# Appendix A – Expert Opinion Report by Dr. Jennifer Jacobs

**MEMORANDUM**

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| **To:** | Winifred Said, SFWMD Project Manager |
| **From:** | Dr. Jennifer Jacobs |
| **Date:** | May 19, 2006 |
| **Project Name:** | Alternative Methodologies for Estimation of Long Term Potential Evapotranspiration in RSM |
| **Re:** | Expert Opinion Report – Final Draft |

## 1.0 Introduction

The scope of work requests an evaluation of the approach and relative appropriateness of data sets used for alternative methodologies to estimate potential evapotranspiration (PET). It also requests a recommendation for a methodology for input into the District's Regional Simulation Model. Application of the standard method and scaling based on land use is beyond the scope of this review.

This review was conducted using documents and data provided by the SFWMD. Data and documents were used directly and the assessment is based on these materials and their findings with no attempt to systematically review the accuracy of the data and calculations or to conduct quality control exercises to vouch that it was error free.

A day long workshop was conducted on April 13th. The workshop participants from SFWMD were M. Irizzary-Ortiz, C. Pathak, W. Said, P. Trimble, and K. Tarboton. W. Abtew and J. Obeysekera participated for brief periods during the day. The SFWMD staff was knowledgeable regarding evapotranspiration and climate data. As a team, they had a comprehensive grasp of the evapotranspiration physics, climate databases, and predictive models.

## 2. 0 Requested Evaluations

### 2.1 Data Sources

The Regional Simulation Model (RSM) has two simulation periods; 1965 to 2000 and 1895 to 2005. PET must be estimated for both periods. SFWMD identified seven climate datasets identified to support PET calculations (Table 1). Three of the datasets include measured data. Four of the datasets are distributed data products that may include measured and/or modeled climate data. There are no glaring omissions in the datasets.

Unfortunately, no single dataset is ideal to calculate PET for the entire region and period.

For the 1965 to 2000 period, there are a number of data options. SFWMD has prioritized datasets that 1) can provide data over the entire period, 2) include solar radiation values, and 3) have a high spatial resolution. As documented by M. Irizarry-Ortiz, SFWMD, temperature-based methods do "not capture the statistics of the measured solar radiation

Table 1. Potential data sets for Regional PET Development based on the review conducted by P. Trimble, SFWMD. Additional information and links to documentation on potential datasets for regional PET development are provided in the HESM PET Development Workshop document dated April 13, 2006.

| **Data Set** | **Period** | **Variables** | **Model Resolution** | **Source** | **Issues** |
|---|---|---|---|---|---|
| NOAA NCDC | 1890s – present | T | Numerous Airport Locations | Measured | Only Temp. |
| Sampson | 1961-1990 | Rs, U, T, RH | 4 Coastal Locations | Measured | Short Record Only Coastal |
| SFWMD | 1990s | Rs, RN, U, T, RH | 10 – 20 Pt. Locations | Measured | Very Short Record |
| Land Data Assimilation Systems (LDAS) | Dependent on observation or assimilated data | Rs, U, T, RH | 12 km 1/8$^{th}$ degree | Data Product | Data Access Challenges Similar to HYDRO51 except Rs is temp. based |
| 51- year-Hydro (HYDRO51) | 1948-1998 Eventually to real time | Rs, U, T, RH | 12 kilometers | Data Product | Data Access Challenges 1999 and 2000 data are not currently available |
| North American Regional Reanalysis NARR | 1979-2005 | Rs, U, T, RH | 32 km | Data Product | Coarse Resolution |
| VIC Retrospective Land Surface Data Set | 1950-2000 Possibly back to the 1920s | Rs, U, T, RH | 12 km 1/8$^{th}$ degree | Data Product | Rs from Tmin and Tmax Reanalysis |

reasonably well" and "solar radiation accounts for approximately 70% of the variability in evapotranspiration in South Florida". Thus, SFWMD has spent considerable effort identifying data products that provide measured solar radiation values and comparing these values to values from the ground-based networks. The three measured datasets, NOAA NCDC, Samson, and SFWMD network, do not have solar radiation values for the entire period of record. The LDAS and VIC datasets use temperature-based methods to estimate of solar radiation.

The remaining datasets, NARR and the HYDRO51, have solar radiation data for much of the 1965 to 2000 period. Of the datasets, NARR only has data from 1979-2005 and has a relatively coarse resolution (32 km pixels). The HYDRO51 dataset has the best spatial resolution (12 km), has data from 1948-1998, and provides solar radiation from the GOES satellite for a portion of the record (P. Trimble, SFWMD). However, as the first GOES satellite was launched in 1975, additional review of the solar radiation product is recommended (http://ww2010.atmos.uiuc.edu/(Gh)/guides/rs/sat/goes/oldg.rxml). The HYDRO51 dataset appears to be the most viable.

Based on SFWMD studies, the direct application of HYDRO51 solar radiation values is not recommended. SFWMD compared HYDRO51 solar radiation data to NOAA Samson solar radiation measurements at West Palm Beach, Miami, and Daytona Beach. Their results show that the HYDRO51 solar radiation values are consistently higher than the NOAA Samson measured solar radiation. Differences were not consistent throughout the year. For West Palm Beach and Miami, the largest differences were observed in June. Relatively smaller differences were observed in July, August, and September. In addition, the variations in daily HYDRO51 values were typically smaller than those found for Samson measurements. SFWMD's proposed approach to rescale HYDRO51 solar radiation data to match monthly means and variability is reasonable. Data should be reviewed to determine if this approach results in month to month discontinuities.

P. Trimble, SFWMD, conducted a preliminary comparison of PET values from NARR, HYDRO51 and mesoscale simulations for annual and July and August values for 1973, 1989, and 1993. Both NARR and HYDRO51 significantly overestimate PET. The HYDRO51 spatial distribution appears to provide a reasonable pattern that resolves PET much better than that of the four Samson stations. The HYDRO51 distributions also agree reasonably well with independent results from the Pielke mesoscale model. The HYDRO51 annual patterns differ from July and August patterns. These results suggest that HYDRO51 can provide reasonable spatial distributions of PET, but that annual spatial patterns are inadequate to capture the seasonal variability. These findings support the direct use of HYDRO51 climate data to characterize the spatial variability of PET for the 1965-2000 period and suggest that the distributions will be a useful template for the 1895-2005 period.

The NOAA NCDC temperature dataset is recommended by SFWMD for completing PET estimates for the 1895-2005 period. Given the paucity of historical data, this is a reasonable approach. As documented by M. Irizarry-Ortiz, SFWMD, the best temperature-based method is the Hargreaves and Samani $K_r$ method. The selection of $K_r$

values to force a match an "expected north to south gradient" is not recommended. Rather, $K_r$ values should be identified using a combination of measured data and distributed spatially based on HYDRO51 solar radiation data. The Hargreaves and Samani method is also supported by Irmak et al. (2003) for Gainesville, Florida. Additionally, Irmak et al. (2003) identify an approach to combine solar radiation, estimated using the Hargreaves and Samani method, with temperature and relative humidity data to estimate net radiation.

### 2.2 PET Approaches

There are numerous methods to estimate PET. The most commonly used methods include the Penman-Monteith, the Penman, the ASCE-2000 (FAO56) reference ET, and the Priestley-Taylor methods. In addition, SFWMD has developed and applied the Simple method. Advantages of the first four methods are that they are well documented, have been through considerable peer review, and are widely recognized. Disadvantages with the first three methods are the significant data requirements including solar radiation, relative humidity, temperature, and wind speed.

The Simple method has been shown to provide reasonable estimates of annual ET for Florida marsh systems. A significant advantage of this method is that it requires only solar radiation. In the Final Peer Review Report v5.5, the panel questioned "whether use of this highly specialized, unfamiliar methodology gives more accurate results than well-known algorithms, such as the Priestley-Taylor method if it was regress against temperature and calibrated for use in the areas." Thus, two challenges to using the Simple method are knowledge regarding its accuracy and a lack of physical justification.

A series of analyses performed by M. Irizarry-Ortiz, SFWMD, showed that the Simple method provides reasonable annual estimates of PET. However, the results in Technical Paper EMA #417 by W. Abtew suggest that the simple method overestimates ET in the winter and underestimates ET in the summer. For this review, a single site analysis was conducted to compare interannual differences among methods. Measured climate data from station ENR308 for the period 4/8/94 to 10/1/2002 were used for the comparison. Daily PET values were calculated using the Simple method, the Priestley-Taylor method, and the FAO56 reference ET method. Average PET values for the period were 52.8 in, 55.2 in, and 52.6 in for the Simple method, the Priestley-Taylor method, and the FAO56 reference ET method, respectively.

Figures 1 and 2 show annual cycles of the differences among PET values predicted by several methods. Figure 1 clearly shows that the PET values from the Simple method overestimate those values predicted by the Priestley-Taylor and the FAO56 reference ET methods during the winter. Modest underestimates are shown during the summer. These results are consistent with preliminary comparisons between the Simple method and measured ET at a number of Florida stations measuring evapotranspiration (personal communication with E. Douglas, University of New Hampshire). These results support the Technical Paper EMA #417 findings. Additional reviews with NOAA climate station data are recommended to confirm this result.

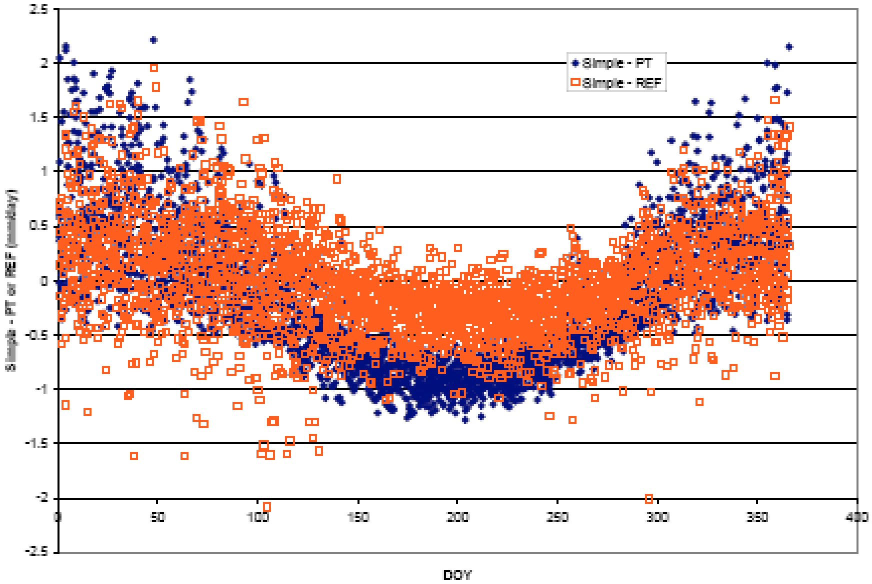


Figure 1. The difference between daily PET calculated by the Simple method and the Priestley-Taylor method (Diamonds) and the Simple method and the FAO56 reference ET method (Squares). Values were calculated using climate data for ENR308 from 4/8/94 to 10/1/2002. Data provided by M. Irizarry-Ortiz, SFWMD.

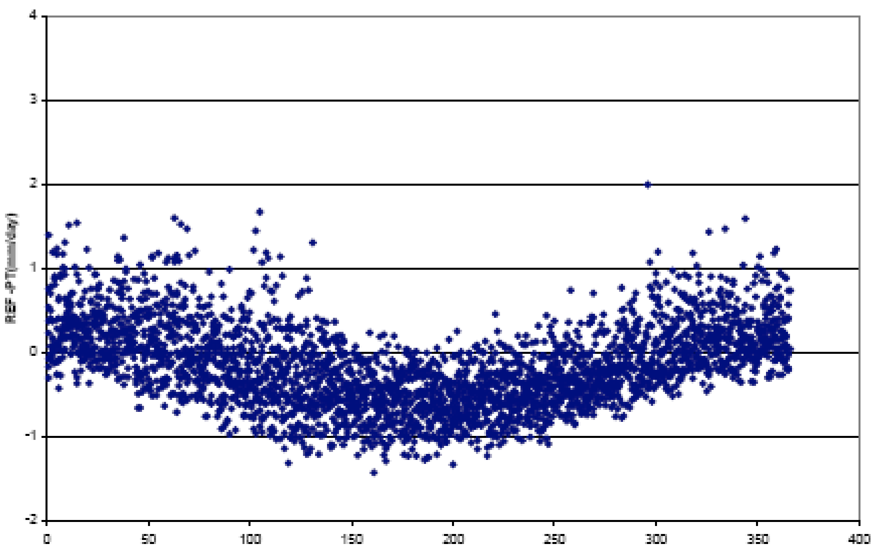


Figure 2 The difference between daily PET calculated by the FAO56 reference ET method and the Priestley-Taylor method. Values were calculated using climate data for ENR308 from 4/8/94 to 10/1/2002. Data provided by M. Irizarry-Ortiz, SFWMD.

Figure 2 indicates that there is an annual pattern to the differences between the Priestley-Taylor and FAO56 reference ET methods. The source of this annual difference is apparent when the equations are considered. Appendix A details these equations. The Penman-Monteith method is commonly referred to as a combination equation because it combines a radiation term and an aerodynamic term. The ASCE Evapotranspiration in Irrigation and Hydrology Committee's (ASCE-ET) standardized reference evapotranspiration surface is a short crop (similar to grass). Their standardized reference evapotranspiration is equation based on the Penman-Monteith equation (Walter et al., 2000). As a part of the standardization, the Penman-Monteith equation and associated equations for calculating aerodynamic and bulk surface resistance are combined and reduced to a single equation. The Priestley-Taylor method effectively assigns the aerodynamic term of the combination equation a constant percent of the radiation term and assumes no bulk surface resistance. Using calculated values of reference ET, M. Irizarry-Ortiz's results showed that the relative magnitude of the radiation and aerodynamic terms differs monthly. Thus, the Priestley-Taylor and reference method would not be expected to provide identical predictions. Figure 2 supports this finding.

The reference ET equation assumes that the weather data are measured on an actively growing grass crop that is completely shading the ground and has adequate water. A challenge to applying the reference ET equation is that climate stations rarely meet reference conditions. This deviation of the climate stations from reference conditions results in inaccurate weather data from the equation's standpoint. These values have to be adjusted to represent the reference conditions. As reviewed by Brutsaert (2005), Bouchet' (1963) hypothesis, also known as the advection aridity relationship, suggests that the effect of aridity under non-potential conditions would mainly show up in the aerodynamic term of the combination equation and not in the radiation term. Because few climate stations are maintained under reference conditions, Bouchet's hypothesis implies that a combination equation will overestimate potential ET during non-potential conditions. In Florida, these conditions are most likely to occur seasonally during the winter and under drought conditions. Thus, the PET values calculated using a reference ET or Penman-Monteith equation would be affected by non reference conditions. Because the Priestley-Taylor method is calculated based on net radiation, non reference conditions should have a limited effect on PET values calculated using the Priestley-Taylor method.

## 3.0 Recommendations

The HYDRO51 dataset rescaled to match monthly means and variability is recommended to provide a consistent dataset for the 1965 to 2000 period. This recommendation is subject to successful calculations of PET using the HYDRO51 climate data. A comparative analysis is currently being conducted. The NOAA NCDC temperature dataset is recommended for completing PET estimates for the 1895-2005 period using Hargreaves and Samani method to estimate solar radiation. If net radiation is required for PET estimates, the Irmak et al. (2003) method should be evaluated.

For daily estimates of PET, it is recommended that a standardized PET method be adopted to replace the Simple method. Because the Simple method has been shown to consistently provide reasonable estimates of annual PET in the District, it could be used to verify the annual PET estimates from a selected standardized method. There are two viable candidates for a standardized PET method. The first is the reference ET method and the second is the Priestley-Taylor method. The reference ET method has the advantages of a long history, being a peer-reviewed tool, and offering a wide arrange of crop and vegetation coefficients to predict PET for specific land uses. However, the method requires significant climate data that are not available for much of the period of record. These could be estimated using historical mean values or determined from measured values. The Priestley-Taylor method also has a long history, is recognized as a standard method, has been successfully used to model measured evapotranspiration in Florida, and requires limited data input. However, it does not account for wind speed and atmospheric water vapor pressure differences among sites. Exploration with measured datasets would provide insight to which method best reflects measured PET. Without results from such comparisons, a definitive statement as to which method better estimates PET is not possible.

The Regional Simulation Model's application to natural systems from 1895 to 2005 suggests the need for a consistent means to estimate PET throughout the period. In addition, the impact of non reference surface conditions at climate stations should be considered. The Priestley-Taylor method has fewer data requirements and is considered less sensitive to non reference conditions. The Priestley-Taylor method is recommended to meet SFWMD's long-term modeling objective.

**References**


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## Appendix A
## Standardize Potential Evapotranspiration Equations

The Penman-Monteith model is an extension of the Penman equations that allows the equation to be applied to a range of surface vegetation through the introduction of plant specific resistance factors. and is given as

$$\lambda \rho_w ET_o = \frac{\Delta (R_n - G) + \rho_a c_p (e_s - e_d)/r_a}{\Delta + \gamma (1 + r_s/r_a)}$$

where $ET_o$ is the potential evapotranspiration (mm day$^{-1}$), $\lambda$ the latent heat of vaporization (J g$^{-1}$), $\rho_w$ the density of water (g m$^{-3}$), $\Delta$ the slope of the saturation vapor pressure temperature curve, $\gamma$ the psychrometric constant, $R_n$ the net radiation (W m$^{-2}$), G the soil heat flux (W m$^{-2}$), $e_s - e_d$ the vapor pressure deficit of the air (mb), $e_s$ the saturation vapor pressure of the air (mb), $e_d$ the actual vapor pressure of the air (mb), $\rho_a$ is the mean air density at constant pressure, $c_p$ the specific heat of air, $r_s$ the bulk surface resistance, and $r_a$ the aerodynamic resistances. The aerodynamic resistance will estimated using Monin-Obukhov similarity and assuming neutral conditions by

$$r_a = \frac{\ln[(z-d)/z_o]\ln[(z-d)/z_{ov}]}{k^2 u}$$

where u is the wind speed at 2 m, z the height at which the wind speed u was measured, d the displacement height estimated to be $0.67z_{veg}$, $z_{veg}$ the vegetation height, $z_o$ the roughness height for momentum was approximated as $0.1z_{veg}$, $z_{ov}$ is the roughness height for water vapor and was approximated as $0.1z_o$ and k is the Von Karmen's constant (0.4).

An ASCE Evapotranspiration in Irrigation and Hydrology Committee (ASCE-ET) recommended standardized reference evapotranspiration surface is a short crop (similar to grass) and their standardized reference evapotranspiration is equation based on the Penman-Monteith equation (Walter et al., 2000). As a part of the standardization, the "full" form of the Penman-Monteith equation and associated equations for calculating aerodynamic and bulk surface resistance are combined and reduced to a single equation. The FAO 1998 Penman-Monteith method to estimate $ET_o$ is given by

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T + 273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)}$$

where $ET_o$ is the reference evapotranspiration, *mm day$^{-1}$*.

The Priestley-Taylor method uses the concept of the theoretical lower limit of evaporation from a wet surface as the "equilibrium" evaporation to estimate PET. Here where

$$\lambda \rho_w ET_{PT} = \alpha \frac{\Delta}{\Delta + \gamma}(R_n - G)$$

where $ET_{PT}$ is the potential evapotranspiration (mm $day^{-1}$), $\lambda$ the latent heat of vaporization (J $g^{-1}$), $\rho_w$ the density of water (g $m^{-3}$), $\alpha = 1$, $\Delta$ the slope of the saturation vapor pressure temperature curve, $\gamma$ the psychrometric constant, $R_n$ the net radiation (W $m^{-2}$), and G the soil heat flux (W $m^{-2}$).

Equilibrium conditions reflect evaporation from a wet surface under conditions of minimum advection that result in the actual vapor pressure of the air approaching the saturation vapor pressure. Priestly and Taylor (1972) showed that for conditions of minimum advection with no edge effects, $\alpha = 1.26$.