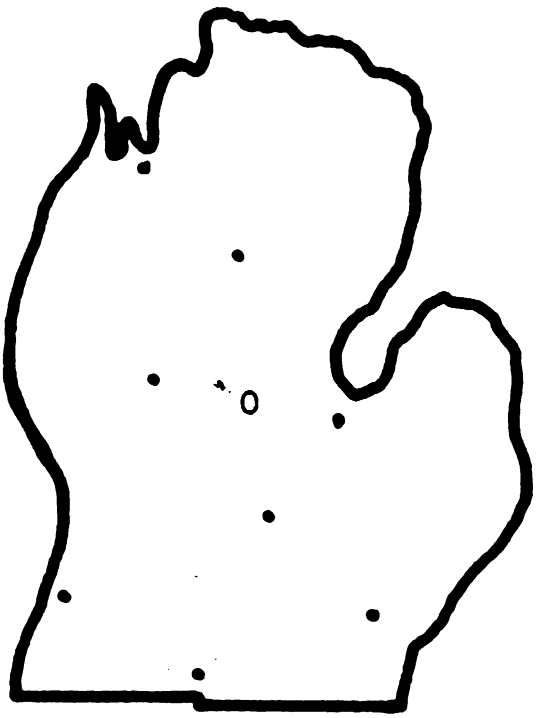
A. Probability of 1 year in 10



B. Probability of 5 years in 10

Figure 11 Moisture deficient days in June for a 3 - inch reservoir.

A. Probability of 1 year in 10



B. Probability of 5 years in 10

Figure **12** Moisture deficient days in **June** for a 4 - inch reservoir.

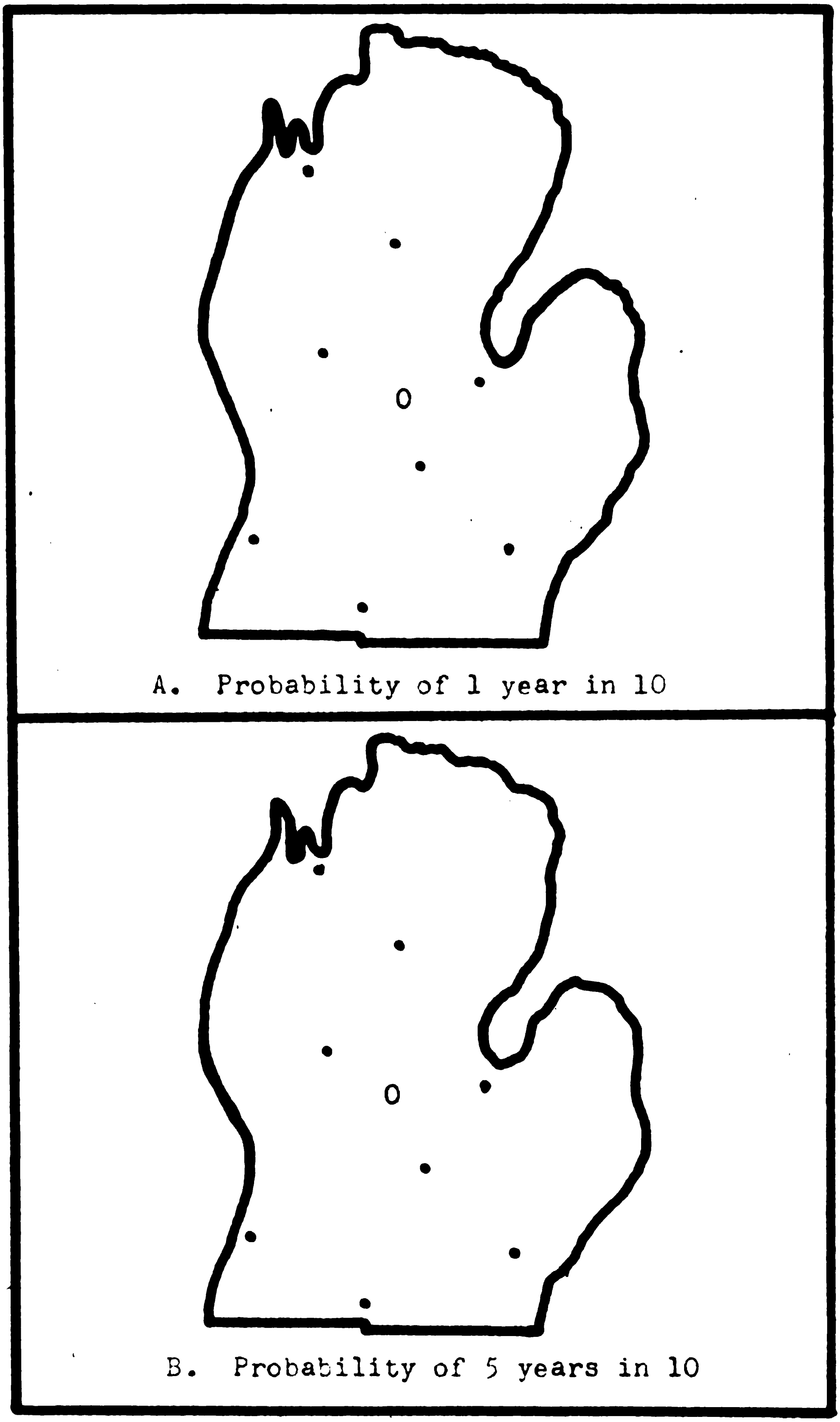
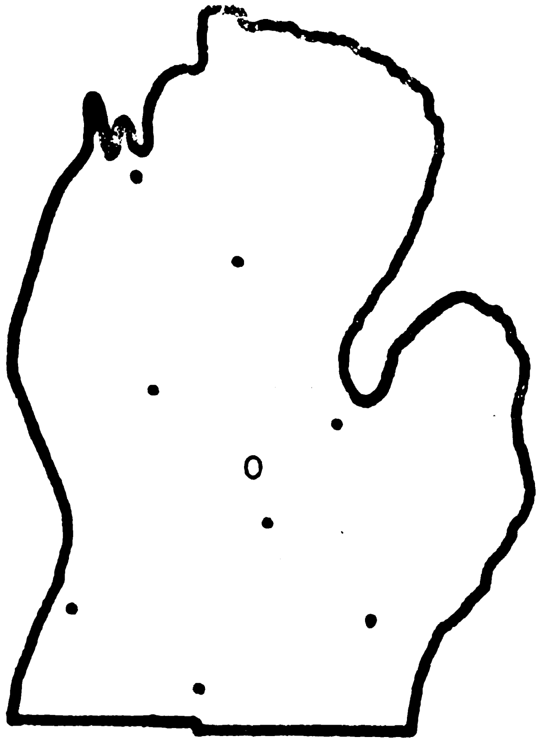
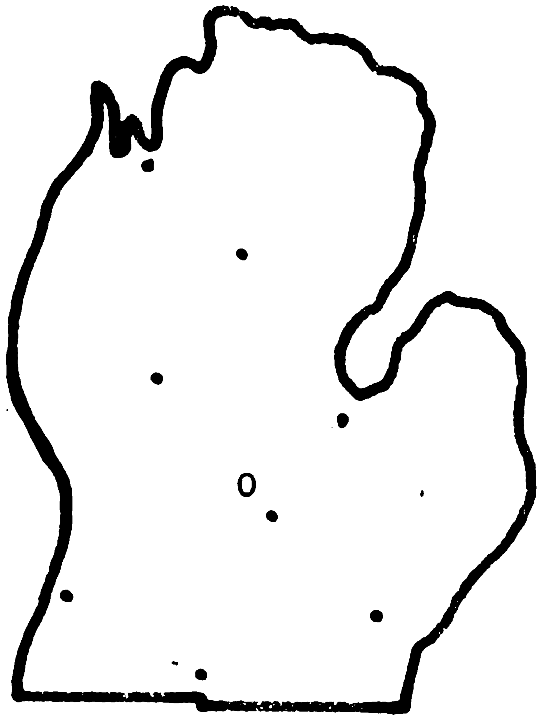


Figure 13 Moisture deficient days in June for a 5 - inch reservoir.

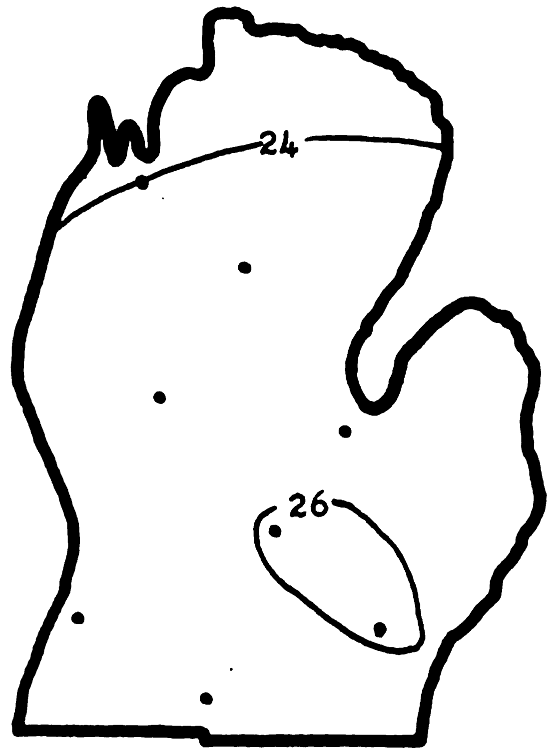


A. Probability of 1 year in 10

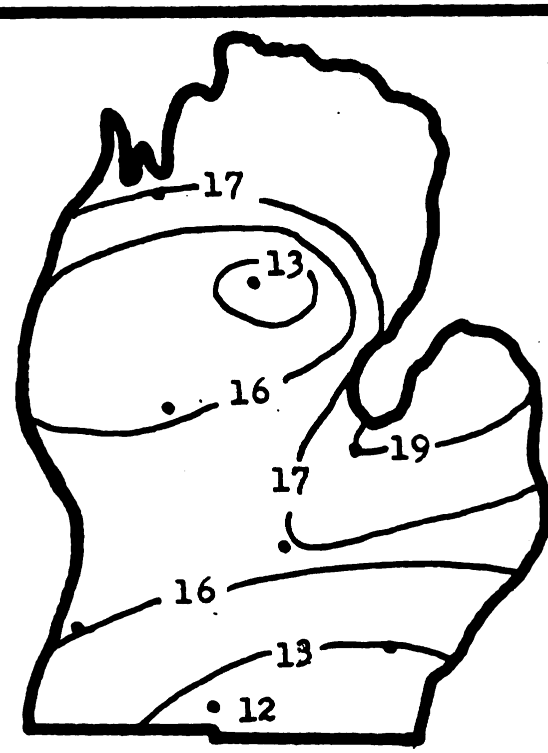


B. Probability of 5 years in 10

Figure 14 Moisture deficient days in June for a 7-inch reserve.

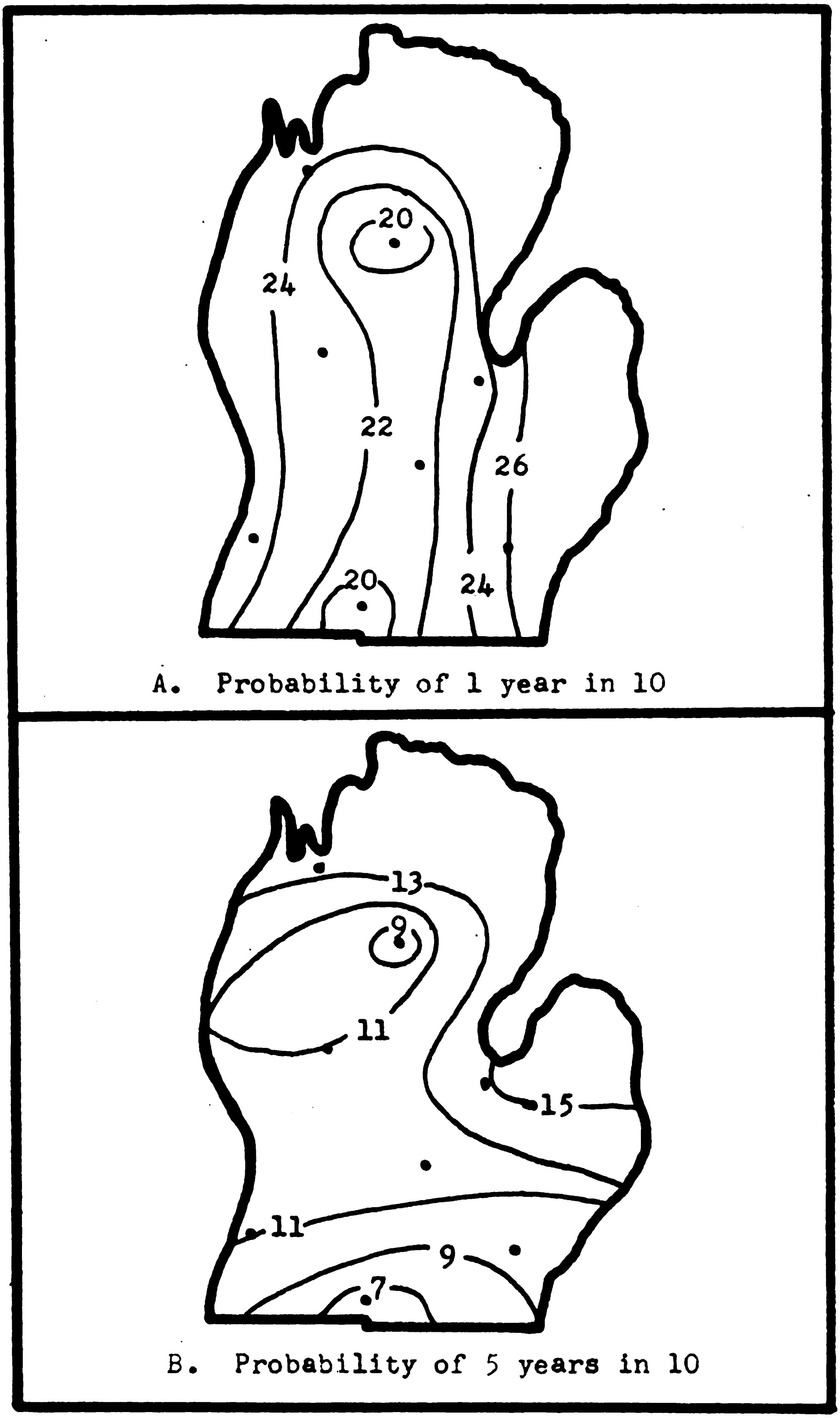


A. Probability of 1 year in 10



B. Probability of 5 years in 10

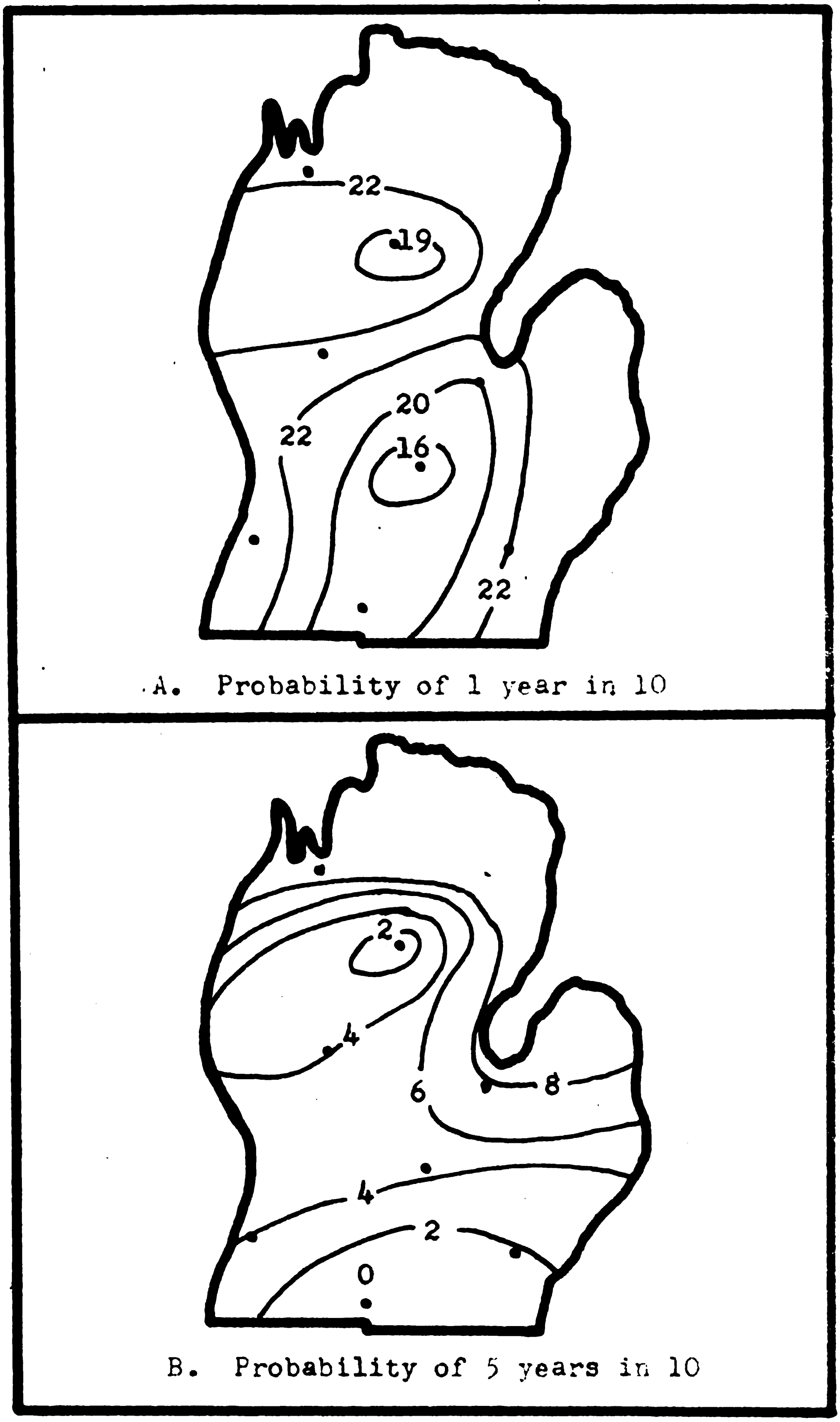
Figure 15 Moisture deficient days in July for a 1 - inch reservoir.



A. Probability of 1 year in 10

B. Probability of 5 years in 10

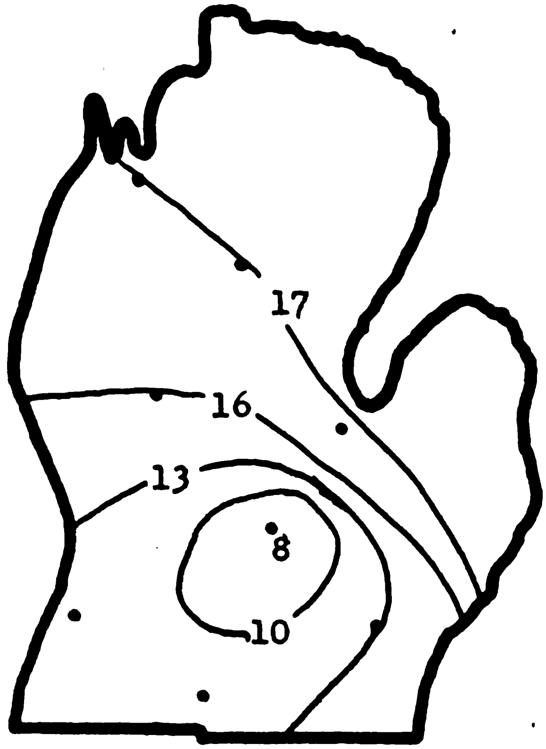
Figure 16 Moisture deficient days in July for a 2 - inch reservoir.



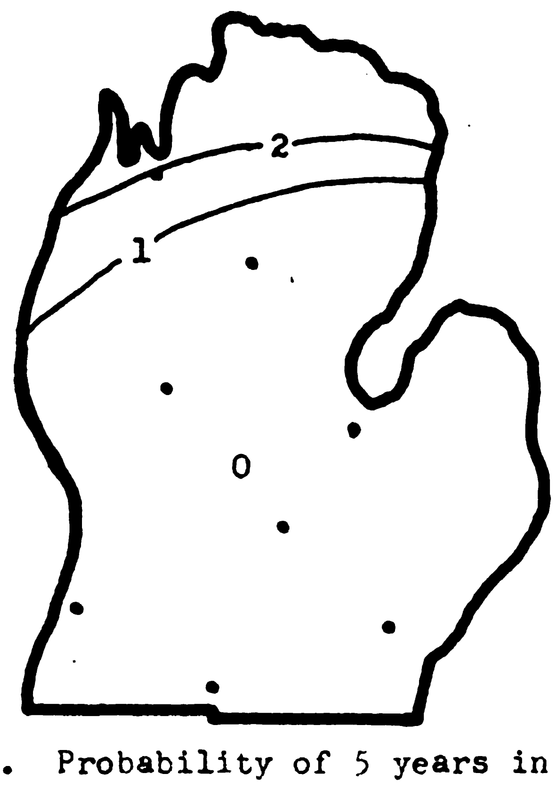
A. Probability of 1 year in 10

B. Probability of 5 years in 10

Figure 17 Moisture deficient days in **July** for a 3 - inch reservoir.

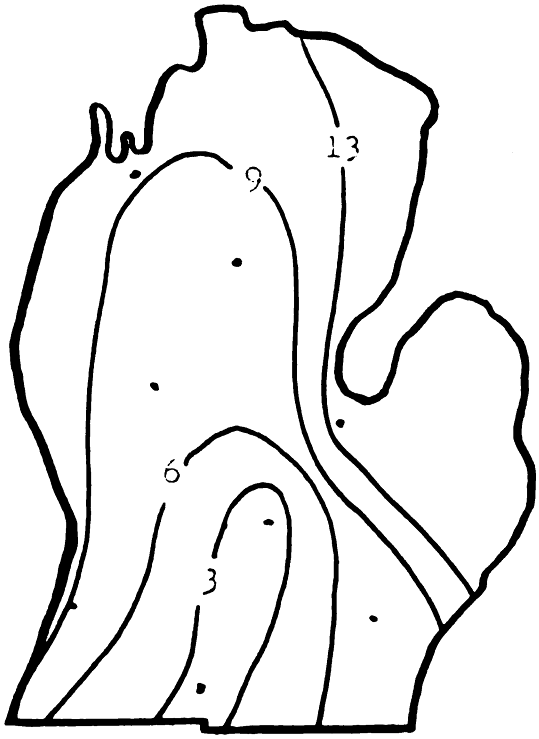


A. Probability of 1 year in 10

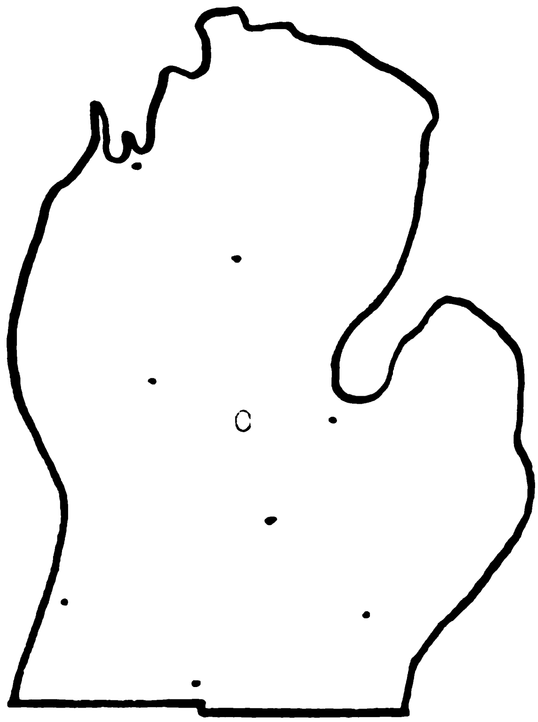


B. Probability of 5 years in 10

Figure 18 Moisture deficient days in July for a 4- inch reservoir.

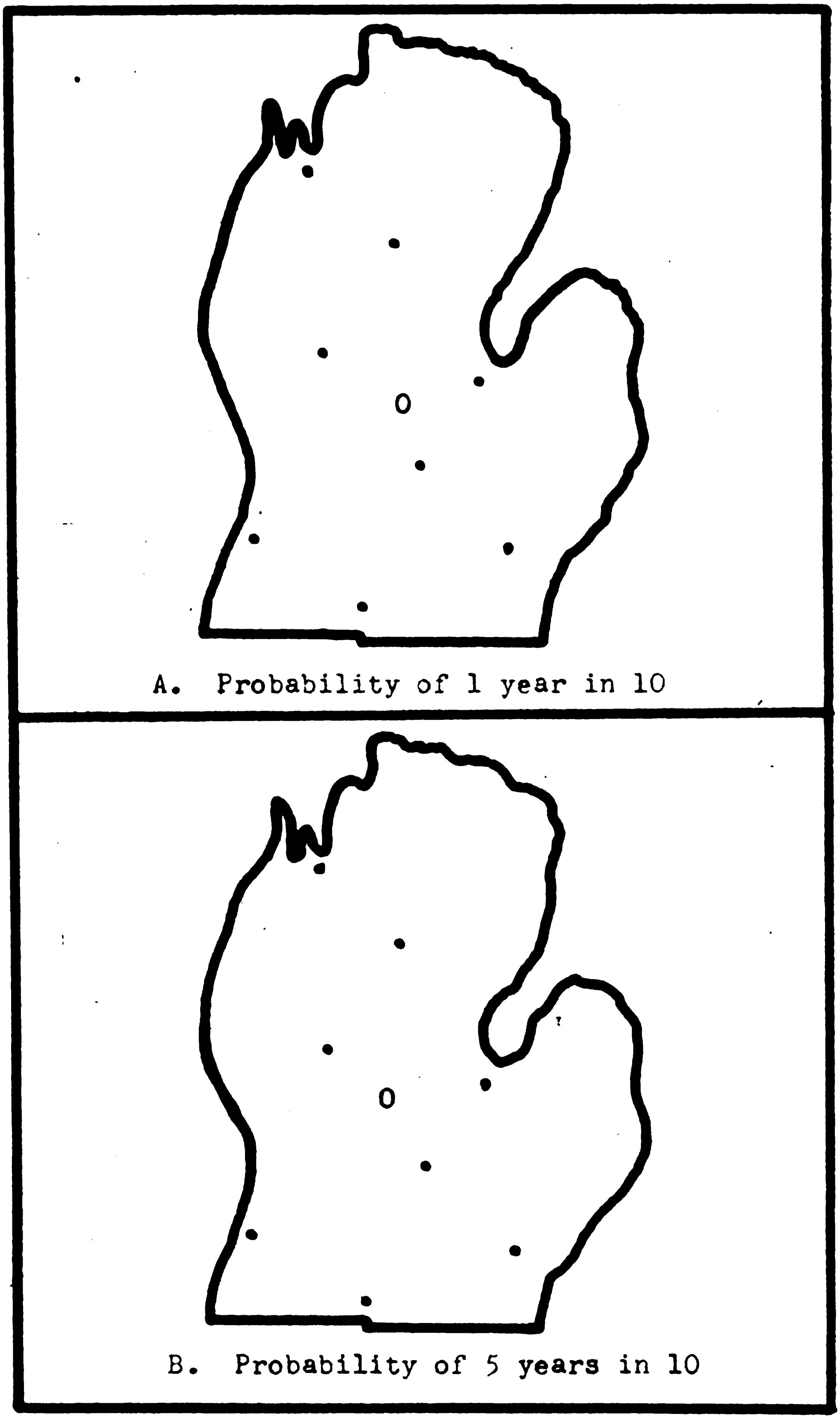


A. Probability of 1 year in 10.



B. Probability of 5 years in 10.

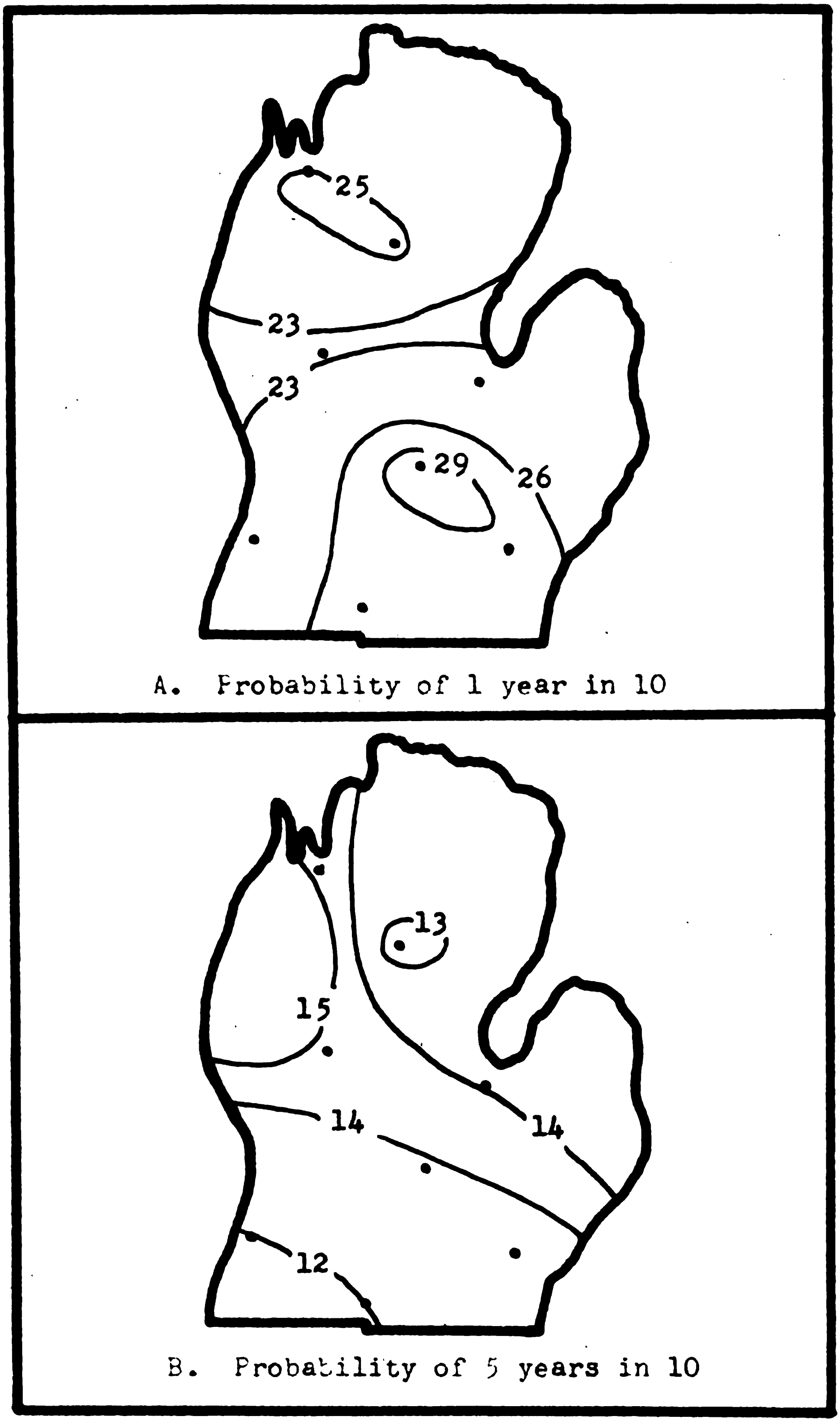
Fig. 19 Moisture deficient days in July for a 5 - inch reservoir.



A. Probability of 1 year in 10

B. Probability of 5 years in 10

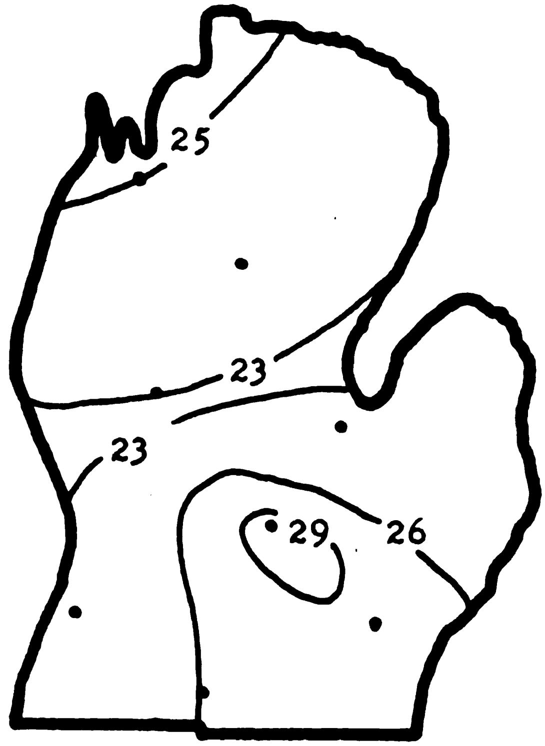
Figure 20 Moisture deficient days in July for a 7 - inch reservoir.



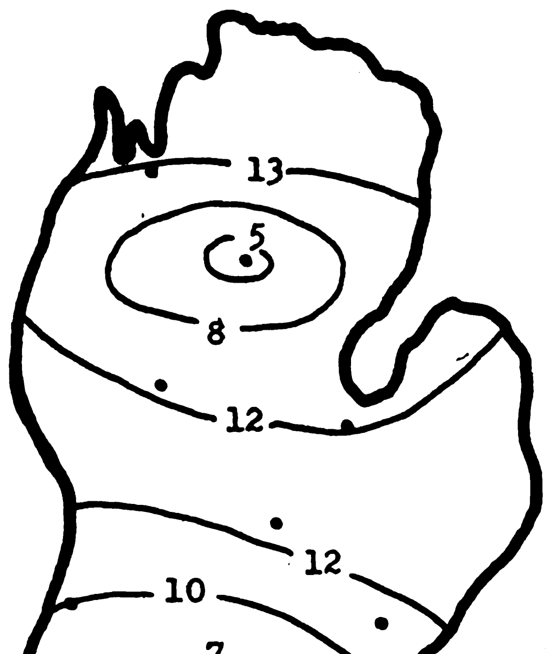
A. Probability of 1 year in 10

B. Probability of 5 years in 10

Figure 21 Moisture deficient days in Aug. for a 1- inch reservoir.

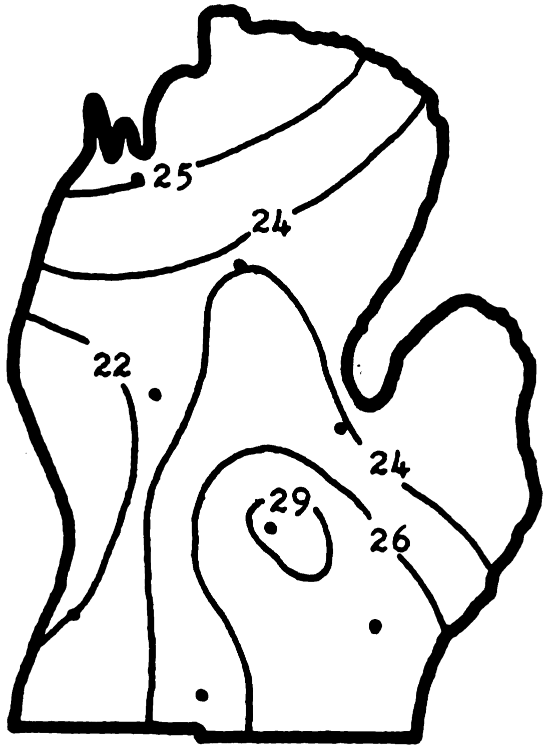


A. Probability of 1 year in 10



B. Probability of 5 years in 10

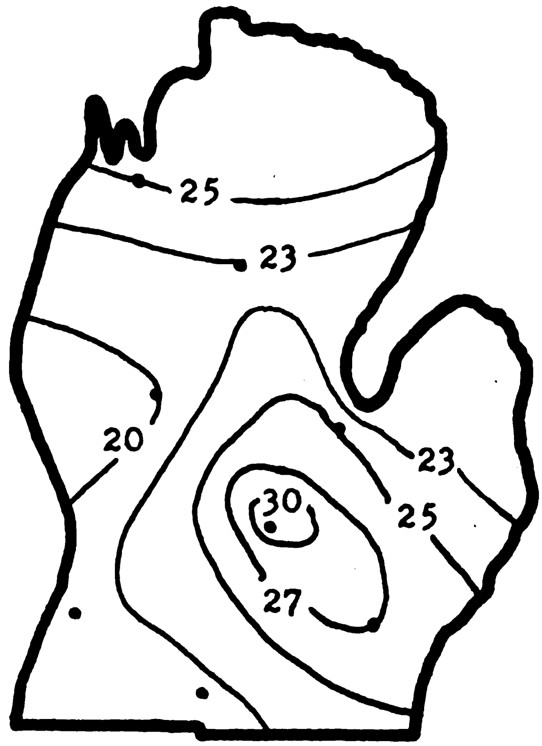
Figure 22 Moisture deficient days in Aug. for a 2- inch reservoir.



A. Probability of 1 year in 10

B. Probability of 5 years in 10

Figure 23 Moisture deficient days in Aug. for a 3 - inch reservoir.



A. Probability of 1 year in 10

B. Probability of 5 years in 10

Figure 24 Moisture deficient days in Aug. for a 4 - inch reservoir.

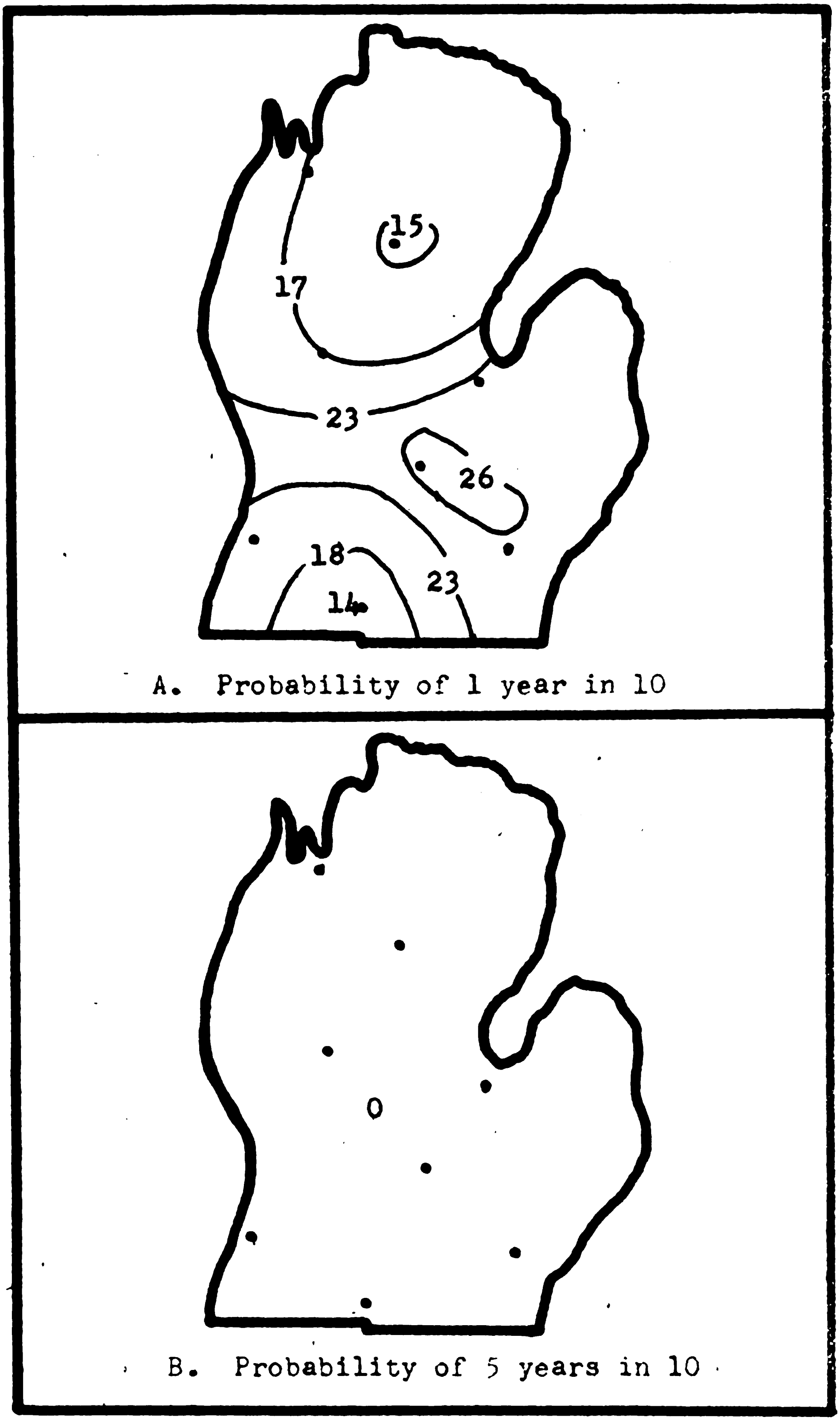
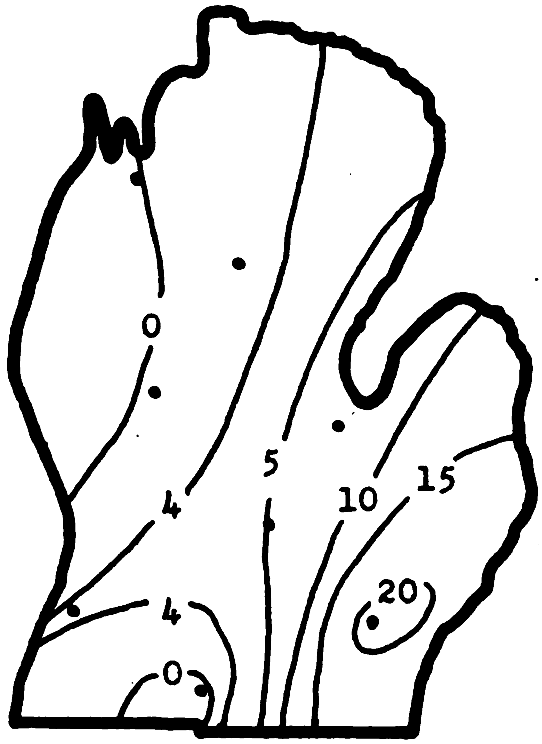
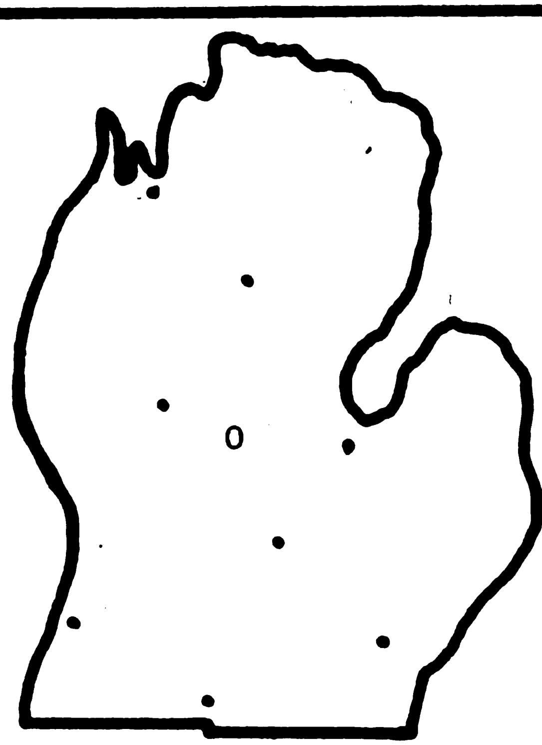


Figure 25 Moisture deficient days in **Aug.** for a 5 - inch reservoir.

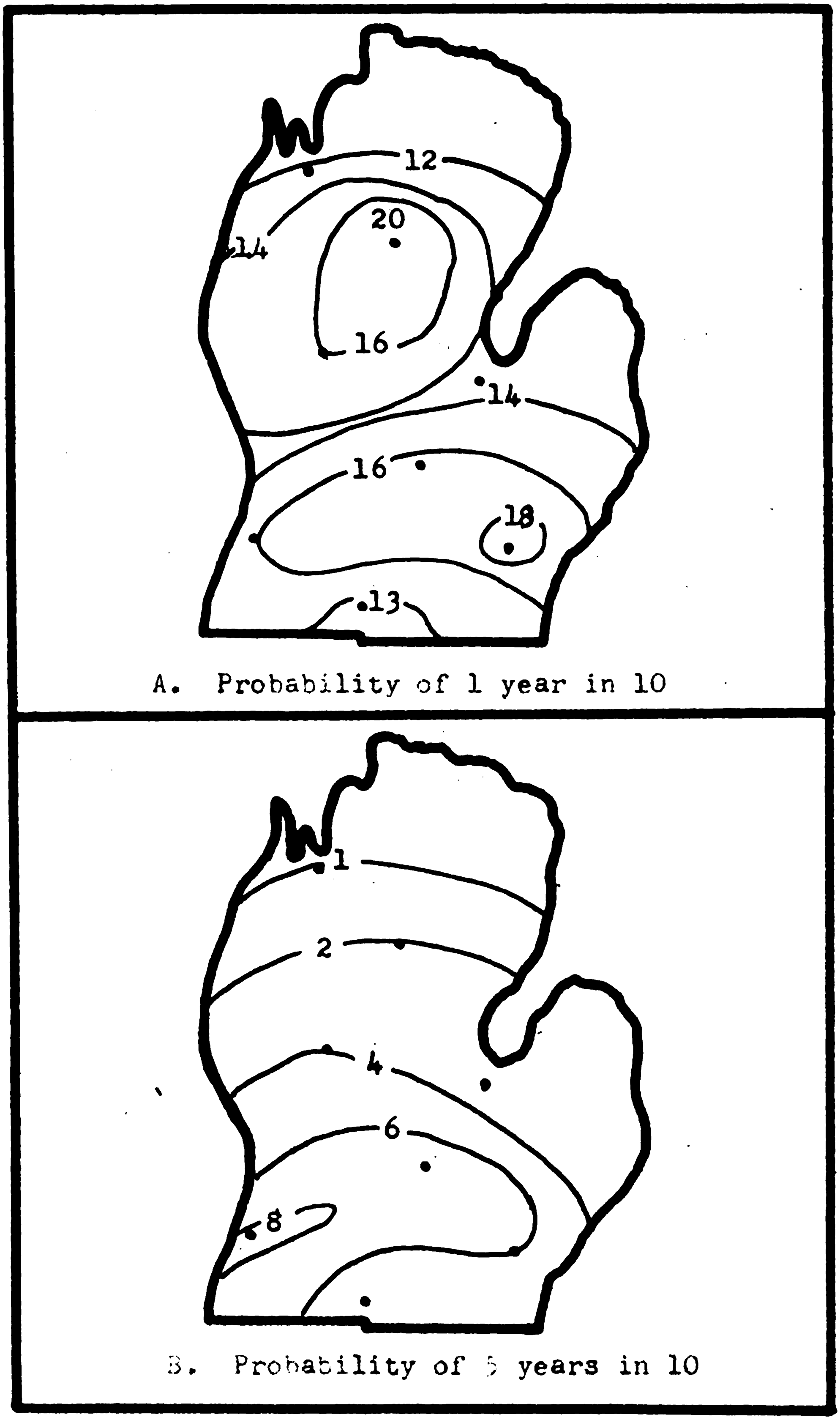


A. Probability of 1 year in 10



B. Probability of 5 years in 10

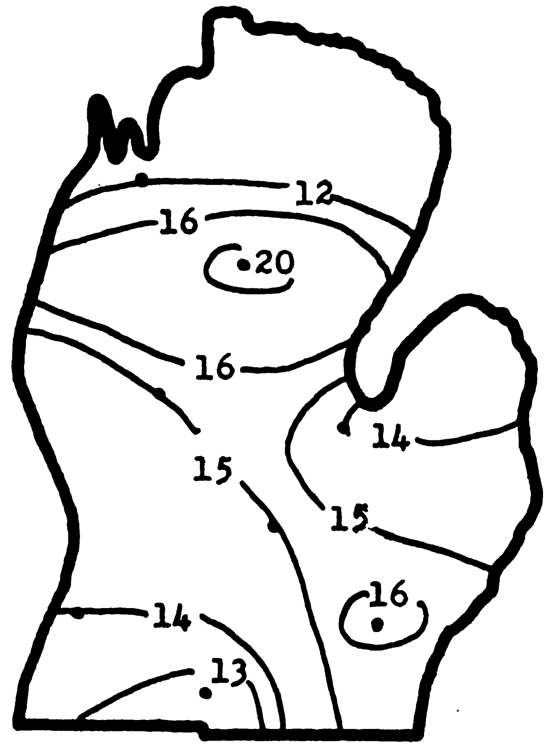
Figure 26 Moisture deficient days in Aug. for a 7 - inch reservoir.



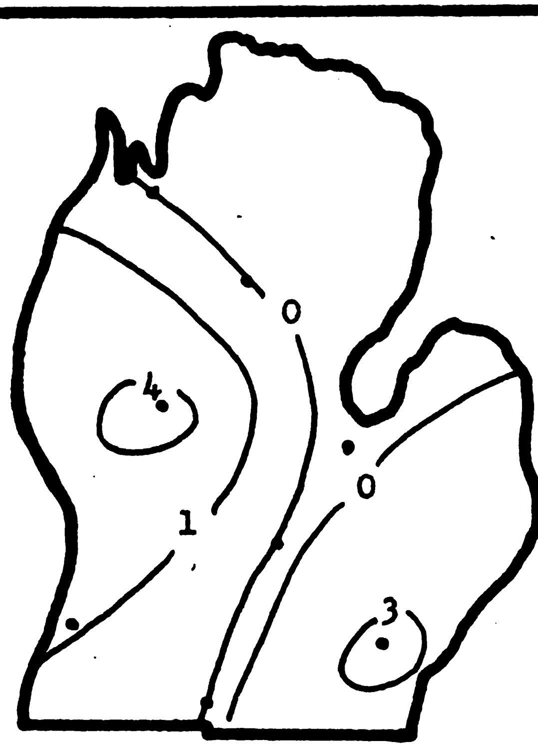
A. Probability of 1 year in 10

B. Probability of 5 years in 10

Figure 27 Moisture deficient days in Sept. for a 1 - inch reservoir.

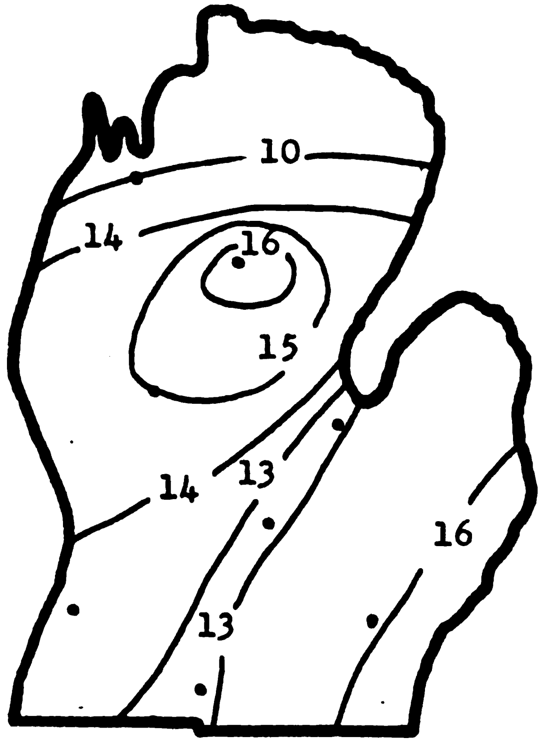


A. Probability of 1 year in 10

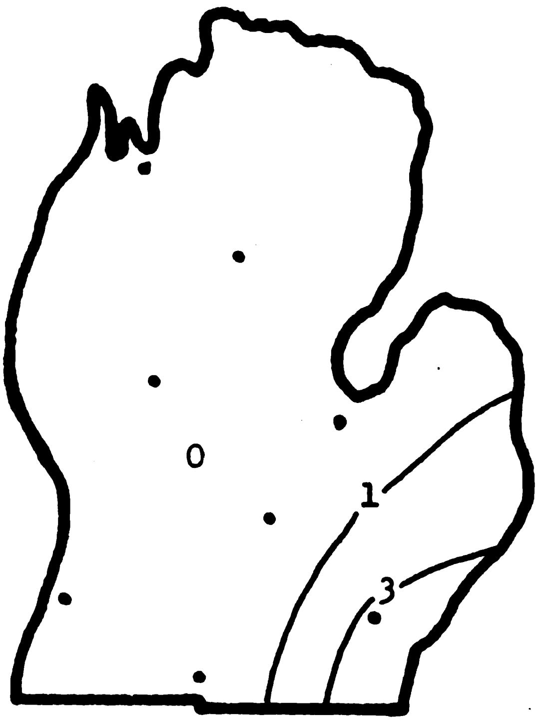


B. Probability of 5 years in 10

Figure 28 Moisture deficient days in Sept. for a 2 - inch reservoir.



A. Probability of 1 year in 10.



B. Probability of 5 years in 10

Figure 29 Moisture deficient days in Sept. for a 3- inch reservoir.

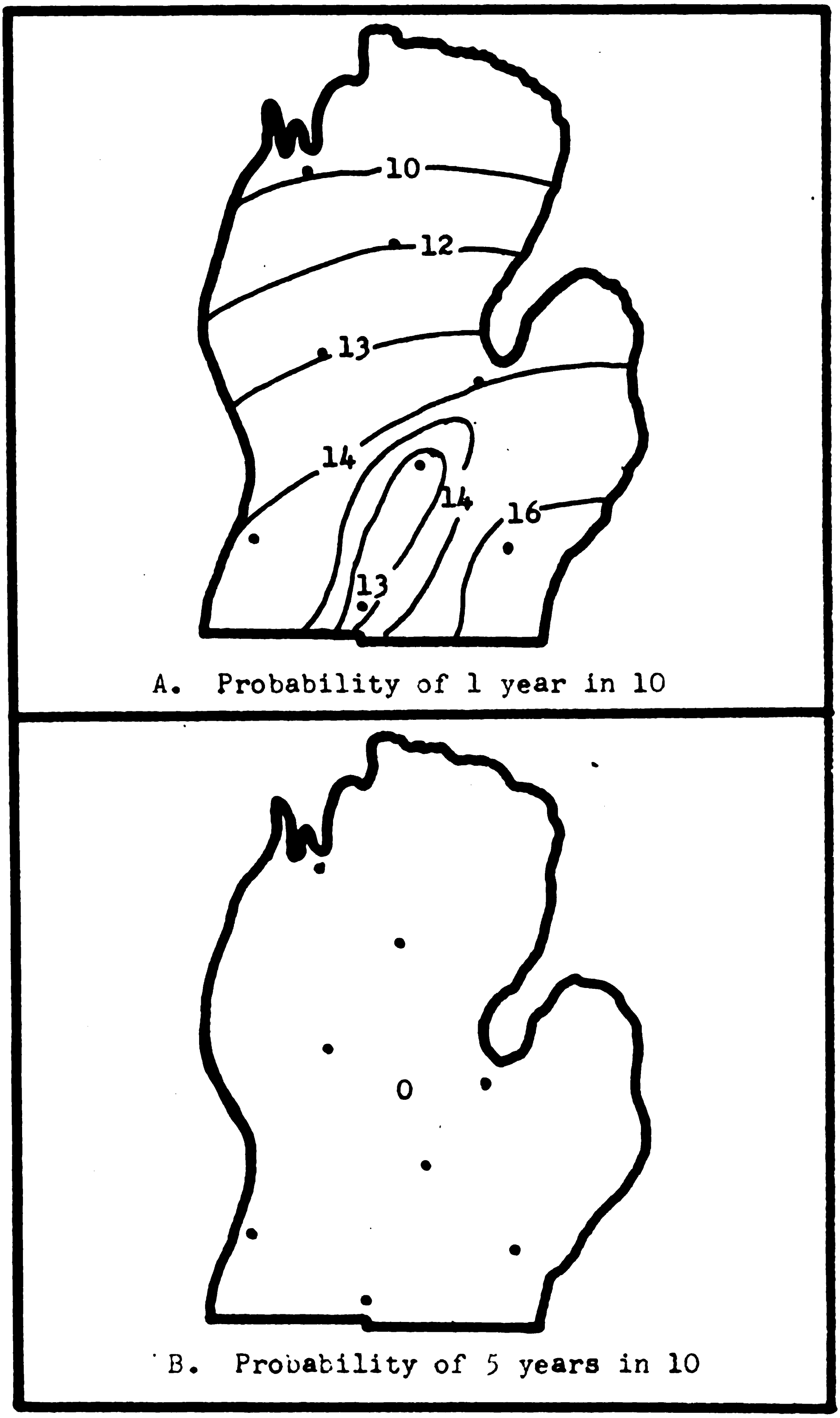
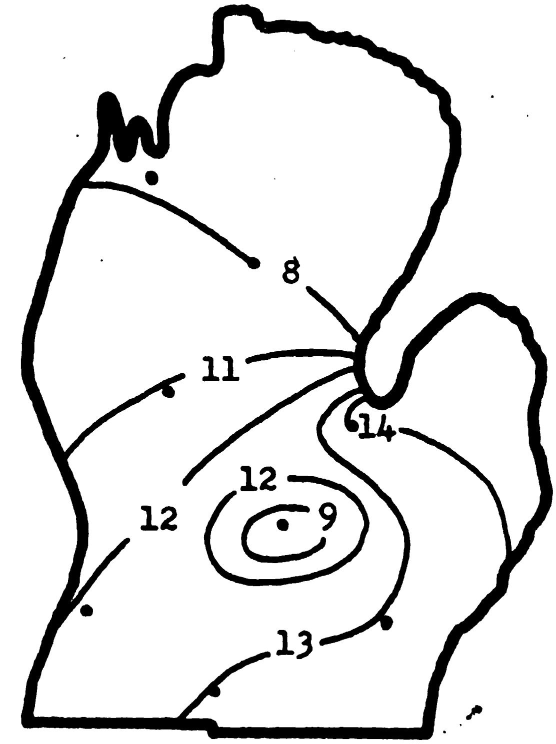
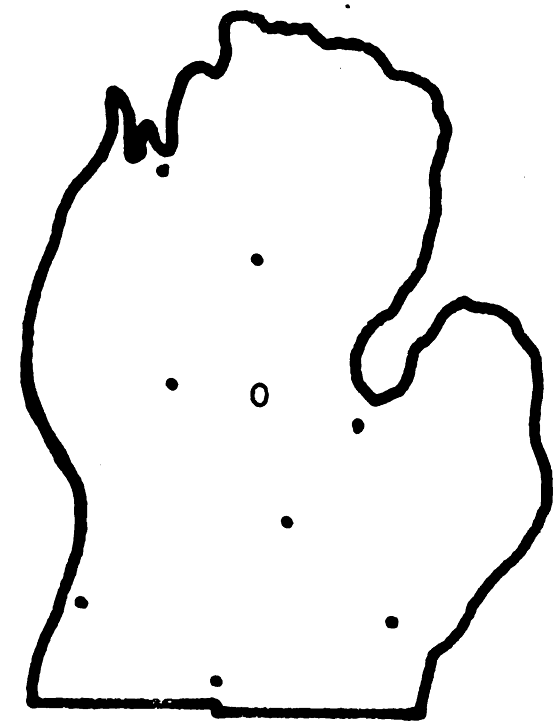


Figure 30 Moisture deficient days in Sept. for a 4 - inch reservoir.

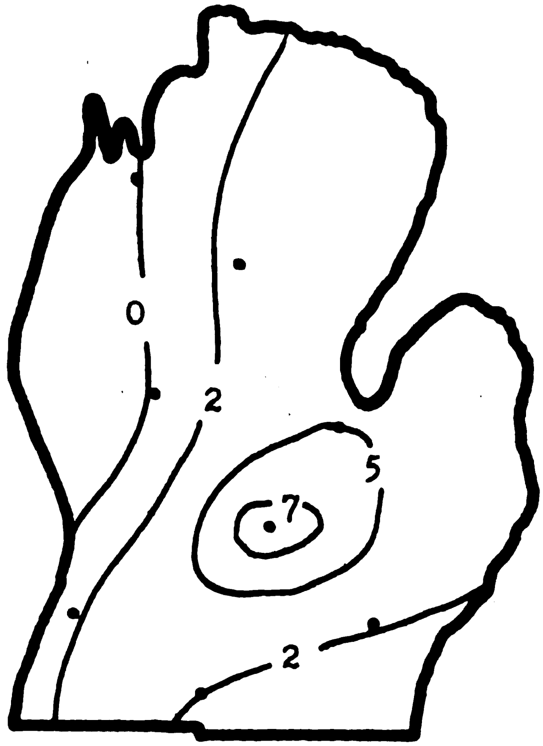


A. Probability of 1 year in 10

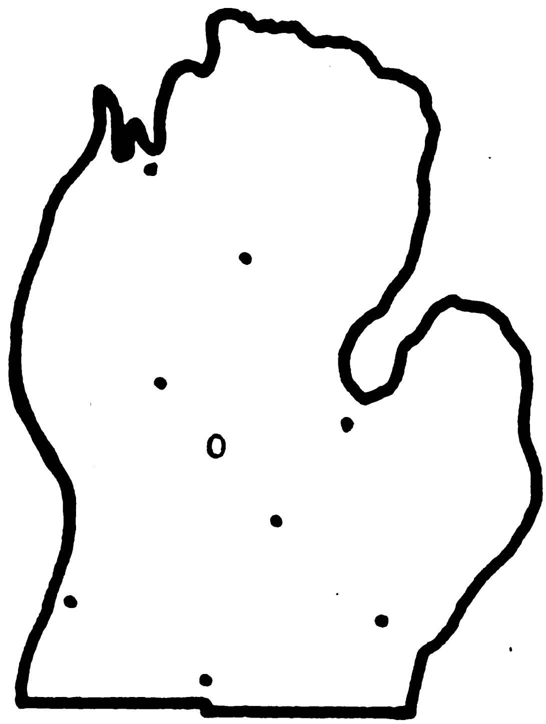


B. Probability of 5 years in 10

Figure 31 Moisture deficient days in **Sept.** for a **5** - inch reservoir.



A. Probability of 1 year in 10



B. Probability of 5 years in 10

Figure 32 Moisture deficient days in **Sept.** for a 7 - inch reservoir.

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APPENDIX I

EVAPOTRANSPIRATION FOR JULY, EAST LANSING

Temp. = 71.1 °F - 2° correction = 69.1 °F
σT_a^4 = 15.04 (69.1 °F Appendix III)
e_a = 18.2 (Appendix B, II.)
e_d = percent RH (e_a) = 71 (18.2) = 12.9
n/N = 73 percent
N = 15.1 hr. sunrise to sunset
r = .2 for vegetation
R_a = 15.9 mm/day
= .64 (69.1 °F Appendix A, II.)
Wind = 7.2 mph $\left(\frac{\log 6.6}{\log 60}\right)$ 3.30 mph @ 6.6'
Wind = 7.2 mph @ 60'
u_2 = 24 (3.3) = 79 miles per day @ 6.6'

$$H_t = R_a (1-r)(.18 + .55\ n/N) - \sigma T_a^4 (.56 - .092\ e_d)(.1 + .9\ n/N$$
$$= (15.9)(1-.2)(.18 + .55 \times .73) - (15.04)(.56 - .092 \times 12.9)(.1 + .9 \times .73)$$
$$= 15.9\ (.8)(.18 + .402) - 15.04(.56 - .33)(.1 + .657)$$
$$= 7.38 - 262$$
$$= 4.76$$

$$L_a = .65\ (1 + .0098\ u_2)$$
$$= .65\ (1 + .0098 \times 79)$$
$$= 1.15$$

$$S = La/La + .16$$
$$= 1.15/1.15 + .16$$
$$= .879$$

$$D = N/24 + 1/\pi \sin N\pi/24$$
$$= 15.1/24 + 1/3.14 \sin 15.1(3.14)/24$$
$$= .63 + .318 \sin 1.96$$
$$= .63 + .318 \sin 112^\circ$$
$$= .63 + .318\ (.92)$$
$$= .63 + .292$$
$$= .922$$

$$E_a = .35\ (1 + .0098\ u_2)(e_a - e_d)$$
$$= .35\ (1 + .0098 \times 79)(18.2 - 12.9)$$
$$= .35\ (1 + .774)(53)$$
$$= .35\ (944)$$
$$= 3.29 \text{ mm/day}$$

APPENDIX I CONTINUED:

$$E_t = \frac{\Delta H_t + .27\ E_a}{\Delta + .27/SD}$$

$$E_t = \frac{.64(4.76) + .27(3.29)}{.64 + .27/.879(.922)}$$

$$E_t = \frac{3.05 + .89}{.64 + .27/.8}$$

$$E_t = \frac{3.94}{.64 + .338} = \frac{3.94}{.978}$$

E_t = 4.02 mm/day

E_t = .158 inches/day

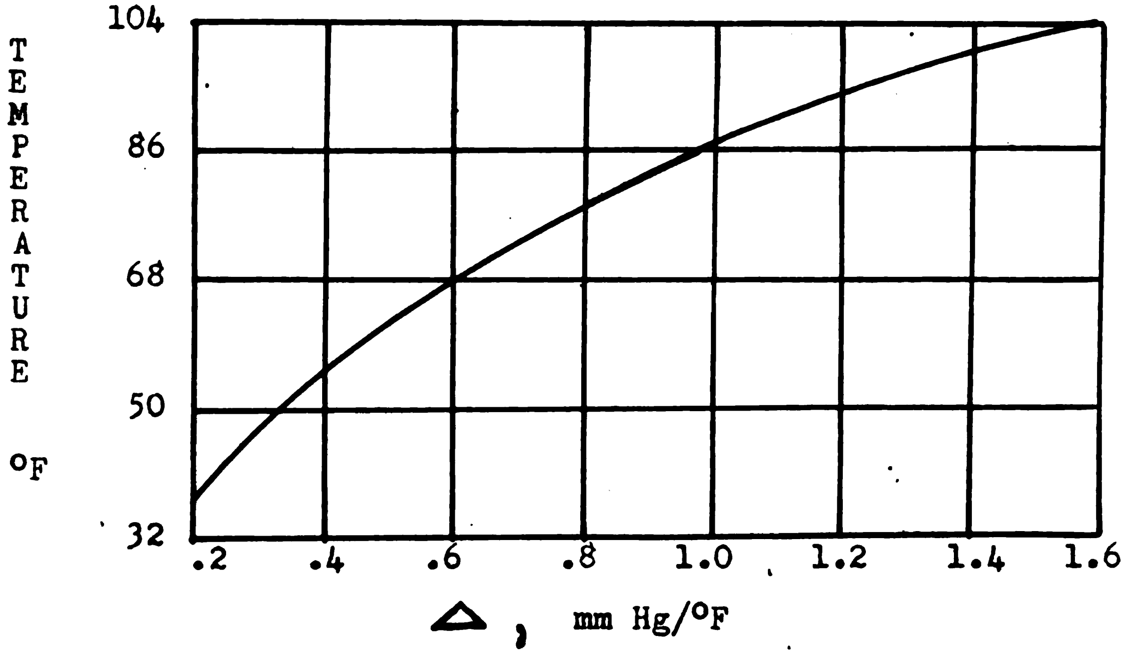
Actual E_t = .158 x .75 .119 inches/day

The data does not warrent .000 accuracy so E_t is rounded off to .00

E_t = .16

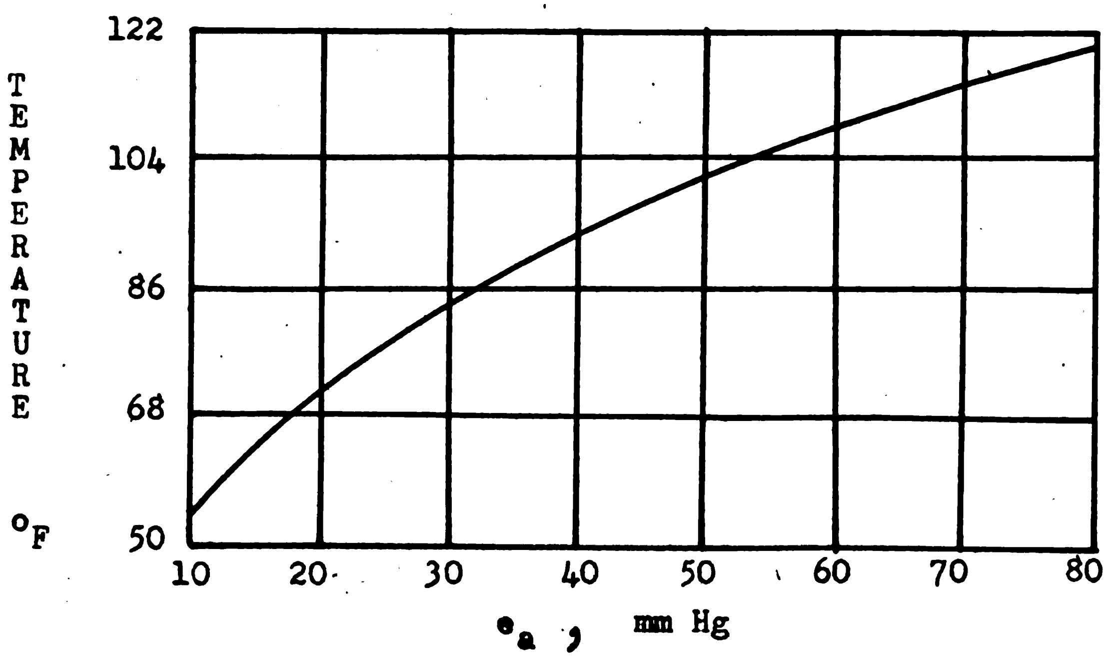
Actual E_t = .12

APPENDIX II



A. Temperature vs. slope of saturated vapor pressure curve.

(From reference 4.)



B. Temperature vs. saturation vapor pressure.

(From reference 4.)

APPENDIX III

Temperature °F	σT_a^4 mm H_2O/day *
35	11.48
40	11.96
45	12.45
50	12.94
55	13.45
60	13.96
65	14.62
70	15.09
75	15.65
80	16.25
85	16.85
90	17.46
95	18.10
100	18.80

* Heat of vaporization was assumed to be constant at 590 cal/gm of H_2O

(reference 4)

APPENDIX IV

CLIMATOLOGICAL DATA USED TO COMPUTE EVAPOTRANSPIRATION

Month	R_a mm/day	n/N %	N hr.	t °F	RH %	u_h mph	E_t in/day
GRAND RAPIDS							
May	15.7	60	14.9	58.2	64	10.5	.12
June	16.9	65	15.4	68.5	66	9.5	.16
July	15.9	72	15.1	73.6	67	8.7	.17
August	14.1	69	14.1	71.6	66	8.5	.14
September	11.9	58	12.2	64.1	70	9.7	.09
EAST LANSING							
May	15.7	62	14.9	56.5	65	9.1	.11
June	16.9	67	15.4	67.4	68	8.0	.16
July	15.9	73	15.1	71.1	66	7.2	.16
August	14.1	69	14.1	69.0	68	7.0	.14
September	11.9	58	12.2	61.8	72	8.0	.09
DETROIT							
May	15.7	58	14.9	57.8	63	10.1	.12
June	16.9	65	15.4	68.1	64	9.4	.16
July	15.9	69	15.1	73.1	62	9.0	.18
August	14.1	66	14.1	71.3	65	9.7	.14
September	11.9	61	12.2	64.3	68	9.5	.10
ALPENA							
May	15.7	58	14.9	50.9	68	10.2	.11
June	16.9	64	15.4	61.5	70	9.3	.15
July	15.9	70	15.1	67.4	68	9.0	.16
August	14.0	63	14.1	65.8	72	9.0	.14
September	11.6	51	12.2	58.4	75	9.9	.08