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Abstract

A regional estimate of potential evapotranspiration (ETp) for central and south Florida is provided based on cumulative literature and lysimeter studies of evaporation and evapotranspiration measurements and estimations. General estimates of annual ETp for the south Florida Water Management District range from 122 cm in the north to 137 cm in the south. Open water and wetland systems evaporate at the potential rate. Otherwise, actual evapotranspiration will be lower due to limited availability of water or moisture. A network of weather stations and an ETp computation software developed in-house is currently being used at the South Florida Water Management District to develop a daily ETp database. A simple ETp estimation model that was previously calibrated with lysimeter data is being applied.

Introduction

Evapotranspiration is one of the major parameters in south Florida hydrology. As a major component of the hydrologic cycle, there is a need for reasonably accurate estimates of evaporation from water bodies and evapotranspiration from vegetation. Evapotranspiration depends on the availability of energy, on the mechanism of mass transfer, energy transfer and the availability of water. Evaporation and evapotranspiration are functions of solar radiation, temperature, wind speed, vapor pressure deficit, atmospheric pressure, characteristics of the surrounding environment and type and condition of vegetation. South Florida is an area of high rainfall, high humidity and generally low wind speed. Air temperature is high with relatively warm winter months. Solar radiation is abundant with seasonal and daily variation. Most of the variation of daily ET is explained by solar radiation (Abtew, 1996a). Annual lake evaporation in the continental United States spatially ranges between 51 cm in the extreme northeast to 218 cm in southern California (Viessman et al., 1977).

Through the years, various measurements and estimates of evapotranspiration data have been reported for different locations in central and south Florida which is the focal area of this study. A one-year study of evapotranspiration from a central Florida freshwater marsh yielded an estimate of 131.7 cm for the year. The method was based on diurnal water-table fluctuation monitoring (Dolan et al., 1984). Lysimeter studies at the

Agricultural Research and Education Center at Belle.Glade in south Florida (26° 39' N, 80° 38' W) reported measured annual water requirements of planted sugarcane to be 117.7 cm, 123.0 cm and 136 cm per year for water table depths of 89 cm, 61 cm, and 30.5 cm, respectively (Shih and Gascho, 1980).

A two-year lysimeter study of evapotranspiration in three wetland environments (cattails, mixed vegetation marsh and open water/algae) was conducted in the Everglades Nutrient Removal Project a constructed wetland in south Florida (26° 38' N, 80° 25' W). An average rate of 3.6 mm per day (133.2 cm yr^{-1}) evapotranspiration was reported (Abtew, 1996a). Figure 1 depicts an open water/algae lysimeter in an open water marsh at the Everglades Nutrient Removal Project. Mao et al. (2002) used three lysimeters, similar in design to the above, to measure evaporation from open water and evapotranspiration from cattails and sawgrass in a marsh in Indian River County, Florida (≈ 27° 40' Latitude). They reported an annual average ET rate of 117.2 cm, 118.6 cm and 128.8 cm for open water, cattails and mature sawgrass, respectively, over a three-year study period.

Two land tank (3.2 m in diameter and 1.7 m deep) evaporation studies for six years at the Everglades Experiment Station in south Florida (current Agricultural Research and Education Center at Belle Glade) reported average yearly water evaporation of 137 cm (Stephens, 1959). Based on a water budget analysis using seven years of data from 1940 to 1946, an average annual Lake Okeechobee evaporation rate of 132 cm was reported (Stephens, 1959). A two-year evapotranspiration study in south Florida, based on the Bowen-ratio/energy balance method, reported a wide range of average annual

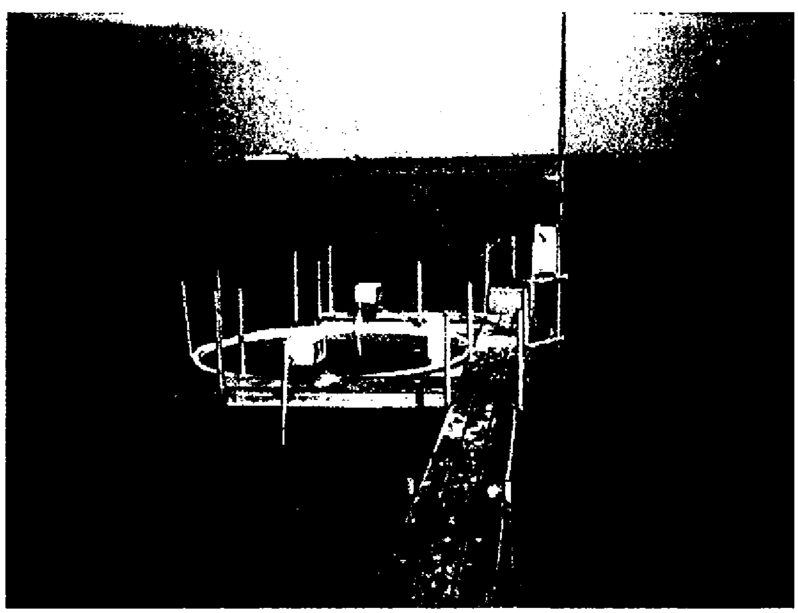
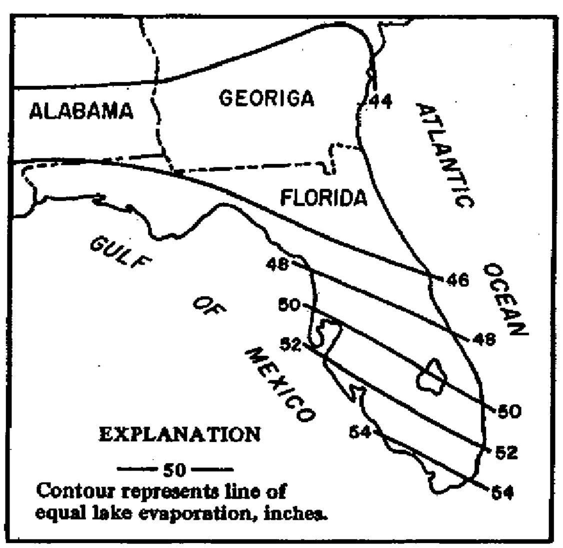


Figure 1. An open water/algae lysimeter in the Everglades Nutrient Removal Constructed Wetland.

evapotranspiration rates between open water and vegetated sites that were dry for part of the year (German, 2000). This study reported an annual average evapotranspiration rate of 122.2 cm for the nine sites in the Everglades Protection Area and vicinity. The maximum annual average evapotranspiration rate was 145.8 cm for an open water site and the minimum was 107.7 cm for a sparse sawgrass site that was dry part of the year.

Annual lake evaporation estimates for the Lake Okeechobee area were reported as 129.5 cm (Viessman et al., 1977) and 127 cm (Visher and Hughes, 1969, Figure 2). Using weather parameters observed on the lake, an annual average Lake Okeechobee evaporation estimate was reported as 132 cm (Abtew, 2001). An annual isohyetal line showing an average annual lake evaporation of 127 cm running southeast to northwest from the West Palm Beach area to west central Florida was published (Linsley and Franzini, 1979). Based on 1968 data from the U.S. Department of Commerce, Hanson (1991) provided mean annual lake evaporation estimates for the contiguous United States with the South Florida Water Management District area being in the range of 102 to 127 cm and 127 to 152 cm. The gradient was increasing north to south in a southeast-to-northwest pattern. Waylen and Zorn (1998) graphically presented annual evaporation rates for Florida, with an increasing gradient from 115 cm in the north to 134.9 cm in the south. The gradient lies diagonally in a northwest to southeast direction.

One of the indications of how well evapotranspiration estimation methods perform in south Florida is whether or not the annual estimate falls within the expected limits. Temporal variation in annual potential evapotranspiration in many parts of Florida is slight when compared to annual variation in rainfall which ranges between 50 percent greater than normal to about 50 percent less than normal (Visher and Hughes, 1969). A lysimeter evapotranspiration measurements at Coshocton, Ohio between 1948 and 1965 indicated a maximum annual range of 17.8 cm (USDA, 1968).



AVERAGE ANNUAL LAKE EVAPORATION

Figure 2. Average annual lake evaporation in inches (Visher and Hughes, 1969).

In open water and wetland systems in south Florida, where water is available all year round, the potential evaporation and evapotranspiration is the same as the actual evaporation and evapotranspiration for the period under consideration. Based on the literature review and the recent lysimeter measurements of wetland evapotranspiration, Figure 3 depicts assumed average ETp over the region.

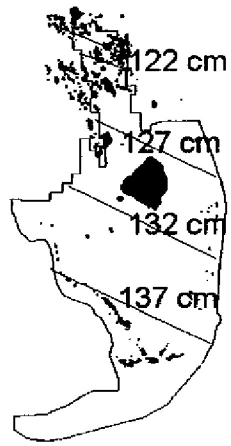


Figure 3. Estimated potential evapotranspiration isohyetal lines for the South Florida Water Management District.

Central and South Florida Hydrologic System

The water resources management area of the South Florida Water Management District extends from central Florida near Orlando in the north to the Florida Keys in the south. The area includes the Kissimmee River, Lake Okeechobee and Everglades systems. The hydrology of the area is comprised of lakes, impoundments, canals and wetlands. The major lakes are Lake Okeechobee, Lake Kissimmee and Lake Istokpoga. In the south-southeast, the Everglades Protection Area comprises the Water Conservation Areas and the Everglades National Park, which consist of expansive wetlands and impoundments. In the southwest, the Big Cypress National Preserve is a large forested wetland. The water management system comprises a large network of canals and water control structures.

South Florida Hydrometeorology

Rainfall. South Florida is a sub-tropical region that is relatively wet, warm and humid. The wet season lasts from June through October and accounts for 66 percent of the annual rainfall. The driest month is December, followed by January (Table 1). Runoff generated by wet-season rainfall and dry-season high-rainfall events is stored in ponds, lakes, impoundments, wetlands and aquifers resulting in potential evaporation and evapotranspiration over large areas. The average annual rainfall for the south Florida Water Management District area is 134 cm (Ali and Abtew, 1999).

Meteorology. The annual average air temperature is 23.1 °C with monthly average temperature increasing from 17.9 °C in January to 27.4 °C in August. The average wind speed is 3.1 m s^{-1}. The annual average relative humidity is 80.7% with annual average minimum and maximum values of 67% and 92%, respectively. The area has significant sunshine with an annual average solar radiation flux rate of 0.1908 kw m^{-2}. Table 1 depicts the monthly average meteorological parameters as computed from weather stations with varying lengths of record from 1988 to 2002. The average potential evapotranspiration is estimated based on Equation 1.

Table 1. District-wide average monthly weather parameters.

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Tmean (oC)	17.9	19.0	20.6	22.7	25.0	26.6	27.3	27.4	26.3	24.8	21.5	18.8
Tmax (oC)	23.2	23.3	24.8	25.9	27.3	28.5	29.2	29.2	28.0	27.5	25.2	23.3
Tmin (oC)	9.7	12.0	14.7	18.0	21.8	24.3	24.7	24.5	23.8	20.3	16.1	10.5
Rhmin (%)	62.8	63.9	60.9	58.3	65.2	71.6	73.1	74.3	74.3	67.1	67.0	65.9
Rhmax (%)	94.0	92.2	91.3	89.6	90.1	90.9	90.8	91.2	92.7	92.5	93.9	95.0
WS@10m (m/s)	3.22	3.42	3.66	3.56	3.18	2.73	2.53	2.53	2.69	3.18	3.31	3.11
Rs (MJ M^{-2} d^{-1})	11.87	14.62	18.14	20.44	21.40	19.43	19.15	18.58	16.06	14.69	12.34	10.91
ETp (mm/d)	2.57	3.16	3.93	4.42	4.63	4.20	4.14	4.02	3.47	3.18	2.67	2.36
Rainfall (cm)	5.59	5.99	7.45	6.55	11.84	19.94	17.73	17.86	18.36	11.99	5.84	4.83

Daily Potential Evapotranspiration Estimation

At the Everglades Nutrient Removal Project, a constructed wetland, three lysimeters were installed to measure evapotranspiration from cattail marsh, mixed vegetation marsh and open water/algae marsh (Figure 1). These lysimeters were operated from 1993 to 1995. The main part of the lysimeter system has a polyethylene tank 3.53 m in diameter and 91 cm deep with automated water level control and monitoring (Abtew and Obeysekera, 1995, Abtew, 1996b). Daily evapotranspiration was computed from the water balance. The results of the study were applied to test and calibrate six evapotranspiration estimation models: Penman-Monteith, Penman-Combination, Priestly-Taylor, Modified Turc, Radiation/Tmax method and Radiation (Simple) method. The performance of each method was compared.

The input data requirements increase from the Radiation method to the Penman-Monteith method. In south Florida, most of the variance (73%) in daily evapotranspiration is explained by solar radiation (Abtew, 1996a). The effect of humidity and wind speed is relatively minimal. A similar conclusion was reported after a two-year lysimeter study of potential evapotranspiration from St. Augustine grass in Fort Lauderdale (Stephens and Stewart, 1963). Stephens and Stewart (1963) developed a monthly potential evaporation estimation for St. Augustine grass in Fort Lauderdale from monthly average temperature and monthly solar radiation that corresponded very well with their lysimeter measured data. The following are three simpler methods: Equation 1 (Simple), Equation 2 (Modified Turc) and Equation 3 (Radiation/Tmax). These methods require only solar radiation and air temperature, and demonstrate comparable performance to the complex methods with numerous input requirements (Abtew, 1996a).

$$ET_p = K_1 \frac{Rs}{\lambda} \tag{1}$$

Where ETp is daily potential evapotranspiration (mm d^{-1}), Rs is solar radiation (MJ m^{-2} d^{-1}), λ is latent heat of vaporization (MJ kg^{-1}) and K_1 is a coefficient (0.53).

$$ET_p = K_2 \frac{(23.89Rs + 50)T\max}{T\max + 15} \tag{2}$$

Where Tmax is maximum daily temperature (°C) and K_2 is a coefficient (0.012).

$$ET_p = \frac{1}{K_3} \frac{Rs \times T\max}{\lambda} \tag{3}$$

Where K_3 is a coefficient (56°C).

There are 25 weather stations in the South Florida Water Management District monitoring network. Solar radiation, humidity, wind speed and air temperature sensors are common equipment in the weather stations. Some are equipped with net radiometers to measure net solar radiation. A computer program, ET_SF, was developed to directly access a meteorological database holding fifteen minute interval field observations and then compute potential ETp using each of the six methods (Reardon and Abtew, 2002). The program can access data from all the weather stations in the network and computes ETp for the respective site. A time series of measured and model-estimated evapotranspiration at the Everglades Nutrient Removal constructed wetland, renamed Stormwater Treatment Area 1 West, is shown in Figure 4. The average daily evapotranspiration is 3.64 mm. Average monthly weather parameters for the constructed wetland are shown in Table 2. The simple model (Equation 1) was applied to eleven weather stations that fairly represented most of the District area for 2001. The monthly average District area-wide ETp is shown in Figure 5 as computed from simple average of the stations. The yearly sum was 134.7 cm. There was a severe drought in 2000 and 2001 in central and south Florida.

Table 2. Mean monthly weather parameters at the Everglades Nutrient Removal Constructed Wetland site (1994 to 2002).

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Tmean (oC)	17.7	19.0	20.6	22.6	25.0	26.4	27.2	27.3	26.7	24.7	21.4	19.1
Tmax (oC)	25	24.3	25.8	26.9	27.2	28.2	28.9	29	28.5	27.4	25.2	23.6
Tmin (oC)	8.8	11.7	15.3	18.1	22.0	23.9	24.8	24.8	24.2	20.6	16.6	10.3
Rhmin (%)	71.1	72.7	72.7	68.8	74.5	80.1	81.2	81.4	81.3	76.4	76.8	76.5
Rhmax (%)	96.8	95.9	96.5	94.6	94.2	95.5	94.8	96	97	96.2	96.9	98
WS@10m (m/s)	3.49	3.62	3.89	3.44	2.95	2.68	2.50	2.46	2.55	3.22	3.40	3.31
Rs (MJ M^{-2} d^{-1})	12.48	14.56	18.38	20.30	22.08	19.61	19.92	18.57	15.98	15.02	12.96	11.23
ET (mm/d)	2.68	2.96	3.82	4.44	4.93	4.38	4.46	4.15	3.50	3.28	2.76	2.41
Rainfall (cm)	3.66	5.20	7.94	6.13	7.67	18.90	17.07	17.32	18.64	14.68	6.28	4.32

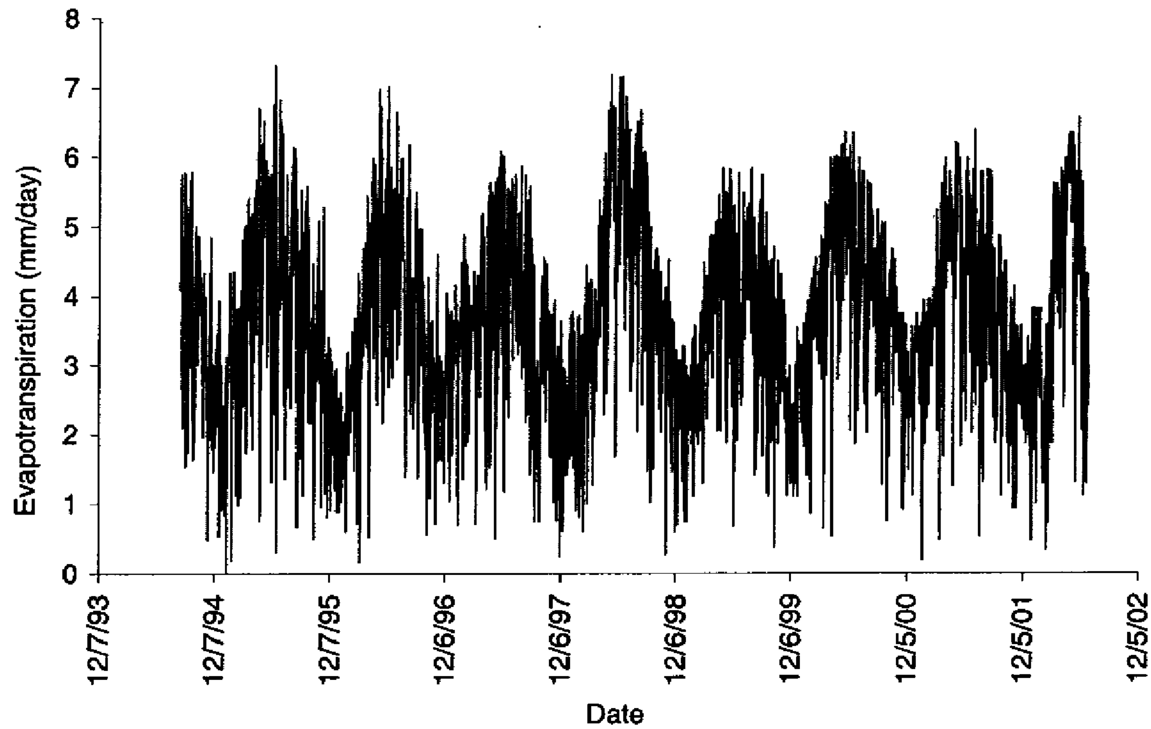


Figure 4. Daily measured and model estimated evapotranspiration at the Everglades Nutrient Removal (renamed Storm Water Treatment Area 1 West) in South Florida.

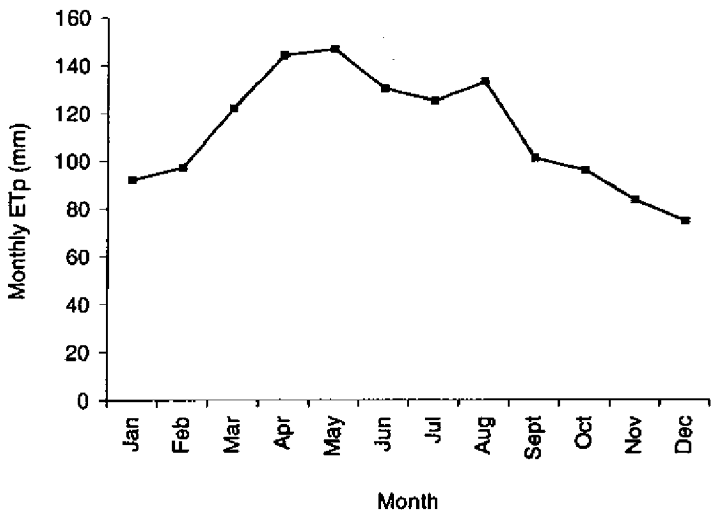


Figure 5. District-wide average potential ET for 2001.

Summary

A regional estimation of ETp for central and south Florida is provided based on cumulative information of reported evaporation and evapotranspiration measurements and estimations. General estimates of annual ETp for the South Florida Water Management District area range from 122 cm in the north to 137 cm in the south. A network of weather stations and an ETp computation software developed in-house is currently being used to develop a daily ETp database at the South Florida Water Management District. A simple ETp estimation model that was previously calibrated with lysimeter data is being applied.

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