CLIMATE

By G. E. Ferguson

INTRODUCTION

The climate of southern Florida reflects strongly the influence of dominant features of its geographical position. This area is nearer to the equator than any other part of continental United States, and all parts of it are within 60 miles of the coast on either the Gulf of Mexico or the Atlantic Ocean side. The effects of this low latitude and marine exposure make the general climatic conditions markedly dissimilar from other areas in the United States. Its distinctive climate is a major contributing factor to development of both the coastal and inland areas of southeastern Florida. Both tourists and more permanent residents are attracted to the coastal areas by the comparatively warm sunny weather that prevails during the winter months. This weather also favors the successful growing of off-season truck produce and semitropical crops in the interior agricultural areas.

This climate is characterized by warm weather, usually ample rainfall, and usually light but persistent winds. Each of these climatic elements has a distinct influence on the hydrology and water resources of the area and is treated separately below. Climatic data for areas adjacent to, as well as within, the area of study are presented for the purpose of better definition and understanding.

THE HYDROLOGIC CYCLE

Water evaporating into the atmosphere as vapor from the oceans and other open bodies of water, or from the land surface, is joined with water that is transpired (breathed) into the air from plants, and ascends to form clouds, which, when conditions are right, release the moisture as precipitation upon the earth below. This circulation of water from the surface of the earth to the atmosphere and back again is called the hydrologic cycle. Figure 2 is a schematic representation of this cycle.

The permeable nature of the geologic materials in most of southern Florida allows the rainfall to sink into the ground and become stored in the aquifer. However, not all of the rain contributes to these underground reservoirs. Some of the rain is evaporated again before it sinks into the ground, some reaches the sea through river and canal flows, some remains temporarily in storage in lake basins, some that has entered the ground is caught by plant rootlets and returned to the atmosphere through the leaves of plants as transpired water; the remainder of the rainfall may eventually per-

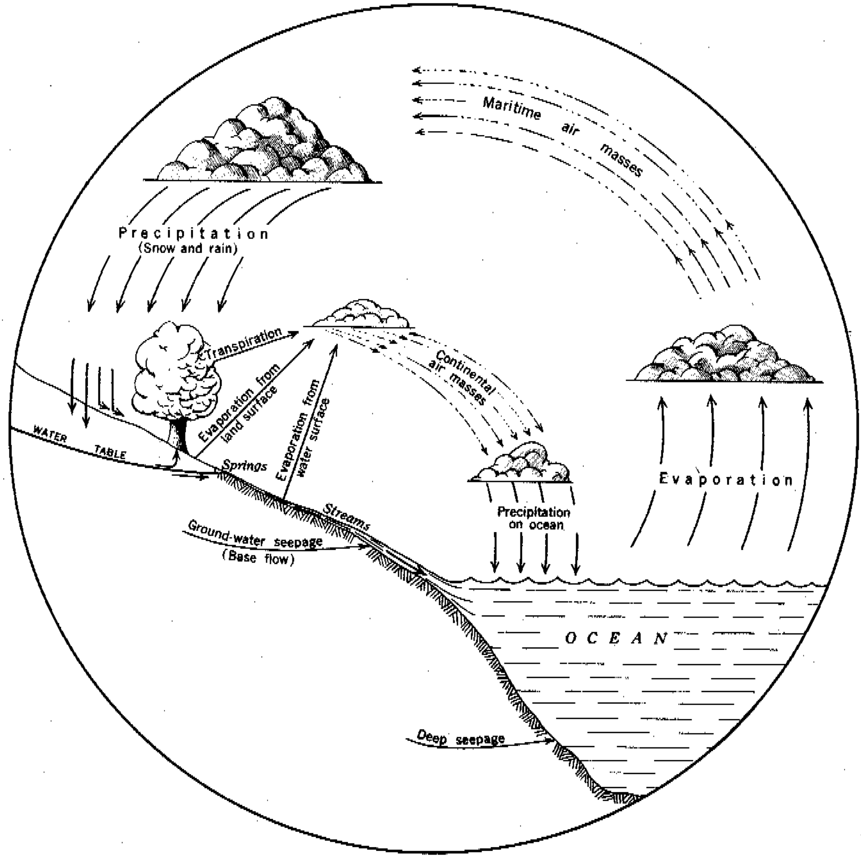

Figure 2. —Schematic representation of the hydrologic cycle.

colate through the soil and contribute to the ground water. Thus, the hydrologic cycle is rather complex, because although some water returns to the clouds very soon after precipitation, some returns again only after long periods spent in geologic formations, or in the ocean, and some, through chemical combination with minerals, may never return.

PRECIPITATION

Of all the climatic elements, precipitation has the greatest and most direct effect upon the water resources of southeastern Florida. Figure 2 illustrates the importance of the role that precipitation plays in the hydrologic cycle. The characteristics of the water supplies in the area are dependent to a large degree on recharge from rainfall during the preceding few weeks or months. Successful evaluation and further development of water supplies, therefore, necessitate a knowledge of the characteristics and amounts of rainfall that are likely to occur.

In southeastern Florida, the study of precipitation is restricted to rain only, because snow is practically unknown, and light hail occurs only at rare intervals.

RAINFALL RECORDS

The characteristics of rainfall of a place or region are largely determined from actual measurements at rain gages established at points within and adjacent to the area in question.

The locations of rain gages in southern Florida are shown on plate 1. The recording and nonrecording types are shown by different symbols. An index number shown for those gages in and adjacent to the areas under direct study, facilitates reference to a description of that gage given in table 2. This table gives the location, length of record, and operating agency for each gage.

In the fall of 1939 the United States Geological Survey established and started operating 18 recording-type rain gages in areas (principally in the Everglades) without adequate means of investigating water resources.

AVAILABILITY AND PUBLICATION OF RECORDS

Nearly all of the records of rainfall collected in the area under study were published by the U. S. Weather Bureau in its current reports. For this reason, no complete rainfall tabulations are included in this report. The U. S. Weather Bureau's "Climatological Data, Florida section," which is published monthly, includes daily and monthly precipitation at all gages in the area except at a few privately operated stations. A special annual issue of "Climatological Data" contains a summary of monthly and annual totals. Temperature, evaporation, wind, and other current climatic data are included in this publication.

Daily and hourly rainfall at recording rain-gage stations are listed for Florida in the monthly "Hydrologic Bulletin" by the Weather Bureau which are open for inspection at Weather Bureau offices. The "Climatic summary of the United States, section 105, southern Florida 1930" (Martin, 1930) contains valuable compilations and average values of monthly and annual precipitation for the period prior to 1931.

Table 2.—*List of rain gages in southern Florida showing locations and periods of record*

[Includes stations pertinent to study of water resources of southeastern Florida. Refer to U. S. Weather Bureau publications for names of observers or parties furnishing current records published therein. See reference notes for parties collecting unpublished records and for governmental agencies operating gages as part of their research programs. Type of data collected as of Dec. 31, 1946, is explained on pl. 1. Records for many older stations are not continuous, but breaks in record of 2 years, or less, are not indicated herein. Absence of termination date indicates station was in operation at end of 1946. HGS is abbreviation for Hurricane Gate Structure]

Number on plate 1	Location (by counties)	Period of record
	BREVARD COUNTY	
1	Malabar	1902-26
2	Melbourne[1]	1937-
3	Melbourne[2]	1941-
4	Merritt Island	1878-
5	Micco	1893
6	Rockledge	1908-12
7	Titusville	1887-95, 1901-
	BROWARD COUNTY	
8	Dania[3]	1939-
9	Dania (Wacico Grove)	1913-
10	Flamingo Groves[4]	1932-
11	Fort Lauderdale	1912-
12	Griffin	1913-23
13	Hillsboro Canal near Deerfield Beach[5]	1921-23
14	North New River Canal at Lock No. 2[5]	1913-26, 1939-44
15	North New River Canal at 20-Mile Bend[2]	1940-
16	Pompano	1940-
	CHARLOTTE COUNTY	
17	Punta Gorda	1914-
	COLLIER COUNTY	
18	Deep Lake[2]	1940-42
19	Everglades	1926-
20	Immokalee[2]	1940-45
21	Lake Trafford[2]	1942-
22	Marco	1900-06, 1942-43
23	Monroe[2]	1940-43
24	Naples	1942-
	DADE COUNTY	
25	Coconut Grove (Chapman Field Gardens)	1923-
26	Coral Gables	1927-33
27	Dinner Key[6]	1939-44
28	Hialeah[2,7]	1940-
29	Homestead	1910-
30	Homestead[2,8]	1940-
31	Matheson Hammock[9]	1939-
32	Miami	1855-58, 1872-80, 1895-
33	Miami (Airport)	1939-
34	Miami (Allapattah)	1921-25, 1927-33
35	Miami Beach	1926-31, 1941-
36	Pennsuco[10]	1926-
37	Pennsuco[2] (4 miles northwest)	1940-
38	Peters	1942-
39	Tamiami Trail at Dade-Broward Levee[2,11]	1940-
40	Tamiami Trail at 40-Mile Bend[2]	1940-

Table 2.—*List of rain gages in southern Florida showing locations and periods of record*—Continued

	DE SOTO COUNTY	
41	Arcadia	1899-
42	Nocatee	1899-1906
	GLADES COUNTY	
43	Benbow[12]	1929-
44	Lakeport[13]	1928-
45	Liberty Point[12]	1929-
46	Moore Haven	1918-
47	Moore Haven (HGS No. 1)[14]	1940-
48	Ortona[14]	1940-
	HARDEE COUNTY	
49	Wauchula	1933-
	HENDRY COUNTY	
50	Bare Beach[12]	1929
51	Big Cypress Indian Reservation[2,15]	1940-43
52	Clewiston[16]	1925-
53	Clewiston[14]	1940-
54	Felda[14]	1940-
55	LaBelle	1929-
56	LaBelle[14]	1940-
57	Townsite[12]	1929-
	HIGHLANDS COUNTY	
58	Avon Park	1892-96, 1902
59	Avon Park[14]	1940-
60	DeSoto City	1925-33
61	Lake Placid	1933
62	Venus[14]	1928-32, 1940-
	HILLSBOROUGH COUNTY	
63	Mullet Key	1892-97
64	Plant City	1892-
65	Tampa	1890-1942
66	Tampa (MacDill Field)	1942-
67	Temple Terrace	1922-26
	INDIAN RIVER COUNTY	
68	Fellsmere	1911-
69	Sebastian	1897-1901
70	Vero Beach	1923-26
71	Vero Beach[1]	1940-
	LAKE COUNTY	
72	Clermont	1892-
	LEE COUNTY	
73	Bonita Springs[2]	1942
74	Captiva	1939-
75	Fort Myers	1851-58, 1871-83, 1886-1940
76	Fort Myers	1940-
	MANATEE COUNTY	
77	Bradenton	1869-
	MARTIN COUNTY	
78	Indian Town	1929-34
79	Port Mayaca[14]	1940
80	Saint Lucie Lock No. 2[14]	1940-
81	Stuart	1935-

Table 2.—*List of rain gages in southern Florida showing locations and periods of record*—Continued

	MONROE COUNTY	
82	Flamingo	1901-08
83	Key West	1832-38, 1843-45, 1849-65, 1870-
84	Key West[1]	1941-
85	Lignumvitae Key	1941-
86	Long Key	1916-35
87	Pinecrest	1928-30
88	Sand Key	1903-25
89	Tavernier	1936-
	OKEECHOBEE COUNTY	
90	Bassenger	1913-17
91	Fort Drum[2]	1942-
92	Kissimmee River at State Route 70[2]	1931-
93	Okeechobee	1913-
94	Okeechobee (HGS No. 6)[14]	1940-
	ORANGE COUNTY	
95	Hart Lake[2]	1942-
96	Isleworth	1916-
97	Lake Hiawassee[17]	1939-
98	Orlando	1892-1944
99	Orlando (Airport)	1940-
	OSCEOLA COUNTY	
100	Hatchineha Lake[2]	1942-
101	Holopaw	1941-
102	Kissimmee	1888-89, 1892-
103	Kissimmee[14]	1940-
104	Nittaw[2]	1942-
105	St. Cloud	1913-33
	PALM BEACH COUNTY	
106	Belle Glade[8]	1924-
107	Belle Glade (HGS No. 4)[14]	1940-
108	Belle Glade State Prison Farm	1936-
109	Belvedere Road at Military Trail[18]	1940-42
110	Boca Raton	1941-
111	Boca Raton at E-2[18]	1928-
112	Boca Raton Road at Range Line[18]	1940-
113	Boynton Control No. 10[18] (also Boyton Beach)	1928-
114	Boynton Road at E-2[18]	1928-
115	Boynton Road at Military Trail[18]	1940-
116	Bryant[12] (near) (Azucar)	1929-
117	Canal Point[19]	1922-
118	Canal Point (HGS No. 5)[14]	1940-
119	Canal Point (6 miles SE)[20] Pump station No. 1	1939-
120	Canal Point (9 miles SE)[20] Pump station No. 2	1941-
121	Delray Road at E-2[18]	1928-
122	Delray Road at Military Trail[18]	1940-
123	Greenacres City[18]	1928-
124	Hypoluxo	1890-96, 1900-
125	Jupiter	1888-1911, 1920-29
126	Lake Harbor[12]	1929-
127	Lake Worth Road at E-1[18]	1940-
128	Loxahatchee[2,21]	1940-
129	North Dyke, Auxiers[18]	1928-
130	North New River Canal at bend south of Okeelanta[2]	1940-
131	North New River Canal at County Line[2]	1940-
132	Pahokee Section 34[12]	1939-
133	Pelican Section 23[12]	1931-
134	Range Line at Lateral 28[18]	1940-
135	Ritta[22]	1913-32, 1937-
136	Runyon[12]	1942-

Table 2.—*List of rain gages in southern Florida showing locations and periods of record*—Continued

	PALM BEACH COUNTY—Continued	
137	Shawano Plantation[23]	1929-
138	South Bay[12]	1929-
139	South Shore[12]	1940-
140	West Palm Beach[5]	1920-32
141	West Palm Beach[24]	1927-
142	West Palm Beach	1929-
143	West Palm Beach[1]	1938-
	PASCO COUNTY	
144	St. Leo	1895-
	PINELLAS COUNTY	
145	Clearwater	1931-
146	Pinellas Park	1911-37
147	St. Petersburg	1891-94, 1914-
148	Tarpon Springs	1891-
	POLK COUNTY	
149	Bartow	1887-
150	Davenport	1923-45
151	Fort Meade	1851-54, 1885-1920
152	Frostproof	1895-97
153	Grape Hammock[14]	1940-
154	Haines City[17]	1942-
155	Homeland	1893-95
156	Kissimmee River at State Route 60[2]	1932-43
157	Lake Alfred[8]	1924-
158	Lake Wales	1921-37
159	Lakeland	1915-
160	Mammoth Groves	1921-32
161	Mountain Lake	1935-
162	Winter Haven	1941-
	SAINT LUCIE COUNTY	
163	Fort Pierce	1852-58, 1901-
	SARASOTA COUNTY	
164	Sarasota	1930-
165	Venice	1941-

[1] Operated by U. S. Civil Aeronautics Authority.
[2] Operated by U. S. Geological Survey.
[3] Operated by Florida Power & Light Co.
[4] Operated by Flamingo Groves, Inc.
[5] Operated by Everglades Drainage District.
[6] Operated by Pan American Airways.
[7] Operated by city of Miami.
[8] Operated by State Agricultural Experiment Station.
[9] Operated by Dade County.
[10] Operated by Graham Dairy.
[11] Prior to July 1942 located 2 miles west.
[12] Operated by U. S. Sugar Corp.
[13] Operated by J. L. Beck.
[14] Operated by Corps of Engineers.
[15] Observations by Bureau of Indian Affairs.
[16] Operated by Clewiston Drainage District.
[17] Operated by Soil Conservation Service.
[18] Operated by Lake Worth Drainage District.
[19] Operated by Department of Agriculture and U. S. Sugar Corp.
[20] Operated by Pahokee Drainage District.
[21] Also Loxahatchee Groves record from 1929.
[22] From 1937, location 1 mile west and operation changed to U. S. Sugar Corp.
[23] Operated by Shawano Plantation, Inc.
[24] Operated by West Palm Beach Water Co.

CHARACTERISTICS OF RAINFALL

ANNUAL RAINFALL

The average annual rainfall in southeastern Florida varies from a maximum of more than 60 inches along the east coast in the vicinity of Miami and Fort Lauderdale to less than 50 inches in the interior areas in the vicinity of Lake Okeechobee, and along the Florida Keys off the southern end of the peninsula. The areal distribution for the State is shown in figure 3, on which is plotted average annual rainfall at the several stations for the number of years of record indicated. Isohyetal lines were not drawn, because it is believed that additional years of record will be needed to define the areal distribution of rainfall in the Everglades. There are wide areas in the Everglades where rainfall is as yet unmeasured. Even without isohyetal lines figure 3 can provide a satisfactory illustration of the general areal distribution of rainfall in southern Florida by scanning the annual averages shown in their respective positions, as qualified by the indicated period or number of years of record. A study of this map indicates that the mean rainfall over the southeastern Florida area is somewhat greater than the 53-inch average for the entire State and that it is nearly twice as great as the 29-inch average for the entire continental United States.

The variations in annual values from the mean or average for the period of record can be illustrated from a study of the rainfall records, for Miami, where the record since 1901 shows a mean deviation from average of 12.1 inches (equal to 21 percent of the 57.3-inch average). The minimum annual rainfall was 28.66 inches in 1944, and the maximum rainfall was 85.36 inches in 1908. During the past 7 calendar years of study (1940-46) the average annual rainfall was 46.7 inches (about 11 inches below the long-term average).

An examination of the 51-year continuous record of rainfall at Miami reveals two 6-year below-normal sequences (1913-1918 and 1941-46) and a 6-year sequence above normal (1929-1934). These sequences may encourage inquiry in regard to the persistence of rainfall to continue an above-normal or below-normal trend. A count of the rainfall of the 51-year Miami record indicates that the rainfall for 28 years continued the same in relation to normal as the preceding year. The ratio 28/50 = 0.56 is slightly above the 0.50 ratio for simple chance. A count of total precipitation in 2-year successive groups (e.g., 1896 + 1897; 1897 + 1898, etc.) gives a persistence ratio of 26/48 = 0.54, and of 3-year groups 26/46 = 0.57; the tendency for rainfall to continue the same in relation to normal is probably not significant.

There is a record of rainfall at Okeechobee near the mouth of the Kissimmee River that began in 1913 (there is no record for

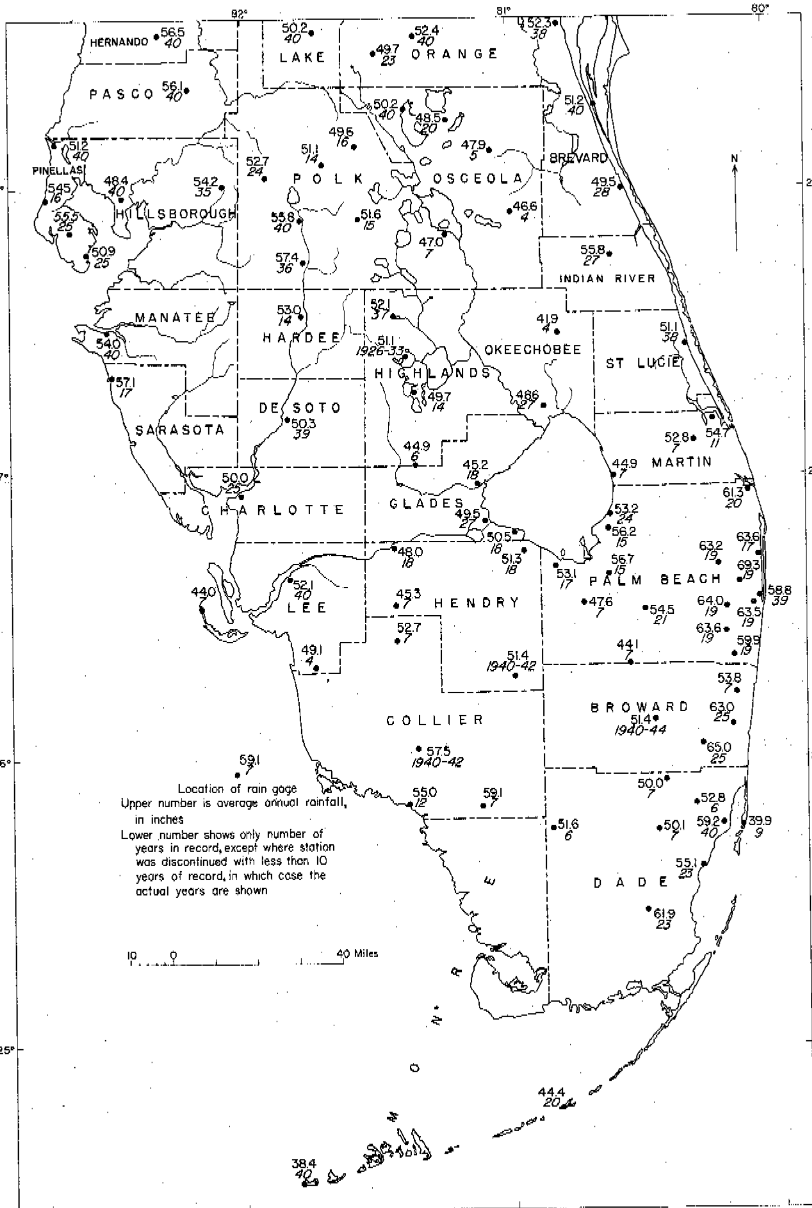

Figure 3.—Map showing average annual precipitation, in inches, for southern Florida.

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Table 3.—*Annual precipitation (in inches) in vicinity*

Station		County	Length of record (years)[1]	Average annual precipitation[2]	1932	
Location	No. on plate 1				Depth	Percent of normal
Arcadia	41	De Soto	47	50.30	33.52	67
Avon Park	59	Highlands	50	52.12	38.67	74
Bartow	149	Polk	60	55.78	52.74	95
Bradenton	77	Manatee	64	54.00	46.32	86
Belle Glade	106	Palm Beach	23	56.70	65.09	115
Clermont	72	Lake	54	50.20	38.16	76
Coconut Grove	25	Dade	23	[4]55.10	64.75	....
Davenport	150	Polk	23	49.63	41.11	83
Everglades	19	Collier	21	55.05	60.20	109
Fellsmere	68	Indian River	35	55.75	50.26	90
Fort Lauderdale	11	Broward	34	62.98	64.97	103
Fort Myers	75	Lee	63	52.06	52.85	101
Fort Pierce	163	St. Lucie	52	51.06	49.91	98
Homestead	29	Dade	37	61.88	69.75	113
Hypoluxo	124	Palm Beach	54	58.75	69.85	119
Key West	83	Monroe	99	38.36	40.42	105
Kissimmee	103	Osceola	56	50.24	47.11	94
La Belle	55	Hendry	16	[4]46.87	51.57	110
Lake Alfred	157	Polk	24	51.14	38.90	76
Lakeland	159	Polk	32	52.70	41.32	78
Merritt Island	4	Brevard	68	51.20	56.27	110
Miami	32	Dade	55	59.18	79.90	135
Moore Haven	46	Glades	29	49.52	54.97	111
Okeechobee	93	Okeechobee	28	48.61	45.78	94
Orlando	98, 99	Orange	55	52.45	39.90	76
Plant City	64	Hillsborough	50	54.24	42.64	79
Punta Gorda	17	Charlotte	33	49.98	43.69	87
St. Leo	144	Pasco	54	56.12	40.49	72
St. Petersburg	147	Pinellas	36	50.90	50.19	99
Sarasota	164	Sarasota	17	[4]54.89	46.56	85
Tampa	65, 66	Hillsborough	57	48.35	44.72	92
Tarpon Springs	148	Pinellas	56	51.18	45.85	89
Titusville	7	Brevard	54	52.31	47.19	90
West Palm Beach	142	Palm Beach	17	[4]63.03	63.38	101

See footnotes at end of table.

of Kissimmee–Everglades drainage basin, 1932–46

1933		1934		1935		1936		1937		1938	
Depth	Percent of normal	Depth	Percent of normal	Depth	Percent of normal	Depth	Percent of normal	Depth	Percent of normal	Depth	Percent of normal
47.71	95	42.27	84	50.08	100	56.29	112	61.16	121	42.78	85
57.42	110	44.95	86	53.47	102	65.77	126	53.02	102	37.12	71
68.02	122	65.64	118	52.35	94	51.73	93	59.38	106	44.77	80
50.93	94	56.23	104	54.28	101	57.32	106	52.04	96	46.11	85
65.26	115	62.24	110	48.81	86	64.57	114	58.44	103	40.99	72
65.12	130	54.43	108	54.89	109	48.88	97	53.34	106	37.06	74
51.28	....	55.45	....	50.82	....	79.09	....	55.16	....	47.39	
62.37	126	59.15	119	38.84	78	47.88	96	48.92	99	34.57	70
49.63	90	56.88	103	55.36	101	65.52	119	51.68	94	48.89	89
62.66	112	65.85	118	62.72	112	67.00	120	60.88	109	41.00	74
75.23	119	64.78	103	52.85	84	76.49	121	....	....	41.05	65
46.36	89	46.20	89	50.21	96	67.13	129	44.22	85	42.00	81
69.92	137	41.32	81	46.44	91	73.86	145	69.17	135	38.22	75
70.33	113	65.18	105	69.73	113	84.12	136	65.10	105	40.42	65
67.48	115	52.45	89	54.39	93	57.01	97	43.00	73	40.32	69
52.02	136	31.50	82	39.62	103	50.46	131	44.29	116	22.58	59
65.44	130	58.50	116	40.45	81	45.59	91	54.88	109	33.03	66
45.55	97	43.86	93	44.63	95	53.64	114	43.83	93	41.26	88
54.52	107	64.43	126	42.11	82	53.97	106	53.32	104	37.50	73
58.89	112	58.89	112	55.23	105	49.78	94	51.52	98	44.70	85
56.01	109	52.84	103	48.40	95	58.33	114	44.98	88	42.79	84
66.05	111	68.79	116	47.91	81	77.30	131	57.50	97	43.74	74
41.45	84	48.20	97	40.87	83	57.30	116	60.33	122	33.78	68
54.42	112	49.16	101	51.46	106	55.46	114	50.96	105	43.31	89
57.42	109	50.30	96	49.27	94	52.18	99	59.10	113	34.55	66
71.76	132	56.37	104	49.49	91	55.21	102	56.19	104	44.41	82
51.96	104	52.61	106	47.36	95	56.55	113	50.27	101	43.98	88
64.97	116	69.85	125	57.55	103	55.85	100	60.73	108	49.16	88
51.10	100	52.37	103	45.75	90	52.87	104	58.91	116	39.93	78
64.66	118	47.61	87	57.18	104	65.48	119	46.99	86	57.41	105
50.07	103	56.48	117	53.71	111	49.35	102	55.00	114	41.93	87
48.81	95	52.22	102	48.25	94	55.90	109	64.25	125	46.81	91
58.67	112	47.79	91	66.36	127	53.91	103	49.31	94	35.18	67
86.46	137	53.72	85	59.13	94	71.48	113	62.98	100	44.34	69

Table 3.— *Annual precipitation (in inches) in vicinity*

Station		County	Length of record (years)[1]	Average annual precipitation[2]	1939		1940	
Location	No. on plate 1				Depth	Percent of normal	Depth	Percent of normal
Arcadia	41	De Soto	47	50.30	59.32	118	57.55	114
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Bartow	149	Polk	60	55.78	54.21	97	45.83	82
Bradenton	77	Manatee	64	54.00	54.63	101	48.05	89
Belle Glade	106	Palm Beach	23	56.70	55.49	98	54.94	97
Clermont	72	Lake	54	50.20	51.30	102	47.83	95
Coconut Grove	25	Dade	23	[4]55.10	51.87	....	56.15	....
Davenport	150	Polk	23	49.63	61.77	124	49.32	99
Everglades	19	Collier	21	55.05	50.70	92	54.69	99
Fellsmere	68	Indian River	35	55.75	60.23	108	58.58	105
Fort Lauderdale	11	Broward	34	62.98	48.46	77	70.75	112
Fort Myers	75	Lee	63	52.06	65.33	125	56.55	109
Fort Pierce	163	St. Lucie	52	51.06	44.13	86	50.29	99
Homestead	29	Dade	37	61.88	64.04	103	70.37	113
Hypoluxo	124	Palm Beach	54	58.75	49.53	84	62.42	106
Key West	83	Monroe	99	38.36	42.12	110	41.50	108
Kissimmee	103	Osceola	56	50.24	54.85	109	49.58	99
La Belle	55	Hendry	16	[4]46.87	43.10	92	50.49	108
Lake Alfred	157	Polk	24	51.14	58.91	115	40.03	78
Lakeland	159	Polk	32	52.70	57.98	110	44.22	84
Merritt Island	4	Brevard	68	51.20	......	....	54.31	106
Miami	32	Dade	55	59.18	57.39	97	71.65	121
Moore Haven	46	Glades	29	49.52	49.74	100	58.50	118
Okeechobee	93	Okeechobee	28	48.61	56.20	116	52.97	109
Orlando	98, 99	Orange	55	52.45	52.42	100	54.02	103
Plant City	64	Hillsborough	50	54.24	60.64	112	43.61	80
Punta Gorda	17	Charlotte	33	49.98	55.79	112	55.50	111
St. Leo	144	Pasco	54	56.12	50.90	91	43.87	78
St. Petersburg	147	Pinellas	36	50.90	61.41	121	43.49	85
Sarasota	164	Sarasota	17	[4]54.89	62.81	114	44.05	80
Tampa	65, 66	Hillsborough	57	48.35	51.71	107	42.98	89
Tarpon Springs	148	Pinellas	56	51.18	55.05	108	46.67	91
Titusville	7	Brevard	54	52.31	48.42	93	55.68	106
West Palm Beach	142	Palm Beach	17	[4]63.03	46.57	72	87.52	139

[1]Through 1946.
[2]Except as noted, normals given are as published in "Climate and Man," Yearbook of Dept. of Agr. 1941.
[3]November and December 1945 rainfall estimated.
[4]Computed from 1943 "Climatological Data," U. S. Weather Bureau.
[5]December 1941 rainfall estimated.
[6]Record incomplete.
[7]February 1938 rainfall estimated.
[8]April 1941 rainfall estimated.
[9]Station relocated.
[10]November and December 1942 rainfall estimated.

of Kissimmee–Everglades drainage basin, 1932–46—Continued

1941		1942		1943		1944		1945		1946	
Depth	Percent of normal	Depth	Percent of normal	Depth	Percent of normal	Depth	Percent of normal	Depth	Percent of normal	Depth	Percent of normal
55.68	111	53.82	107	57.08	113	41.57	83	53.55	106	49.55	99
55.53	106	53.67	103	51.01	98	47.68	91	54.66	105	50.70	97
56.13	101	56.30	101	53.61	96	48.99	88	58.08	104	50.22	90
48.01	89	47.81	89	68.52	127	29.45	55	53.89	100	42.04	78
63.53	112	65.82	116	43.20	76	52.12	92	50.65	89	70.94	125
52.66	105	47.11	94	49.20	98	56.11	112	[8]59.6	119	49.00	98
59.32	108	54.90	100	50.77	92	43.34	79	55.15	100	62.64	114
62.09	125	50.72	102	47.78	96	55.36	112	67.74	136	....	
[5]51.6	94	36.50	66	40.64	74	42.24	77	57.42	104	56.27	102
78.83	141	60.60	109	61.20	110	64.70	116	52.44	94	56.44	101
55.01	87	53.05	84	47.38	75	41.61	66	([6])	....	([6])	
62.92	121	53.92	103	62.45	120	34.17	66	52.58	101	42.45	82
73.43	144	47.46	93	49.63	97	48.34	95	51.88	102	43.59	85
76.47	124	63.31	102	56.80	90	51.15	83	54.28	88	64.27	104
[8]64.87	110	67.45	115	46.37	79	34.70	59	56.41	96	53.34	91
52.01	136	29.03	76	36.53	95	31.93	83	40.93	107	31.68	83
63.10	125	45.50	91	41.50	83	43.34	86	50.13	100	48.75	97
55.97	119	43.88	94	47.65	102	48.60	104	62.74	134	50.40	108
57.30	112	44.99	88	53.64	105	58.02	113	60.55	118	51.89	101
59.76	113	39.57	75	49.40	94	40.70	77	52.24	99	47.05	89
59.79	117	39.10	76	40.09	78	47.34	92	49.61	97	51.55	101
51.34	87	56.80	96	44.82	76	28.66	48	34.54	58	39.04	66
61.64	124	44.74	90	39.54	80	42.70	86	45.48	92	40.88	83
53.42	110	44.03	91	39.81	82	36.38	75	43.41	89	37.45	77
59.65	114	41.29	79	49.40	94	[9]48.85	93	55.95	107	50.13	96
61.20	113	48.82	90	57.98	107	45.41	84	59.78	110	44.89	83
45.44	91	51.77	104	48.90	98	38.89	78	56.54	113	50.07	100
60.05	107	60.09	107	63.30	113	54.30	97	81.93	146	51.79	92
45.77	90	44.64	88	56.20	110	38.40	75	62.66	123	45.75	90
55.83	102	46.14	84	75.93	138	35.75	65	55.38	101	39.03	71
54.25	112	38.66	80	44.89	93	34.87	72	66.65	138	59.12	122
62.46	122	[9,10]68.8	124	59.59	116	([6])	....	58.75	115	61.53	120
66.38	127	48.63	93	47.57	91	65.57	125	60.55	116	51.21	98
66.64	106	66.36	105	50.69	80	44.91	71	73.02	116	66.93	106

1923). Average rainfall at Okeechobee for a 33-year period is 47.9 inches. The average deviation is 6.8 inches, or 14 percent of the average, indicating a slightly less variable rainfall regimen than at Miami. During the 7-year study period, rainfall averaged 43.9 inches, 4 inches less than the long-term average. Persistence of precipitation trends is about the same as at Miami; 18/31 (=0.58) for 1-year period, 9/14 (=0.64) for 2-year groups, and 4/8 (=0.50) for 3-year groups, indicating little, if any, persistence in rainfall trends at Okeechobee.

AREAL DISTRIBUTION

Annual rainfall variations in southern Florida during the 15-year period 1932-46 are shown by figures in table 3 and are indicated on the maps in plate 2. Every year shows areas of above-normal rainfall and areas of below-normal rainfall. Although quite definite areas of above- and below-normal precipitation may be delineated, it seems unusual that factors producing rainfall in Florida would not have been sufficiently uniform, in any of the 15 years, to produce rainfall either entirely above, or entirely below, normal for the entire southern part of the peninsula. Some examples of great contrast between stations can be noted. In 1932, precipitation at Miami totaled 135 percent of normal (third highest of the record), whereas at Arcadia it totaled only 67 percent of normal (lowest of record).

In 1945 the difference in annual precipitation between two stations (Coconut Grove and Miami), only about 11 miles apart, was 20.61 inches. The difference in rainfall between Miami and two nearby stations (with short records and therefore not listed in table 3) is even more pronounced. In 1944 it was 27.8 inches in Pennsuco (about 19 miles distant), and in 1946 it was 27.95 inches in Peters (15.5 miles distant).

There are also considerable variations in the monthly rainfall for stations only a few miles apart. For example, Miami and Miami Airport gages are about 5 miles apart, yet some of the monthly rainfalls have differed by more than 11 inches, and it is not uncommon for the daily rainfall at these two stations to differ by more than 2 inches.

No detailed studies of rainfall patterns have been made, but it is apparent that there is usually a considerable variation in both daily and annual rainfall within distances of a few miles; most of the precipitation occurs as local showers, which have a high intensity over only a few square miles or over a few city blocks.

SEASONAL DISTRIBUTION

The seasonal distribution of rainfall at selected stations in southern Florida is shown in figure 4. The concentration of a large part of the annual rainfall during the summer months is a characteristic common to all of the Florida peninsula; this rainfall distribution coincides to some extent with the demands of evapotranspiration, and therefore it tends to maintain a more nearly uniform moisture condition. During the 5-month period, June to October, southern Florida usually receives more rain than any other section of the country. Aside from this general characteristic, monthly distribution of rainfall over southern Florida is not uniform; rather, the contrasts that occur in short distances are remarkable when compared with the coastal plain of the country immediately to the north. On the west coast of the peninsula June and July are the rainiest months. On the lower east coast (illustrated by Miami and Key West) there are two high points, one in spring and the other in fall—September and October are the rainiest months of the year. At inland stations there is an intermediate distribution (see graph for Kissimmee, fig. 4).

The contrast between the distribution of rainfall during July and during October is of special interest. During July, the average rainfall exceeds 9 inches in the region about Tampa Bay. In the Miami region, July precipitation is about 6 inches. Normal October precipitation exceeds 9 inches along a narrow coastal fringe between

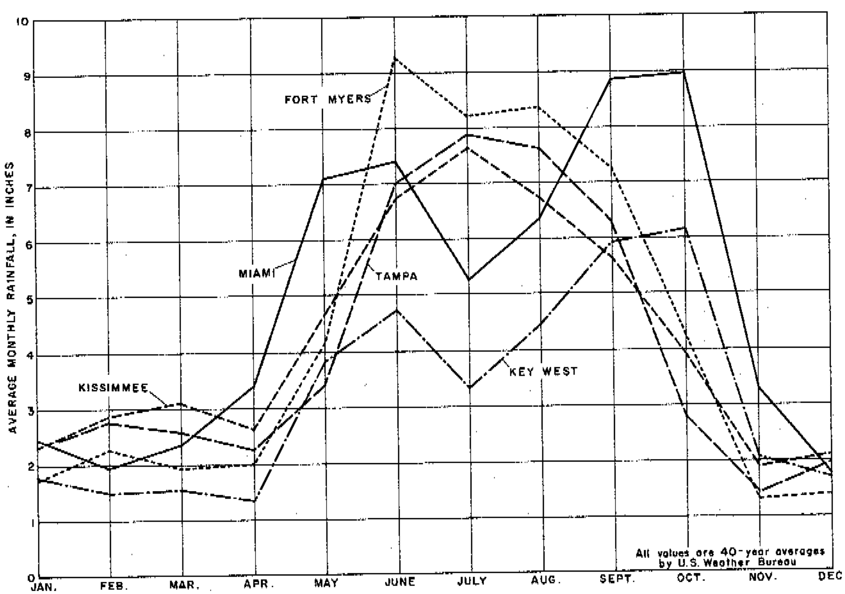

Figure 4. —Graph showing seasonal distribution of rainfall at selected locations in southern Florida.

Homestead and Jupiter. Thirty miles inland, October rainfall averages about 5 inches, and on the west coast, notably in the Tampa Bay region, it is only about 3 inches. The high July rainfall on the west coast probably reflects the activity of convectional or air-mass thunderstorms, which are common over the Gulf during that month. The high October rainfall on the east coast doubtless arises from the influence of the West Indian hurricanes that are particularly active in the early fall. The rainfall regimen at Miami seemingly has more in common with that at Nassau in the Bahamas (about 150 miles to the east) than it has with the regimen at Fort Myers (about 115 miles to the northwest on the Gulf coast of the peninsula).

The usual long dry winter and spring seasons, as clearly illustrated by all graphs on figure 4, are closely associated with the recurring droughts in the area. Little recharge to water supplies can be expected after the end of October; therefore, the lowest water levels generally occur in the spring and following a year in which the precipitation of both the summer and fall seasons was below average. Successful development of water supplies and operation of water-control projects require careful consideration of this seasonal distribution of rainfall.

Actual seasonal behavior in rainfall at the water plant at Hialeah during the 7 years of this investigation is illustrated in plate 3. The graph illustrates the vagaries in seasonal distribution that may take place from year to year and suggests that normal distribution of rain among the months rarely occurs at a given place in any one year. See pages 215-221 for a discussion of rainfall characteristics in the Miami area and pages 511-569 for a discussion of the relationship between rainfall and runoff.

STORM RAINFALL

Periods of storm rainfall are usually associated with the tropical disturbances that generally occur during the fall months. Not all of these disturbances produce heavy rainfall, but some produce rainfall amounts that approach, if not equal, the greatest recorded anywhere in continental United States. The 24-hour rainfall recorded at Canal Point, Palm Beach County, on November 6-7, 1932, as 21.92 inches (Clayton, Neller, and Allison, 1942, p. 27) is believed to be the heaviest on record in southeastern Florida. This compares with a 24-hour recorded maximum for Florida of 23.22 inches—at New Smyrna Beach on October 10-11, 1924 (Theaman, 1943)—and for the continental United States of 38.2 inches at Thrall, Tex., Sept. 9-10, 1921 (U. S. Corps of Engineers, 1945).

The Gulf coast is noted for its frequency of thunderstorms, which occur on the average on 80 to 90 days annually, a greater number than

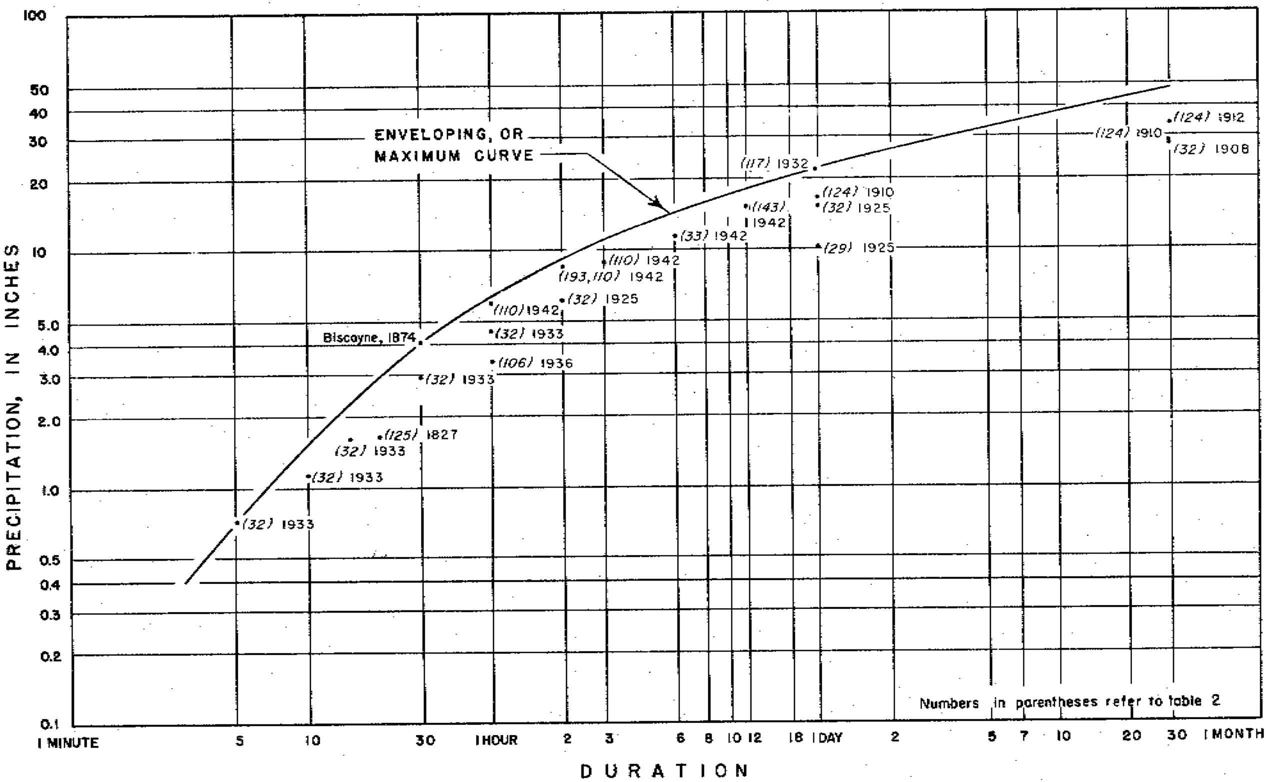

Figure 5. —Chart showing relation of amount of precipitation to duration of storms in southern Florida.

Table 4.—*Amounts of 24-hour rainfall to be expected at rare intervals*

Station	County	Average annual precipitation[1] (inches)	Years of record used for frequency array	Average of annual maximum 24-hour rainfalls (inches)	24-hour rainfall, in inches, which probably will be equaled or exceeded once in:			Maximum recorded 24-hour rainfall (inches)
					5 years	10 years	25 years	
Miami	Dade	59.18	42	6.20	8.3	10.0	12.1	15.10
Belle Glade	Palm Beach	56.70	19	4.26	5.4	6.8	9.2	10.90
Orlando	Orange	52.45	43	3.57	4.3	5.3	6.8	8.02
Okeechobee	Okeechobee	48.61	23	3.32	4.2	4.7	5.4	6.02
Avon Park	Highlands	52.12	40	3.70	4.5	5.6	7.1	8.52
Kissimmee	Osceola	50.24	42	3.64	4.3	5.5	7.3	11.60

[1]Climate and Man, Yearbook of Agriculture: U. S. Department of Agriculture, p. 809-810, 1941.

at any other place in the country. Thunderstorms are most frequent in July and August when they occur on the average of about 20 days each month on the Gulf coast. Graphic records of rainfall from the automatic recording rain gages verify casual visual observations that the greatest part of the rain falls during heavy showers of a few minutes' duration. The exception is the prolonged and generally widespread rainfall during the disturbances of tropical origin. Fall-season hurricanes in particular bring torrential rainfalls over the relatively narrow bands they traverse.

The outstanding torrential rainstorms in southern Florida are plotted in figure 5 to show the depth of rainfall in relation to its duration. A curve has been drawn showing the highest limits of intensity on record as defined by the plotted points. Rainfall shown by this enveloping curve has occurred but rarely in southern Florida; the record on which it is based is equivalent to a great many station years. No estimate can be given of the frequency with which rainfall of the extraordinary depths shown can be expected at any given place. Nevertheless, the recurrence of such rainfall is a distinct possibility.

The frequency of 24-hour rainfall at several of the long-term stations in southeastern Florida was studied to find the depth of 24-hour rainfall expected to be equaled or exceeded once in 5, 10, and 25 years on the average. The results are given in table 4 for six stations.

The data in table 4 indicate somewhat greater depths of 24-hour rainfall at Miami and at Belle Glade (possibly the same is true in the intervening Everglades) than at any of the other stations listed, which are in the Kissimmee basin. This difference in intensity is associated with corresponding differences in annual rainfall.

The reliability of the frequency data in table 4, especially for the 25-year interval, is open to speculation because of the errors arising from the relative shortness of the record as well as deficiencies in the statistical theory available. The data in the table, however, probably are a fair appraisal of the frequency of storm rainfall to be expected in southeastern Florida.

DROUGHT RAINFALL

The sufficiency of water supplies in southeastern Florida depends as much on the nature and frequency of droughts as on the average or normal supply. In general, an economy (agricultural or urban) is adapted most easily to a climatic regimen that remains fairly uniform from year to year. Wide fluctuations from the normal result in stress, and unless facilities are available to store supplies, droughts may impose a limit to possible development.

In a general sense, a drought may be defined as a period in which rainfall has been so deficient as to hinder the growth of native vegetation and to affect water supplies adversely. It is difficult to define a drought precisely because various things are affected to different degrees by any given deficiency in rainfall. This is true even with respect to native vegetation (a drought, in this case, exists when vegetation wilts or defoliates unseasonally), because vegetation may be situated variously with respect to available water supplies. Shallow-rooted plants may be affected by even ephemeral shortages, whereas deep-rooted species in the same area may be affected adversely only after months of sustained deficiency. Water supplies, too, are variable in their response to deficiencies in rainfall. Deep ground water, especially in artesian aquifers, responds only to changes in rainfall over long periods, and it is almost unaffected by month to month variations. Headwater streams, on the other hand, vary frequently in rate of discharge and respond to vagaries in daily or even hourly rainfall. Furthermore, during development of a region, if unreasonable demands are made for water, a situation will be created that may simulate drought.

Although deficiency in precipitation is the prime cause of drought, its effects may be aggravated or ameliorated by variations of temperature. Above-normal temperature would tend to increase transpiration of vegetation and evaporation from the land and so accelerate the loss in soil moisture. Below-normal temperature would tend to conserve soil moisture.

Degree of drought is best measured by the effect upon activities directly concerned; for example, soil moisture with respect to agriculture, and streamflow and ground-water levels with respect to water supplies. However, there are no records of soil moisture, and records of streamflow and ground water are relatively short in comparison with the available records of rainfall. Even though it is difficult to measure a drought in terms of precipitation deficiencies alone, for the purpose of this discussion it may be presumed that the intensity of a drought would be proportional to the amount and duration of the deficiency.

Table 5 lists cumulative deficiency in precipitation at Miami and at Kissimmee during outstanding periods of subnormal rainfall. There are 18 periods listed for Miami and 14 for Kissimmee, but the variability between these stations is such that only about half are common to both. Deficiencies during the other periods were apparently local in extent. For example, the drought of 1944-45 was worse in the record at Miami, but its influence was rather localized (see also pl. 2). Large deficiency in rainfall at one station does not necessarily indicate a drought, because its areal effects may be mitigated by a smaller deficiency or even by a normal rainfall at a nearby station; therefore, table 6 has been prepared to show the cumulative deficiency of average rainfall at all stations in the southern part of the State.

Mean-temperature deviation from normal during the indicated periods is also shown in tables 5 and 6. Plus and minus signs are about equally numerous, thus suggesting that there is no tendency for periods of droughts to be associated with either above- or below-normal temperatures.

At Miami, droughts listed in approximate order of magnitude occurred in 1944-45, 1906-07, 1927-28, 1897-98, and 1913-14. At Kissimmee, the five most severe droughts of record were respectively 1897-98, 1942-43, 1906-07, 1931-32, and 1938-39. The ranking five droughts in southern Florida as a whole are 1931-2, 1906-07, 1942-43, 1897-98, and 1927-28. Three ranking droughts (1931-32, 1942-43, and 1944-45) have occurred since some records of lake and river stages are available. It is fortunate indeed that the intensive study of the water resources of the area was under way during the droughts of 1942-43 and 1944-45 (two of the five most severe droughts in more than 40 years). Significant conditions were recorded, which might otherwise have been unavailable for future guidance.

Climatic analyses by some means that will evaluate the effectiveness of precipitation in terms of the temperature with which it is associated are helpful in a study of droughts. Thornthwaite (1931, p. 635-655) has devised a formula for such an evaluation. Briefly, Thornthwaite has assumed that the rate of evaporation from free-water surfaces is a measure of the characteristics of a region with respect to the natural water loss, or consumption of water through evaporation from land, and through the transpiration of vegetation. He then expresses the effectiveness of the precipitation as a ratio of precipitation to evaporation; his findings are based on an empirical formula which involves precipitation and temperature as factors. Using the results of his formula, he also devised a system of climatic classification and later published a series of maps, one for each calendar year from 1900 to 1939, showing the distribution of the climatic types in the United States (Thornthwaite, 1941).

Normally, southeast Florida, like most of the eastern United States, has a humid climate and adequate rainfall for tree growth. However, the precipitation effectiveness falls toward the lower boundary of the humid classification; therefore, the moist-subhumid type is of frequent occurrence (between 25 and 50 percent of the years), and indeed, much of the central peninsula (including the upper Kissimmee River basin) normally falls within the moist-subhumid classification. The moist-subhumid climate is typical of a lush grassland vegetation (such as the prairies of east Texas). Dry-subhumid, the next lower classification, is typical of a short-grass region (as in central Texas) and would correspond to serious drought in Florida. Thornthwaite demonstrates that this type occurred over scattered and limited areas 10 times in 40 years (1900-1939), but only in 1907 and in 1938 were large areas affected. During

Table 5.—*Precipitation deficiency and temperature in relation*

12 months			6 months			4 months		
Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)
MIAMI								
Aug. 1875-July 1876	16.28	(1)	Aug.-Jan.	13.44	(1)	Sept.-Dec.	12.01	(1)
Oct. 1897-Sept. 1898	25.19	-0.4	Jan.-June	16.70	-1.0	Apr.-July	14.52	-0.6
Nov. 1901-Oct. 1902	22.78	....	Mar.-Aug.	15.08	+.9	Apr.-July	11.31	+1.6
Dec. 1906-Nov. 1907	28.42	+.5	May-Oct.	19.31	+.5	July-Oct.	17.02	+.3
Sept. 1913-Aug. 1914	23.13	-1.2	May-Oct.	18.86	-.7	May-Aug.	14.06	....
June 1916-May 1917	22.27	-.8	Sept.-Feb.	15.39	-.6	Sept.-Dec.	11.17	-.6
Oct. 1917-Sept. 1918	22.77	-1.6	Oct.-Mar.	12.55	-2.1	Oct.-Jan.	11.89	-4.0
July 1919-June 1920	18.54	-.5	July-Dec.	13.29	+.4	July-Oct.	13.89	+.3
July 1923-June 1924	19.11	-1.0	July-Dec.	14.43	-1.1	Sept.-Dec.	13.40	-1.3
May 1927-Apr. 1928	30.61	-.1	Mar.-Aug.	17.90	+.6	May-Aug.	14.26	+1.0
1928-29	(2)	....	Oct.-Mar.	9.63	+1.0	Oct.-Jan.	10.73	+.2
1931	(2)	....	Mar.-Aug.	9.74	-1.1	May-Aug.	14.68	+.4
Aug. 1934-July 1935	22.72	+.4	Oct.-Mar.	13.98	+.2	Oct.-Jan.	9.83	+.3
Oct. 1937-Sept. 1938	20.68	+.1	Oct.-Mar.	11.56	+.1	Oct.-Jan.	8.40	-1.1
Oct. 1937-Sept. 1938	20.68	+.2	Mar.-Aug.	13.39	+.6	May-Aug.	8.21	+.1
July 1942-June 1943	20.61	+.2	July-Dec.	15.44	+1.5	July-Oct.	14.85	+1.4
Aug. 1944-July 1945	35.28	-.7	June-Nov.[4]	22.90	-.8	Aug.-Nov.	17.77	-1.3
May 1945-April 1946	23.85	-.8	Mar.-Aug.[5]	17.67	.0	May-Aug.	14.77	-1.0
KISSIMMEE								
Oct. 1897-Sept. 1898	12.40	(1)	Jan.-June	14.76	(1)	Feb.-May	11.69	(1)
Oct. 1901-Sept. 1902	12.00	(1)	Mar.-Aug.	9.08	(1)	Mar.-June	7.34	(1)
July 1906-June 1907	22.93	(1)	Oct.-Mar.	13.86	(1)	Dec.-Mar.	10.20	(1)
Nov. 1910-Oct. 1911	15.83	+3.3	Feb.-July	10.75	+6.4	Apr.-July	8.52	+3.0
Nov. 1913-Oct. 1914	9.89	+2.4	June-Nov.[6]	11.05	-.4	June-Sept.	6.83	-.3
Jan.-Dec. 1917	12.54	+1.9	Feb.-July	11.68	+5.2	Mar.-June	9.33	+5.2
June 1921-May 1922	11.48	-3.6	June-Nov.	6.74	....	June-Sept.	10.46	-.2
Dec. 1926-Nov. 1927	6.09	[7]+5.4	Dec.-May	8.41	+7.5	Dec.-Mar.	5.95	+8.3
Feb. 1929-Jan. 1930	12.95	[8]+5.0	Aug.-Jan.	8.44	-.7	Aug.-Nov.	6.31	-1.2
May 1931-Apr. 1932	19.76	[9]+2.9	May-Oct.	13.40	-.9	May-Aug.	8.50	-1.2
Nov. 1934-Oct. 1935	12.82	-3.3	Mar.-Aug.	9.63	+3.5	May-Aug.	8.11	+.8
Apr. 1938-Mar. 1939	17.84	+2.3	Apr.-Sept.	9.96	+.2	June-Sept.	8.73	-1.9
July 1942-June 1943	20.77	+2.1	July-Dec.	13.59	+.9	July-Oct.	12.02	-.4
Sept. 1943-Aug. 1944	11.66	-.5	Apr.-Sept.	6.79	....	....	....	....

[1] No record.
[2] Above normal.
[3] 1942.
[4] 1944.
[5] 1945.
[6] 1914.
[7] November and December missing.
[8] Four months' record missing.
[9] Five months' record missing.

to normal during periods of drought at Miami and Kissimmee

3 months			2 months			1 month		
Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)
MIAMI								
Sept. -Nov.	10.49	(1)	Sept. -Oct.	8.30	(1)	Sept.	4.06	(1)
Apr. -June	14.40	-0.8	May-June	11.82	-0.4	June	6.52	+0.7
Apr. -June	8.55	+1.8	Apr. -May	7.34	+1.6	May	6.01	+2.7
Aug. -Oct.	14.76	+.3	Sept. -Oct.	11.83	+.25	Oct.	6.27	-.8
May-July	11.30	+.1	May-June	9.78	+.5	May	5.13	+.1
Sept. -Nov.	9.50	-.8	Sept. -Oct.	88.56	-1.0	Sept.	4.45	-1.5
Oct. -Dec.	10.04	-3.6	Oct. -Nov.	9.58	-2.9	Oct.	7.03	-.3
Aug. -Oct.	13.75	+.7	Sept. -Oct.	10.95	+.8	Sept.	5.54	-.7
Sept. -Nov.	11.94	-2.4	Sept. -Oct.	9.42	-1.5	Oct.	6.37	-1.9
May-July	12.13	+1.1	May-June	11.09	+1.5	May	6.27	+1.0
Oct. -Dec.	9.06	-.5	Oct. -Nov.	7.88	-.1	Oct.	5.51	+.5
May-July	13.17	+.2	June-July	10.56	+.6	June	7.15	+.2
Oct. -Dec.	7.48	+.6	Oct. -Nov.	6.53	+1.0	Oct.	6.00	+2.0
Oct. -Dec.	8.12	-1.3	Oct. -Nov.	6.60	-1.1	Oct.	4.14	-.7
June-Aug.	6.84	-.1	July-Aug.	5.27	+.2	Aug.	5.38	+1.1
July-Sept.	10.98	+1.7	July-Aug.	7.97	+1.9	May[3]	5.21	+.8
Aug. -Oct.	14.74	-1.0	Sept. -Oct.	10.34	-1.4	Sept.	5.77	+.2
May-July	13.04	-1.0	May-June	11.45	-.8	May	6.33	-1.4
KISSIMMEE								
Mar. -May	9.93	(1)	Apr. -May	6.83	(1)	May	4.33	(1)
Mar. -May	6.45	(1)	Apr. -May	5.23	(1)	May	4.34	(1)
Jan. -Mar.	8.14	(1)	Feb. -Mar.	5.93	(1)	Mar.	3.10	(1)
May-July	7.62	+1.0	June-July	4.86	+.2	July	3.40	-3.3
June-Aug.	6.31	-.2	July-Aug.	5.10	-1.5	July	3.44	-3.5
Apr. -June	7.42	+3.1	May-June	5.74	+1.8	June	4.29	+.8
July-Sept.	8.62	-.8	Aug. -Sept.	7.06	+.6	Sept.	5.03	+.8
Dec. -Feb.	5.30	+12.5	Dec. -Jan.	3.82	+3.2	Jan.	2.11	+7.3
Aug. -Oct.	5.62	-1.5	Aug. -Sept.	4.97	-1.2	Aug.	3.98	-.7
May-July	8.29	-.7	May-June	6.56	-.1	June	4.17	-.4
May-July	5.52	+.6	May-June	5.27	+3.3	June	3.36	+1.6
Aug. -Oct.	6.73	-1.3	Aug. -Sept.	7.09	-1.0	Sept.	3.72	+1.6
July-Sept.	8.45	+.7	July-Aug.	7.04	+.8	July	5.95	+1.7
Apr. -June	5.73	....	May-June	5.77	+1.0	June	4.31	+1.2

Table 6.—*Precipitation deficiency and temperature in relation*

12 months			6 months			4 months		
Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)
							SOUTHERN	
Dec. 1891-Nov. 1892	6.51	-1.0	Dec.-May	6.07	-0.5	Feb.-May	5.25	-0.7
June 1895-May 1896	9.20	-8.0	June-Nov.	5.72	-.8	June-Sept.	6.51	-.1
Oct. 1897-Sept. 1898	10.20	+.1	Jan.-June	13.97	-.1	Mar.-June	10.59	+.5
Oct. 1901-Sept. 1902	11.02	-1.6	Mar.-Aug.	8.85	-.2	May-Aug.	7.06	+1.9
Dec. 1906-Nov. 1907	14.08	+.1	Nov.-Apr.	9.71	+.3	Dec.-Mar.	7.99	-.6
Dec. 1910-Nov. 1911	11.62	+.3	Nov.-Apr.	7.60	-.8	Dec.-Mar.	6.20	-.7
Apr. 1913-Mar. 1914	8.58	-1.4	Apr.-Sept.	6.92	-1.1	Apr.-July	5.43	-1.1
Nov. 1915-Oct. 1916	8.71	-.4	Jan.-June	6.07	-.2	Jan.-Apr.	5.02	-.3
Jan.-Dec. 1917	8.95	-.6	Jan.-June	7.87	+.6	Jan.-Apr.	4.68	+1.2
May 1921-April 1922	7.38	+1.3	Nov.-Apr.	5.59	+2.8	June-Sept.	11.62	+.2
Mar. 1927-Feb. 1928	14.51	+.8	Apr.-Sept.	8.67	+1.3	Mar.-June	6.40	+1.6
May 1931-Apr. 1932	15.90	+1.5	May-Oct.	10.29	+.1	May-Aug.	8.84	....
July 1934-June 1935	12.67	+.8	Oct.-Mar.	8.79	+1.0	Oct.-Jan.	5.80	+.8
Apr. 1938-Mar. 1939	11.53	+.9	Dec.-May[3]	7.29	+1.0	Jan.-Apr.[2]	5.85	+1.7
July 1942-June 1943	11.76	+1.0	July-Dec.	10.14	+1.6	July-Oct.	9.54	+.8
June 1944-May 1945	12.22	+1.1	Dec.-May	8.92	-1.6	Feb.-May	7.81	+3.2

[1]1906.
[2]1938.
[3]1937-1938.

to normal during periods of drought in southern Florida

3 months			2 months			1 month		
Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)	Period	Precipitation deficiency (inches)	Temperature in relation to average (°F)
FLORIDA								
Mar. -May	4.55	-0.9	Apr. -May	3.62	+.4	July	3.69	+0.5
Mar. -May	4.78	-.3	Apr. -May	3.68	+.7	June	3.17	+.1
Apr. -June	8.96	+.1	May-June	6.88	+.8	June	4.12	+1.0
June-Aug.	5.14	+.7	Oct. -Nov.	4.21	-2.6	Oct.	2.99	+.3
Jan. -Mar.	6.07	+2.4	Sept. -Oct.	5.04	+.1	Oct.	2.99	-1.4
Dec. -Feb.	5.31	-1.2	June-July	4.18	+.1	June	2.60	+.8
May-July	5.24	-1.0	June-July	4.70	-.9	July	2.44	-.1
Jan. -Mar.	4.82	+.4	Feb. -Mar.	3.42	-2.2	Mar.	1.93	-3.7
Jan. -Mar.	3.73	+2.1	Jan. -Feb.	2.88	+1.7	Jan.	1.71	+4.4
July-Sept.	7.82	+.1	Aug. -Sept.	8.21	+.6	Sept.	4.95	+1.4
Apr. -June	6.07	+2.0	May-June	5.16	+2.0	May	3.18	+1.7
June-Aug.	8.19	+.5	June-July	7.09	+.5	June	5.36	-.2
Oct. -Dec.	4.47	+.9	Oct. -Nov.	3.16	+1.4	Mar.	2.03	+3.3
Feb. -Apr.[2]	4.94	+2.4	Aug. -Sept.	5.29	+.1	Aug.	4.08	+.5
July-Sept.	6.33	+1.4	July-Aug.	5.21	+1.5	Oct.	3.21	+.2
Mar. -May	5.91	+3.0	Apr. -May	3.81	+2.1	May	2.88	-.3

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such years, the maintenance of a state of development predicated on a humid or moist-subhumid climate can be accomplished only by a withdrawal of water stored from previous years.

TEMPERATURE

A knowledge of temperature conditions in southeastern Florida is pertinent to a study of its water resources because of the dominating influence of temperature on rates of water losses throughout the area by evaporation and transpiration. This relationship is discussed in more detail under "Evaporation and transpiration."

The modifying effect of the marine exposure on Florida temperatures can be seen by comparing the area under study with the only other area in continental United States of similar latitude, the extreme southern part of Texas. With similar average annual temperature existing in both areas, in Florida the mean July average is about 2° to 3° F cooler, and the January average is 3° to 5° F warmer than in Texas.

The mean annual temperatures increase gradually southward from 72° F in the upper Kissimmee River basin to about 75° F at the southern tip of the peninsula and 77° F at Key West. This variation is apparent in a north-south direction only; in an east-west direction there is little difference between points on the Gulf and Atlantic coasts or between coastal and inland stations.

Mean January temperatures average about 10° F below the annual mean in the Kissimmee basin. The variation from the mean is less along the lower east and west coasts; January temperatures are generally somewhat higher along the coasts than at inland stations. The areal variation in mean July temperatures is only about one-half that for January and does not conform to any definite trend over the area. This variation seems to be part of the general temperature gradation in the East, where the contrast between north and south is great in winter and small in midsummer.

Record-low temperatures vary from 18° F in the upper Kissimmee River basin to from 26° to 28° F along the southern tip of the peninsula and approximately 40° along the Florida Keys. Frost conditions sufficiently severe to kill vegetation have been observed over the entire mainland of the peninsula, but not along the keys. These killing frosts are rare, and the damage to vegetation, although severe from the standpoint of agriculture, seldom is great enough to affect hydrologic factors pertinent to water supplies. On the contrary, the presence of sizeable supplies of water on, or near the surface, has the effect of limiting damage by low temperatures on the vegetation in the immediate locality.

On the basis of normal monthly temperatures, August is the warmest month of the year in southern Florida, July is a close second, and September and June follow in order. January is the coldest month, and December and February are almost as cold (see pl. 3).

WIND

The wind plays a part in the hydrologic processes as a factor in the determination of evaporation from lake or stream surfaces, from the soil, and from the surfaces of vegetation. Other factors remaining the same, the rate of evaporation increases with the rate of movement of the air or wind. Wind movement is commonly expressed as a rate in miles per hour or as an accumulated quantity in a longer unit of time, as miles per month, and ordinarily it is measured by an anemometer, either the revolving-cup type or the orifice type. Variations of the former type are commonly used, although the Corps of Engineers operates several of the pitot or orifice type in the vicinity of Lake Okeechobee to obtain accurate recording of the high hurricane winds. A simple weather vane operated as a part of, or in conjunction with, the anemometers, indicates wind direction by compass bearing.

To be of greatest value in hydrologic studies, records of wind should be observed at or near the ground, and these records should be representative of the general area. Unfortunately, few wind records satisfy both requirements because in urban or well-settled areas, where most of the gages are installed, wind velocities near the ground usually are affected by nearby buildings or trees, and they do not accurately represent the general area. To avoid this difficulty, anemometers are commonly placed high above the ground. The resulting wind-movement records effectively show variations and trends that are usable in hydrologic studies, but these records may not be representative of the slower movement of winds at plant height and at ground and water surfaces where evaporation and transpiration take place.

On the basis of a 30-year record at Miami (Carson, 1940)—anemometer 168 feet above ground surface—the monthly average air speeds varied from 8.1 miles per hour (mph) in July to 10.8 mph in November, with an average for October to March of 9.9 mph as compared to 8.8 mph for April to September. The general average speed of 9.3 mph is more than twice the general average speed inland at Belle Glade. The anemometer at Miami is 19 feet higher than the anemometer at Belle Glade.

Monthly averages for stations at Belle Glade (Palm Beach County) and at Lake Hiawassee (Orange County), as shown graphically in plate 3, illustrate the seasonal variation shown by the Miami records above. It is significant that the season of greatest wind movement coincides with the usual period of greatest water-supply deficiencies. According to the record at Belle Glade, wind movement is greatest in March (when it averages 6.1 mph) and least in August (2.9 mph).

Other older wind records are available in U. S. Weather Bureau records for Key West (since 1871), Jupiter (1907), and Tampa (1890).

Because of the variations in types, elevations, and exposures of the few anemometer stations in southeastern Florida, it is not practicable to attempt to define areal variation in wind movement. On the basis of the comparison between the Miami and Belle Glade records, it is logical to assume, however, that average wind movement decreases from coastal to inland areas.

The prevailing winds are easterly, especially during the summer and fall; direction of wind movement varies during the rest of the year. Winds of high intensity, which usually accompany the tropical storms in this area, are usually confined to the storm paths, and although they probably have an effect on evapotranspiration losses at that time, they are not important to hydrologic studies of water problems in the area.

EVAPORATION AND TRANSPIRATION

GENERAL STATEMENT

The frequent recurrence of drought in the heavy rainfall area of southeastern Florida indicates that the agencies for removal of water are especially effective. In addition to runoff and deep seepage, these agencies include the evaporation of water into the atmosphere from open water surfaces, from the soil, and from the surfaces of plants. The last named, which involves the escape of water from plant organisms into the air, is known as transpiration. The total of these losses over land areas is usually designated as total evaporation or evapotranspiration, and its role in the hydrologic cycle is important. Unlike rainfall, over which man has little or no control, the natural losses from evapotranspiration may be susceptible to change, especially by drainage developments in the almost level Everglades. Removal of water in the Everglades by evaporation can be either beneficial or detrimental depending upon whether the loss is from excess water during wet periods or from much needed and perhaps deficient supplies during drought periods. Studies of the characteristics and magnitude of these losses have been a pertinent part of the study of the water resources of the area. See pages 222-231 for a discussion of ground-water discharge in relation to evapotranspiration in Dade County.

Temperature, wind, relative humidity, and solar-radiation determine the rate at which the air at a given point takes up water from a wet or moist surface. Temperature generally is regarded as the most important factor. On the basis of data (Williams, 1940, p. 53) from representative river basins over the Eastern and Central United States, a general relationship is indicated between the water loss by evaporation from an area and its mean annual temperature. Because mean annual temperature is generally higher in southern Florida than in other parts of the United States, it follows that evaporation should also be comparatively large.

The effect of wind on evaporation is in the replacing of the moisture-laden air at the water ground, or plant surface with usually drier air capable of continuing the evaporation process and inducing vertical mixing. Therefore, total evaporation from any given surface increases with the air movement or wind.

The relative humidity of the atmosphere is likewise a factor to be considered because it is a measure of the extent to which the air can hold additional water. Because the relative humidity is usually high during, before, and after periods of rainfall, the evaporation losses are decreased during these times.

Solar radiation increases the evaporation processes principally through its effect in raising the temperatures of bodies of water, of the soil, and of vegetation. Direct radiation is especially effective when the temperatures of water-surfaces are raised above that of the surrounding air.

Evapotranspiration from land areas is a more complex process than evaporation from open-water surfaces. Total loss from the former is the sum of losses both from vegetation (transpiration) and from the ground (or water surface when the ground is inundated). Furthermore, the losses over longer periods of time from evaporation pans and open-water areas are fairly uniform because of the continuous supply of water. Losses from land areas, however, may vary more widely because of the greater variations in the amount of water available for evaporation.

To illustrate the complexities and the characteristics of total evaporation losses in southeastern Florida, the process of evapotranspiration in a typical section of the open Everglades will be analyzed. This area is assumed to be covered with a growth of sawgrass and other vegetation rooted in several feet of peat or muck over a rock floor. During the summer months the heavy rains usually cover the surface of the muck with several inches of water. The temperatures are high, the sun is bright, and the shallow, standing water warms rapidly. Water vapor moves from the water surface into the air which circulates, perhaps by convection currents, to the top of the vegetation, and then it is carried away by a gentle wind to be replaced by the drier air. Air turbulence produced by the wind serves to diffuse the vapor towards higher levels. At the same time, the processes of transpiration are active. Water absorbed through the roots of the vegetation is also being given to the atmosphere, both from the moist outer membranes and from the pores of the plants. This combination of conditions is conducive to large water losses.

As a rain storm approaches, the relative humidity of the air increases, and its evaporative capacity is correspondingly decreased. The direct solar radiation is intercepted by clouds, and the air and standing water become cooler. The rate of water loss is greatly reduced as a result of this change. During the period of rainfall it may stop entirely. The rate of loss is likewise lessened at night when somewhat similar conditions of lower temperature, lack of direct solar energy, and increased relative humidity prevail.

As summer passes a lowering of the levels of the standing water takes place during the drier fall and winter months, but because of lower temperatures and shorter periods of sunlight, the evaporation qualities of the atmosphere likewise decrease. The water level then declines below the surface of the ground. Transpiration continues as long as adequate water remains available to the root systems, but the loss from the soil now moistened by capillarity from the lower water level is less than that from free water surfaces. Still later, in some areas the water declines to a level where it can no longer be drawn to the surface and lost by evaporation, and all or part of the vegetation approaches a dormant condition with arrested transpiration losses. Thus, the opportunity for evaporation varies greatly even under natural conditions. Total loss depends as much upon availability of water for evapotranspiration as it does upon weather and air conditions.

EVAPORATION

The direct measurement of evaporation from land and water surfaces meets fundamental obstacles and is subject to many practical limitations (Thornthwaite and Holzman, 1942). The measurement of evaporation losses from small water areas can be made much more rapidly in open tanks called evaporation pans, but it is also beset with difficulties in practical application. Coefficients determined experimentally may be applied to these losses to indicate approximately the losses over natural water surfaces of varying size, depth, and exposure. A list of some of the evaporation pans operated in southeastern Florida is given in table 7. These pans are of three general types, the ventilated pan, the sunken pan, and

Table 7.—*Location, description, and period of record of selected evaporation pans operated in southeastern Florida*

Location	County	Latitude	Longitude	Operator	Years of Record
Standard U. S. Weather Bureau Class A ventilated land pans, 48 inches in diameter and 10 inches deep					
Lake Hiawassee	Orange	28°32'	81°29'	U. S. Bureau of Plant Industry	1939-
Belle Glade	Palm Beach	26°40'	80°38'	U. S. Soil Conservation Service and Florida Experiment Station	1924-
Loxahatchee	Palm Beach	26°41'	80°16'	U. S. Geological Survey	1940-
Big Cypress Indian Reservation	Hendry	26°19'	81°00'	U. S. Geological Survey	1940-43
Hialeah	Dade	25°50'	80°18'	City of Miami water plant in cooperation with U. S. Geological Survey	1940-
Tamiami Canal (40-Mile Bend)	Dade	25°45'	80°49'	U. S. Geological Survey	1940-
Colorado type sunken pans, 3 feet square and 18 inches deep with bottoms about 1 foot below ground surface					
Moore Haven	Glades	26°50'	81°05'	Corps of Engineers	1926[1]-
Clewiston	Hendry	26°45'	80°55'	do	1937[2]-
Belle Glade	Palm Beach	26°42'	80°43'	do	1937[2]-
Canal Point	Palm Beach	26°52'	80°38'	do	1937[2]-
Port Mayaca	Martin	26°59'	80°37'	do	1937[2]-
Okeechobee	Okeechobee	27°13'	80°48'	do	1937[2]-
U. S. Weather Bureau Class A floating pan					
West Palm Beach	Palm Beach	26°42'	80°04'	Everglades Drainage District	1916-31[3]

[1]Records prior to 1926 destroyed. Prior to 1937 operation by Everglades Drainage District (about 1918 to 1930) and Fred A. Flanders (1930-37).
[2]Subject to change when additional data are available.
[3]Original records available only from 1920-28.

the floating pan. The water temperatures in the first type are approximately those of the surrounding air; in the second and third types the water temperatures are approximately those of the soil and water surfaces, respectively.

The only other evaporation pans in the area were operated by the Everglades Drainage District in the vicinity of West Palm Beach and Lake Okeechobee for varying periods between 1915 and 1932. Original records for these pans are not available.

The evaporation loss in pans is determined by differences between successive water-level readings with corrections for rainfall as measured in an adjacent rain gage. Readings are usually made daily to the nearest thousandth of an inch. Surplus water from rainfall is removed from the pan, and water lost by evaporation is replaced at intervals as necessary to maintain the surface within operational limits.

Values as determined from the ventilated standard U. S. Weather Bureau pans would be representative of evaporation losses from natural, small isolated shallow pools of water in the general vicinity of the pan, where similar exposure conditions prevailed. Studies extending over a long period of time have shown that coefficients, if carefully chosen, may be applied to pan values to give approximate natural losses in large bodies of water. According to Harding (1942, p. 75-76), coefficients of 0.70 and 0.78 are generally recommended to be applied to measured evaporation from ventilated and sunken pans, respectively, in order to obtain values of evaporation from extensive water areas.

Such coefficients represent the results of comparison of evaporation from large water bodies as deduced from records of inflow and outflow with evaporation from pans nearby. Even cursory examination of these comparisons will reveal wide variations in the ratios, which approach the above values only when evaporations over long periods of time are considered. For individual months, estimates of evaporation based on reference to a pan may be in error as much as 100 percent, and for days the error may be even greater. Assigning reasons for such variations is beyond the scope of this report; possibly, however, much of the difference may arise from differences in exposure and water temperatures.

For methods used in the evaluation of total evaporation losses from several areas by subtracting runoff from rainfall, see pages 524—531.

Records from three of the listed evaporation pans (ventilated pan at Belle Glade, a sunken pan at Moore Haven, and a floating pan at West Palm Beach) are sufficiently long to permit a determination of seasonal and other characteristics. The fact that each of these

Table 8.—*Monthly and annual evaporation (in inches) for ventilated pan at Belle Glade, Palm Beach County*

[Standard U. S. Weather Bureau 48-inch diameter ventilated pan operated at the Everglades Experiment Station, Belle Glade, by Florida Agricultural Experiment Stations in cooperation with U. S. Soil Conservation Service. Records published in annual reports of Everglades Experiment Station. Mean annual value shown is sum of monthly averages]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total	Deviation (inches)
1925	2.98	3.42	5.08	6.46	5.69	5.83	6.10	5.75	5.49	5.53	3.41	3.30	59.04	-5.29
1926	3.14	4.69	5.62	6.35	6.74	5.97	6.37	6.38	5.33	5.22	3.86	3.57	63.24	-1.09
1927	3.89	3.96	5.51	6.40	7.79	6.38	5.97	5.90	6.07	5.31	4.60	3.51	65.29	+.96
1928	3.72	4.59	6.98	7.21	8.17	6.63	5.80	5.88	....	....	....	....	....	
1929	....	4.31	5.88	6.66	7.65	5.86	6.61	6.86	5.21	4.41	3.93	3.22	....	
1930	4.25	4.01	5.41	5.62	7.04	5.53	7.12	7.01	5.12	4.89	3.64	3.37	63.01	-1.32
1931	3.21	3.46	4.72	4.91	6.59	7.05	7.49	6.32	5.30	4.54	3.78	3.32	60.69	-3.64
1932	3.55	4.02	5.60	6.72	7.15	5.13	7.09	6.22	5.14	5.34	3.42	3.47	62.85	-1.48
1933	3.24	4.46	6.11	6.18	7.15	6.13	5.82	5.03	5.97	4.78	3.86	3.48	62.21	-2.12
1934	3.63	3.69	5.56	6.96	6.40	6.19	7.12	6.70	5.77	5.73	4.03	3.49	65.27	+.94
1935	3.81	4.25	6.52	7.50	8.84	6.55	7.38	7.02	5.54	5.37	4.32	3.50	70.60	+6.27
1936	4.18	3.81	6.22	7.68	7.40	5.94	7.37	6.54	4.92	5.15	4.28	3.14	66.63	+2.30
1937	4.44	3.86	5.30	6.30	7.77	6.70	6.66	6.02	5.58	4.93	3.76	3.12	64.44	+.11
1938	3.69	4.22	5.85	6.78	6.66	6.50	6.64	6.75	5.92	5.34	4.08	3.36	65.79	+1.46
1939	3.88	4.98	6.12	7.46	7.48	6.97	6.62	5.26	5.76	5.09	3.94	3.31	66.87	+2.54
1940	3.16	4.42	5.52	6.55	8.08	6.38	6.78	6.31	4.84	5.71	4.21	2.90	64.86	+.53
1941	3.08	3.73	5.50	6.48	8.04	7.36	6.09	6.74	5.62	5.54	3.55	2.59	64.32	-.01
1942	2.93	3.70	5.80	6.61	7.32	5.90	7.61	6.31	5.25	5.63	4.08	3.05	64.19	-.14
1943	3.53	4.40	5.91	6.53	7.18	5.99	6.62	6.46	5.80	5.16	3.45	2.92	63.95	-.38
1944	3.22	4.68	5.58	6.47	6.87	7.12	6.77	6.20	5.68	4.89	3.74	3.07	64.29	-.04
1945	3.67	3.89	6.17	7.06	7.42	6.09	5.73	6.38	5.44	4.37	4.25	3.04	63.51	-.82
1946	3.20	4.56	5.61	7.60	6.34	5.77	6.74	6.35	5.31	5.33	3.29	3.38	63.48	-.85
Mean	3.54	4.14	5.75	6.66	7.26	6.27	6.66	6.29	5.48	5.16	3.88	3.24	64.33	
Percent of annual	5.5	6.4	8.9	10.4	11.3	9.7	10.4	9.8	8.5	8.0	6.0	5.0	100	
Max.	4.44	4.98	6.98	7.68	8.84	7.36	7.61	7.02	6.07	5.73	4.60	3.57	70.60	
Min.	2.93	3.42	4.72	4.91	5.69	5.13	5.73	5.03	4.84	4.37	3.29	2.59	59.04	

Table 9.—*Monthly and annual evaporation (in inches) for sunken pan at Moore Haven, Glades County*

[Colorado type sunken pan, 3 feet square and 18 inches deep with bottom 15 inches below ground surface. Station operated by Everglades Drainage District (about 1918 to November 1930), by Fred A. Flanders (November 1930 to January 1937) and by Corps of Engineers, U. S. Army (beginning January 1937). Records, December 1926 to December 1940, furnished by Fred A. Flanders (observer since 1921); those beginning January 1941 published in U. S. Weather Bureau Climatological Data-Florida section. Mean annual value shown is sum of monthly averages]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total	Deviation (inches)
1926	...	...	...	...	...	...	...	...	...	...	...	2.67	...	
1927	2.67	2.35	4.69	6.16	6.14	7.00	5.91	4.93	4.72	4.03	3.33	2.67	54.60	+2.76
1928	2.58	2.81	4.86	5.92	6.83	5.43	5.23	4.92	3.76	4.08	2.92	2.70	52.04	+.20
1929	2.11	2.58	4.04	5.10	5.54	4.20	4.74	5.24	3.54	3.20	3.53	3.13	46.95	-4.89
1930	2.91	2.93	3.59	4.35	6.01	4.40	5.54	5.15	4.06	4.29	3.12	2.26	48.61	-3.23
1931	1.92	2.34	3.56	4.12	5.52	6.27	6.08	4.79	4.27	4.00	3.17	2.57	48.61	-3.23
1932	2.98	3.56	3.88	4.74	5.95	4.73	6.00	4.93	4.81	4.04	3.75	2.64	52.01	+.17
1933	3.22	3.10	5.12	4.95	6.17	4.75	4.97	4.82	4.64	4.64	3.62	2.97	52.97	+1.13
1934	3.07	2.76	4.18	5.96	4.86	5.91	5.01	5.04	4.78	4.36	2.92	2.66	51.51	-.33
1935	3.07	3.20	4.78	5.72	6.84	5.17	4.80	4.83	4.47	3.94	3.12	2.74	52.68	+.84
1936	2.01	2.63	4.97	5.77	7.16	5.48	6.99	6.46	4.39	4.19	4.13	2.56	56.74	+4.90
1937	3.00	3.11	4.02	4.11	5.45	4.97	4.94	6.32	4.72	3.83	3.27	2.59	50.33	-1.51
1938	2.82	3.28	4.33	5.68	5.34	4.85	4.62	5.70	3.45	4.57	3.45	2.67	50.76	-1.08
1939	2.88	3.34	5.01	4.79	4.98	4.67	3.76	3.51	4.50	4.10	3.75	2.47	47.76	-4.08
1940	2.63	3.00	3.67	5.15	5.83	4.32	4.95	3.98	3.29	4.71	3.72	2.27	47.52	-4.32
1941	2.50	2.38	3.90	4.45	6.03	5.47	4.86	5.34	4.33	4.54	3.16	2.55	49.51	-2.33
1942	3.07	3.17	4.56	4.93	5.72	4.25	6.36	5.98	4.70	5.65	3.62	2.80	54.81	+2.97
1943	3.18	3.93	5.35	6.28	6.83	5.40	4.76	5.47	4.60	4.91	3.66	3.04	57.41	+5.57
1944	2.91	4.08	5.17	5.79	6.00	5.55	5.40	4.31	5.18	4.50	3.61	3.11	55.61	+3.77
1945	3.13	3.31	5.46	6.64	7.28	5.13	4.38	4.59	3.76	3.86	3.83	2.58	53.95	+2.11
1946	2.72	3.71	4.87	6.50	5.30	4.73	4.72	4.49	4.52	4.67	2.92	2.99	52.14	+.30
Mean	2.77	3.08	4.50	5.36	5.99	5.13	5.21	5.04	4.33	4.31	3.43	2.69	51.84	
Percent of annual	5.3	5.9	8.7	10.3	11.6	9.9	10.1	9.7	8.4	8.3	6.6	5.2	100.0	
Max.	3.22	4.08	5.46	6.64	7.28	7.00	6.99	6.46	5.18	5.65	4.13	3.13	57.41	
Min.	1.92	2.34	3.56	4.11	4.86	4.20	3.76	3.51	3.29	3.20	2.92	2.26	46.95	

Table 10.—*Monthly and annual evaporation (in inches) for floating pan at West Palm Beach, Palm Beach County*

[U. S. Weather Bureau Class A floating pan operated by Everglades Drainage District on side channel of West Palm Beach Canal at West Palm Beach. Records taken from Biennial Report, 1927-28, Everglades Drainage District, p. 36-38. Mean annual value shown is sum of monthly averages]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total	Deviation (inches)
1920	3.7	4.0	4.5	5.3	6.6	6.2	6.0	6.9	4.3	5.8	3.9	3.5	60.7	+6.5
1921	4.2	4.5	4.3	7.7	8.3	8.9	5.2	6.4	5.5	3.8	3.7	3.6	66.1	+11.9
1922	3.3	4.0	5.6	6.3	4.2	3.6	3.8	2.6	2.6	2.2	3.3	3.9	45.4	-8.8
1923	3.7	3.8	4.7	4.9	5.6	6.4	2.4	4.9	3.8	4.9	2.6	2.9	50.6	-3.6
1924	1.9	2.9	4.6	5.0	5.1	4.9	4.7	5.9	3.9	2.9	4.7	2.3	48.8	-5.4
1925	2.7	3.6	2.8	5.2	3.4	4.6	4.7	3.8	4.8	3.7	3.4	2.1	44.8	-9.4
1926	2.4	3.2	3.6	3.5	4.9	3.4	3.0	4.9	5.6	5.5	4.5	4.8	49.3	-4.9
1927	3.8	4.0	5.6	6.2	7.8	6.4	5.8	5.8	6.0	5.5	4.7	3.6	65.2	+11.0
1928	2.9	2.9	4.5	5.8	6.2	5.6	6.0	5.8	4.8	4.9	3.7	3.2	56.3	+2.1
Mean	3.2	3.7	4.5	5.5	5.8	5.6	4.6	5.2	4.6	4.4	3.8	3.3	54.2	
Percent of annual	5.9	6.8	8.3	10.2	10.7	10.3	8.5	9.6	8.5	8.1	7.0	6.1	100.0	
Max.	4.2	4.5	5.6	7.7	8.3	8.9	6.0	6.9	6.0	5.8	4.7	4.8	66.1	
Min.	1.9	2.9	2.8	3.5	3.4	3.4	2.4	2.6	2.6	2.2	2.6	2.1	44.8	

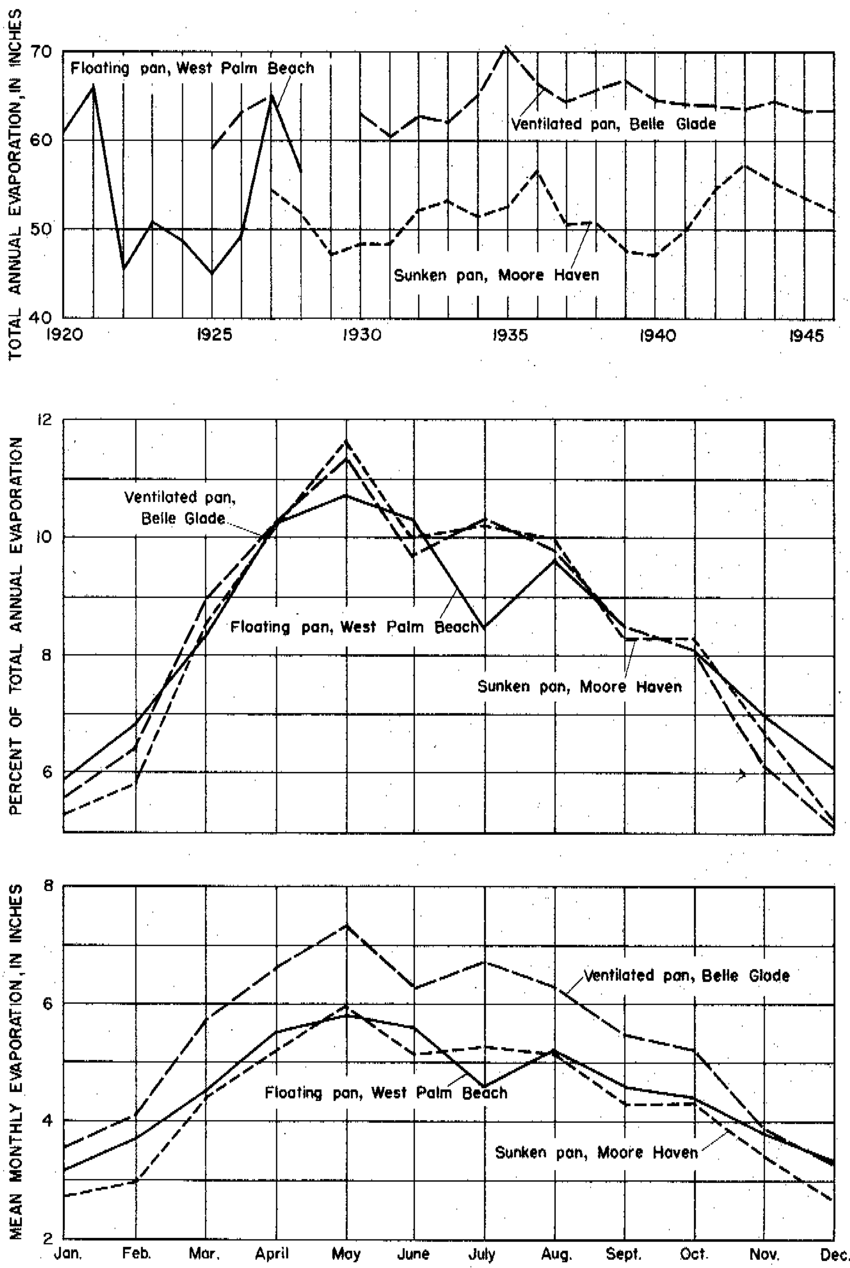

Figure 6.—Graph showing characteristics of evaporation from selected pans in southeastern Florida.

records is for a different type of evaporation pan permits comparative studies of the losses from each pan. Monthly values for each pan for the period of available record are given in tables 8-10, and from these records the mean, maximum, and minimum monthly values and total annual values were computed. Beginning with January 1941, nearly all current evaporation records in the area are published in U. S. Weather Bureau Climatological Data, Florida section. The source of the earlier records is indicated in a note with each tabulation.

It will be noted that the periods of record for the sunken pan at Moore Haven are nearly the same as for the Belle Glade ventilated pan. As a test of the local applicability of the coefficients cited above for determining losses over large bodies of water from records for ventilated (coefficient, 0.70) and sunken (coefficient, 0.78) pans, the mean annual values for the similar years of record (1927, 1930-43) for each pan were calculated. The mean evaporation from the ventilated pan was about 25 percent greater than from the sunken pan. However, after application of the coefficients, the calculated annual loss from Lake Okeechobee would be about 11 percent greater on the basis of ventilated-pan values (64.7 x .70= 45.3 inches) than for the sunken-pan values (51.7 x .78=40.4 inches). The generally recommended coefficient for a floating pan, such as the one at West Palm Beach, is 0.80, which, multiplied by the average annual evaporation for the 1920-28 period of record (54.2 inches) equals 43.4 inches. This is believed to be a reasonably close agreement, and it indicates an average annual loss over Lake Okeechobee of 40 to 45 inches.

Figure 6 illustrates graphically certain characteristics of the losses from these pans and permits ready comparison between them. The values plotted are taken from tables 8, 9 and 10. The most outstanding evaporation characteristics, important because of their relationship to natural evaporation losses over the area, are shown by figure 6 to be as follows:

1. Seasonal variation: May is the month of greatest loss for all pans. Averages show April and June to be next in that order. The total monthly values for the floating and sunken pans generally agree closely; those for the ventilated pan are larger throughout the year and greater differences exist during the summer than dur- the winter months.

An average of mean monthly values for the three types of pans shows the evaporation to be lowest for December, followed closely by January, and with February and November next lowest in that order. The evaporation during the months of December, January, and February average about 0.55 of the evaporation during the three months of April, May, and June.

2. Annual variation: The range in total annual values throughout the period of record is approximately 10 inches for both the ventilated and sunken pans. The range for the values for the floating pan is about twice as great, but direct comparison is difficult because this record covers an earlier period. The annual values for the ventilated and sunken pans have only a slight similarity.

The deviations of annual evaporation from the average annual are listed in tables 8, 9, and 10. The average of these deviations (signs disregarded) is a statistical measure of the year-to-year tendency of evaporation to vary. For Belle Glade the average deviation is 1.80 inches, or 2.8 percent of the average annual; at Moore Haven, 2.55 inches, or 5 percent of the average annual; and at West Palm Beach, 7.1 inches, or 13 percent of the average annual evaporation. The average deviations vary greatly for the three sets of observations. It is not clear whether these deviations are caused by differences in the three pans and their exposures or whether they are caused by differences in climatic factors. However, it may be noted that, in general, the variability is less than that of rainfall (for which the mean deviation at Miami has been reported as 19 percent and at Okeechobee, 13 percent).

Total monthly losses from the ventilated pan at the Hialeah Water Plant, operated by the U. S. Geological Survey during the period of study, are shown in graphical form on plate 3, which also includes other climatological data helpful to a better understanding of the reasons for the seasonal trend of evaporation values. The seasonal distribution of evaporation and the effect of temperature and wind is further illustrated in figure 7, where the observed evaporation has been adjusted as a result of a correlation analysis to a constant value of wind movement so as to bring out the relation of evaporation to temperature. The rate of evaporation reaches a seasonal minimum in December and January. Increases, until about March, are associated with increases in wind movement and temperature; thereafter, although the wind decreases, evaporation losses continue to increase until rising temperatures reach a peak in May. During the summer, evaporation decreases moderately mostly because of a decrease in wind movement. The tendency towards lower relative humidity in April and May and higher relative humidity in September and October may also be an influence, but the seasonal variation in relative humidity is not marked. After the end of the summer rainy season the rate of evaporation continues to decrease with lowering temperatures until the end of the calendar year.

From January until May, as shown on figure 7, the observed evaporation exceeds the amount of evaporation due to temperature alone. During this period, it may be noted that wind movement is about average (3,000 miles per month). From June to December

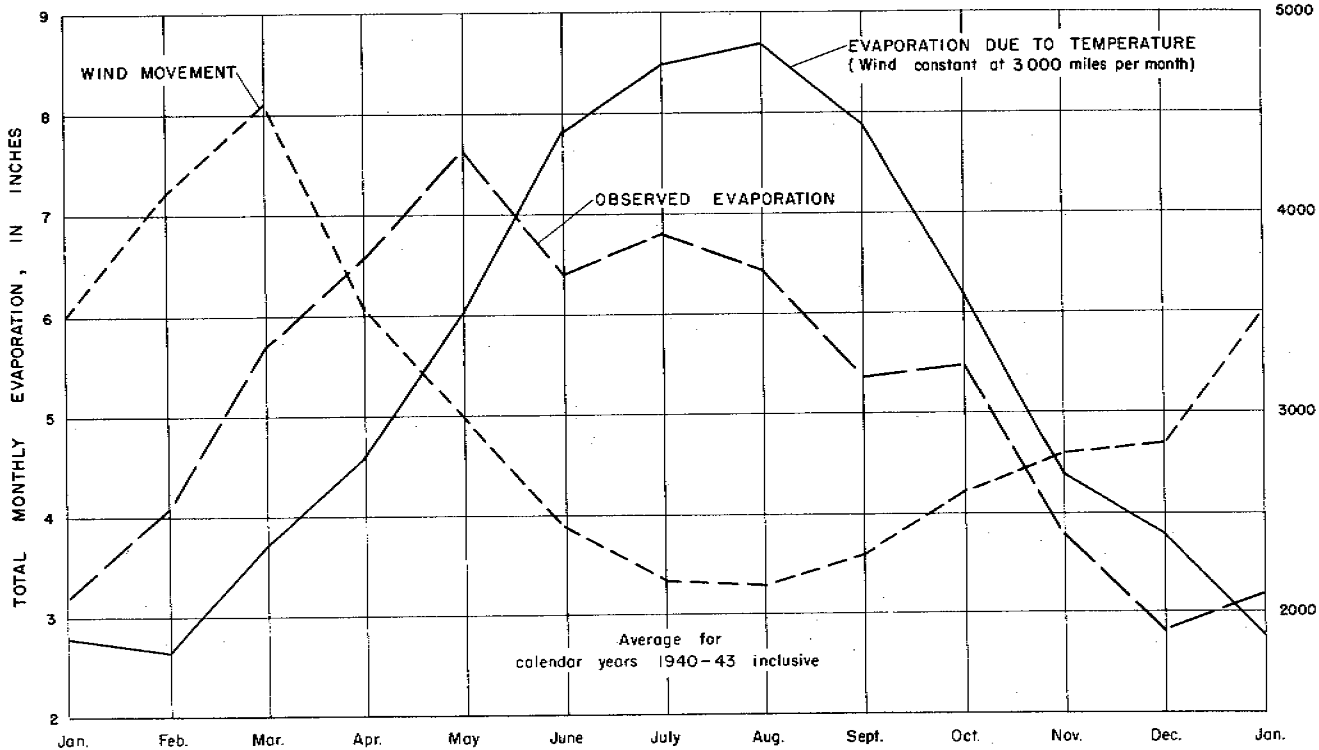

Figure 7.—Study of pan evaporation in relation to temperature and wind movement at Belle Glade.

(the period of less-than-average wind movement) observed evaporation is below that due to temperature. The high wind movement during the January-May period of low rainfall creates a condition that tends to intensify loss of soil moisture during this critical period.

Unlike precipitation, evaporation in the Everglades appears, from a study of the records collected so far, to have no appreciable areal variation. Any observed differences may be due partly to variations in the equipment, its exposure, the method of taking observations, or other causes.

Although the characteristics of seasonal variation in evaporation from natural bodies of water are thought to be somewhat similar to those shown for the pans, it cannot be inferred that such is generally true for evaporation over land areas, where the water supplies vary widely during the year and where the seasonal variation in evaporation may be quite different. The months of greatest evaporation normally would be during the usually wet summer season, when water stands over extensive areas.

EVAPOTRANSPIRATION

Experiments on evapotranspiration were conducted and reported (Clayton, Neller, and Allison, 1942, p. 35) by soil scientists of the University of Florida and the U. S. Department of Agriculture, in 1937 and 1938, at the Everglades Experiment Station near Belle Glade, Fla. The station is southeast of Lake Okeechobee and about 75 miles north-northwest of Miami. The experimenters attempted to determine values for evapotranspiration losses from sawgrass lands. The tanks used were 4 feet wide, 12 feet long, and 4 feet deep; they contained 3 feet of muck soil placed on a 3-inch layer of crushed limestone in the bottom of the tanks. The tanks were set into the ground to a depth of $3\frac{1}{2}$ feet.

After making due allowance for differences between conditions in the tanks and those in the Everglades near Belle Glade, the experimenters estimated the mean annual evapotranspiration from sawgrass land to be about 60 inches. This estimate assumed a water table ranging throughout the year from the land surface to 4 feet or more below the surface and averaging about 2 feet below. For the 2 complete years that the experiment was conducted, the average evapotranspiration loss during the months of May, June, and July was about twice as great as the loss for the months of December, January, and February.

The sawgrass in the glades near Belle Glade has a denser and more vigorous growth than the vegetation in the glades west of

Miami, owing largely to the greater thickness of muck overlying the limestone in the lake area. The muck is approximately 8 feet thick there, whereas it ranges from a few inches to about 3 feet in thickness in the glade areas near Miami. Because of drainage of the glades and recurring muck fires, the sawgrass in the southern glades and near the coastal ridge has been stunted, and in some areas it has been and is being replaced by several species of grasses, sedges, and reeds. These factors probably make the transpiration losses in the glades near Miami and in southern Dade County appreciably less than losses in the glades near Belle Glade. See p. 229 for additional information on evapotranspiration from pine- and grass-land areas south of Miami, obtained from ground-water investigative methods, which indicate approximately 35 inches of annual evapotranspiration, and to pages 544 and 545 which indicate about 42.4 inches average annual evapotranspiration from the Kissimmee River basin.

Experiments were also conducted in a tank at Belle Glade during 1934-36 to determine the amount of evaporation from bare muck soil. The evaporation rates for the 3 years were, respectively, 42.65, 39.21, and 35.97 inches of water; the average yearly depths to the water table were 1.76, 1.33 and 1.43 feet below the muck surface in the tank.

During 1937 and 1938, experiments were conducted with the bare soil in a tank covered with 3 to 4 inches of cane trash. The evaporation rates were, respectively, 12.2 and 9.1 inches of water; the average yearly depth to the water in the tank was 1.4 feet. This shows that the addition to the bare soil of a 3-inch layer of dead cane trash reduced the annual evaporation approximately 30 inches.

The rate of decline of the water table in tanks containing sawgrass was reported not appreciably affected by the depth to water below the land surface so long as the water level remained in the 3-foot thickness of muck. This indicates that the depth to the water table, within this range, did not have a noticeable effect on the total evapotranspiration loss.

The Everglades Drainage District conducted experiments on rates of evapotranspiration loss from tanks operated at West Palm Beach. Of these, Fred M. Elliot, former chief drainage engineer of the District, states that large differences were found in annual total evaporation losses from similar types of vegetation under different water levels. Losses were measured concurrently from two tanks having stands of Para grass growing in muck carefully transplanted from the Everglades. In one of the tanks, water levels were maintained between the top and 12 inches below the top of the muck. In the other, the water was held at considerably lower levels from 30 to 36 inches below the top of the muck. The total evaporation for a year from the former tank was about 110 inches, but during the same period the tank containing the lower water levels showed a loss of 50 to 60 inches. Elliot states further that under comparable water levels the stands of Para grass showed the greatest total evaporation of all types of vegetation under observation. The rate of water loss from corn during its growing season was next highest, with a stand of sawgrass somewhat below that for corn.

CONCLUSION

Because of their great magnitude, a thorough knowledge of the characteristics of evaporation and transpiration losses is highly desirable for the successful study of the water resources of southeastern Florida. Evaporation losses from permanent water areas can be determined with a fair degree of accuracy and are believed to average about 40 to 45 inches per year. Over land areas, however, less-direct methods must be used to determine evaporation and transpiration values, and it has been found practicable to attempt this only for the total rather than for the individual losses.