Technical Memorandum
WRE # 367

Evapotranspiration Estimations for Wetland and Shallow Open-Water Systems in South Florida:
Documentation for C Program etcals

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EXECUTIVE SUMMARY

Large scale constructed wetlands have been implemented for phosphorus load reductions in agricultural drainage and runoff systems. Several studies are currently in progress on these systems at the South Florida Water Management District. Water budget analyses are a major component in describing these wetland systems and their performance. Evapotranspiration estimates are an integral part of the water budget analyses.

This document describes use and background information for the C program etcalc, a numerical program that estimates evapotranspiration rates from cattail and mixed marsh wetlands and shallow open water systems. The program is not intended for use on forested wetlands. The program was developed at the South Florida Water Management District to automate ET estimations for wetland systems using three estimation methods; the Penman-Monteith model, the Penman-Combination model, and a simple equation that estimates daily ET from solar radiation. The program is intended for evapotranspiration estimates typical of weather conditions in South Florida. Program input requirements are described, as well as evapotranspiration estimates using two weather stations located in a constructed wetland. The three evapotranspiration models used by the program are documented and explained. Although the program is an interactive routine, it is recommended that users read this document to explain assumptions and subtle details that were developed for these numerical estimation procedures.
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LIST OF SYMBOLS

Parameters required as inputs to etcalc:

\( \text{Rh}_{\text{min}} = \) minimum daily relative humidity, %
\( \text{Rh}_{\text{max}} = \) maximum daily relative humidity, %
\( T_{\text{min}} = \) minimum daily air temperature, °C
\( T_{\text{max}} = \) maximum daily air temperature, °C
\( T_{\text{avea}} = \) average daily air temperature, °C
\( T_{\text{avch}} = \) average daily water temperature, °C
\( P_{\text{ave}} = \) average daily atmospheric pressure, mm-Hg
\( R_t = \) total daily radiation, kW m\(^{-2}\)
\( R_n = \) net daily radiation, kW m\(^{-2}\)
\( W_{10} = \) average daily wind speed at 10 m height, mph
\( H = \) height of vegetation, m
\( F_c = \) fraction of vegetative cover, dimensionless
\( \text{JD} = \) day of year

Parameters calculated by, or defined within, etcalc:

\( k = \) coefficient to account for variation in type of surface cover
\( \text{ET} = \) evapotranspiration, mm d\(^{-1}\)
\( \rho_{\text{air}} = \) atmospheric density, kg m\(^{-3}\)
\( C_p = \) specific heat of moist air, kJ kg\(^{-1}\)°C\(^{-1}\)
\( W_2 = \) adjusted windspeed at 2 m height, m s\(^{-1}\)
\( G = \) water heat flux, MJ m\(^{-2}\) d\(^{-1}\)
\( ea \) = daily saturation vapor pressure, kPa
\( ea_{\text{max}} \) = daily saturation vapor pressure (based on \( T_{\text{max}} \)), kPa
\( ea_{\text{min}} \) = daily saturation vapor pressure (based on \( T_{\text{min}} \)), kPa
\( ed \) = daily vapor pressure, kPa
\( vpd \) = daily vapor pressure deficit, kPa
\( r_a \) = aerodynamic resistance, s m\(^{-1}\)
\( r_c \) = canopy resistance, s m\(^{-1}\)
\( d \) = displacement height, m
\( z_o \) = aerodynamic roughness, m
\( z_{\text{oh}} \) = roughness length for heat and vapor transfer, m
\( a_w, b_w \) = empirical coefficients, dimensions account for units
\( \Delta \) = slope of vapor pressure curve, kPa \(^{\circ}\)C\(^{-1}\)
\( \lambda \) = latent heat of vaporization, MJ kg\(^{-1}\)
\( \gamma \) = psychometric constant, kPa \(^{\circ}\)C\(^{-1}\)
\( \kappa \) = von Karman constant for turbulent diffusion
INTRODUCTION

Evapotranspiration estimates for open water and aquatic vegetation wetland systems are one of the components used to estimate and predict hydrologic mass balances. Several equations have been developed that can predict evapotranspiration (ET) estimates for different surfaces (Jensen et al., 1990; Maidment, 1993). Prior research on the use of these equations for quantifying ET of constructed wetland systems has been discussed (Abtew, 1996; Abtew and Mullen, 1997; Abtew and Obeysekera, 1995). Generally, ET estimates are made based on daily maximums, minimums, and averages of weather parameters. These parameters include temperature, pressure, relative humidity, windspeed, and solar radiation.

Currently, ET estimates for the Everglades Nutrient Removal (ENR) Project are made from combining multiple output files, containing measured daily weather parameters, into a spreadsheet for daily calculations. Estimates of ET are then reported in tabular or graphical format. The equations used to estimate ET reported in this document are described in detail with respect to their defining variables and constants. The plant communities within the ENR project consisted of natural cattails, mixed marsh, and an open water/algae system. The mixed marsh community included Spikerush (Eleocharis spp.), Pickerel weed (Pontederia cordata), Arrowhead (Sagitteria latifolia), Duckpotato (Sagitteria lancifolia), Maidencane (Panicum hemitomon), and Sawgrass (Caladium jamaicense) (Abtew, 1996). The open water/algae system consisted of an open water periphyton/submerged macrophyte community (Abtew, 1996).

This document describes a numerical estimation procedure written to predict ENR Project ET rates from weather station data using several common ET equations. The equations used are the Penman-Combination, the Penman-Monteith, and a simple equation that estimates daily ET from solar radiation. Program inputs, outputs, and user interactive options are explained. The program was written in C language on a Unix workstation, running SOLARIS 3.5.1, at the South Florida Water Management District (District).
EVAPOTRANSPIRATION MODELS

Simple Evapotranspiration Model

The simplest model to estimate ET rates in South Florida uses daily total radiation. The model used in the numerical estimation routine is (Abtew, 1996):

\[ ET = \frac{k R_s}{\lambda} \]

where,

- \( ET \) = evapotranspiration, mm d^{-1},
- \( k \) = coefficient to account for variation in wetland surface type,
- \( R_s \) = solar radiation, MJ m^{-2} d^{-1},
- \( \lambda \) = latent heat of vaporization, MJ kg^{-1}.

Estimates for \( k \) are 0.54 for cattail, 0.52 for mixed marsh, and 0.53 for open water/algae wetland systems (Abtew, 1996).

Solar radiation is recorded in units of kW m^{-2} in the District database (DBHYDRO). Conversion to MJ m^{-2} d^{-1} is straightforward by multiplying by 86.4 (kW to MJ d^{-1}). This procedure is carried out internally in the numerical program.

Latent heat of vaporization is the energy absorbed during the separation of water molecules (Maidment, 1993). The equation used to estimate this parameter is:

\[ \lambda = 2.501 - (0.002361 \times T_{aveh}) \]

where the constant 2.501 is the energy in MJ required to evaporate 1 kg of water, 0.002361 is a constant (MJ kg^{-1} °C^{-1}) that enables the \( \lambda \) equation to approximate standard steam tables (viz., Jensen et al., 1990), and \( T_{aveh} \) is the average surface temperature of water (°C). Often, water temperature is not available and air temperature is used to calculate latent heat of vaporization.

Penman-Monteith Evapotranspiration Model

The equation for evapotranspiration estimates for wetlands with the predominant vegetation as cattails or mixed marsh was developed in Abtew, (1996):
The term \( r_c \) is canopy resistance (s m\(^{-1}\)), and for cattail the average canopy resistance estimate is 90 (s m\(^{-1}\)), while for mixed marsh conditions, average canopy resistance estimate is 70 (s m\(^{-1}\)). These constants are set internally in the numerical program. The user is prompted for acceptance of these parameters and can change the \( r_c \) values if desired. Aerodynamic resistance \((r_a)\) is calculated as:

\[
r_a = \frac{\ln\left(\frac{z_{10} - d}{z_o}\right) \ln\left(\frac{z_2 - d}{z_{oh}}\right)}{\left(\kappa^2 W_2 0.447\right)}
\]

where,

- \( z_{10} \) = wind speed measurement height (10 m), m,
- \( d \) = displacement height, m,
- \( z_o \) = aerodynamic roughness, m,
- \( z_2 \) = air temperature and humidity measurement height (2 m), m,
- \( z_{oh} \) = roughness length for heat and vapor transfer (0.1 \( z_o \)), m,
- \( \kappa \) = von Karmen constant for turbulent diffusion (0.41), and
- \( W_2 \) = adjusted windspeed, at height \( z_2 \), over the study site, m s\(^{-1}\) (Smith, 1991).

Note that,

\[
d = 0.85 F_c H
\]

where,

- \( F_c \) = fraction of vegetation cover, dimensionless,
- \( H \) = average height of vegetation stand, m, and
- \( z_o \) = 0.13*(H-d)
Also,

\[
W_2 = W_{10} \frac{\ln \left( \frac{z_2 - d}{z_0} \right)}{\ln \left( \frac{z_{10} - d}{z_0} \right)}
\]  

(7)

where,

\[ W_{10} = \text{measured windspeed at height } z_{10}, \text{ m s}^{-1}. \]

Windspeed is generally recorded in units of miles per hour and conversion to m s\(^{-1}\) is straightforward with the numerical factor 0.447. This calculation is done internally in the numerical program. All other variables in the aerodynamic resistance equation are obtained empirically, as described in Abtew (1996), Abtew and Obeysekera (1995), and Smith (1991).

The \( \gamma \) term in the Penman-Monteith equation represents a psychometric constant, in units of kPa °C\(^{-1}\). The equation describing this term (Maidment, 1993) is,

\[
\gamma = \frac{C_p \cdot P_{ave} \cdot 0.001}{0.622 \cdot \lambda}
\]

(8)

where,

\[ C_p \] is the specific heat of moist air (1.013 kJ kg\(^{-1}\) °C\(^{-1}\)), \( P_{ave} \) is the average daily pressure (kPa), 0.001 is a proportionality constant (dimensionless), and 0.622 is the ratio of the molecular weight of water to that for dry air. Recall that the \( \lambda \) term was defined earlier. Note that pressure is recorded in units of mm Hg and conversion to kPa is done internally in the numerical program.

The \( ea \) term in equation 3 represents daily saturation vapor pressure (kPa) and is represented as (Abtew and Obeysekera, 1995):

\[
ea = \frac{1}{2}(e_{a_{max}} + e_{a_{min}})
\]

(9)

where,

\[
e_{a_{max}} = 0.611 \cdot \exp \left( \frac{17.27 \cdot T_{max}}{T_{max} + 237.3} \right)
\]

(10)

and

\[
e_{a_{min}} = 0.611 \cdot \exp \left( \frac{17.27 \cdot T_{min}}{T_{min} + 237.3} \right)
\]

(11)

\( T_{max} \) and \( T_{min} \) are respectively, daily maximum and minimum air temperature in °C.
The ed term in equation 3 represents the daily vapor pressure in kPa. Abtew and Obeysekera (1995) estimate this parameter as:

\[ ed = (0.5 \times e_{a_{max}} \times R_{h_{min}}/100) + (0.5 \times e_{a_{min}} \times R_{h_{max}}/100) \]  

(12)

where,

R_{h_{min}} and R_{h_{max}} respectively represent daily minimum and maximum percent relative humidity.

The C_p term represents the specific heat of moist air, as mentioned earlier, but is estimated using the equation defined for \( \gamma \). This is due to the embedded term \( \lambda \), which, as shown earlier, is estimated using daily average water temperature. Therefore, the C_p term is calculated on a daily basis.

The atmospheric density term, \( \rho_{atm} \) (kg/m³), is represented by the ideal gas law, which, upon simplification (Smith, 1991) becomes:

\[ \rho_{atm} = \frac{3.486 \times P_{ave}}{1.01 \times (T_{ave} + 273)} \]  

(13)

where,

P_{ave} and T_{ave} respectively represent average daily air pressure (kPa) and average daily air temperature (°C). The term \( 1.01 \times (T_{ave} + 273) \) converts temperature in °C to virtual temperature to account for the units embedded in the specific gas constant (shown as \( 1000/(287 \text{ J kg}^{-1} \text{ K}^{-1}) \)).

The G term in equation 3 represents water heat flux (kW m²), and is represented as:

\[ G = 4.18 \times d_w \times (T_{aveh(i)} - T_{aveh(i-1)}) \]  

(14)

where,

T_{aveh(i)} corresponds to average daily water temperature and T_{aveh(i-1)} corresponds to the previous day's average daily water temperature. The constant 4.18 represents water heat flux (MJ m⁻² °C⁻¹) and d_w represents depth of water (m). For numerical estimations, the G value is zero for the first day of ET calculations.

For weather stations without water temperature, air temperature measurements at 2 m height can be substituted for T_{aveh} in equation 14. In the case where air temperature is substituted for water temperature, d_w is multiplied by a factor of 0.844. The calculation for water depth in the absence of water temperature measurements was made by assuming the water heat flux (G) was equivalent for both water temperature results and air temperature results for stations ENR105 and ENR308. The result (an adjusted d_w value) is internal to the numerical program, however, the user is prompted to indicate whether air temperatures were used in lieu of water temperatures.
The $R_a$ variable represented in equation 3 is the net incoming radiation flux measured at the surface. This parameter is measured in units of kW m$^{-2}$ and conversion to MJ m$^{-2}$ d$^{-1}$ was described previously.

The last variable to consider in equation 3, $\Delta$, represents the slope of the vapor pressure curve, also in units of kPa °C$^{-1}$. This variable was described by Maidment (1993) as the gradient of the $e_a$ term, that is:

$$\Delta = \frac{d(e_a)}{dT} = \frac{4098 e_a}{(237.3 + T_{\text{avea}})^2}$$

where, $e_a$ was defined earlier and $T_{\text{avea}}$ is the average daily air temperature.

**Penman Combination Evapotranspiration Model**

Evapotranspiration estimates for open water/algae wetlands used in the numerical estimation routine is obtained from (Abtew, 1996):

$$ET = \left[ \frac{\Delta (R_a - G) + \gamma 6.43 (a_w + b_w W_{w2}) (e_a - e_d)}{\Delta + \gamma} \right] \left( \frac{1}{\lambda} \right)$$

The terms $\lambda$, $\Delta$, $R_a$, $G$, $\gamma$, $W_{w2}$, $e_a$, and $e_d$ were defined previously. The remaining terms $a_w$ and $b_w$ are empirical constants represented as (Abtew and Obeysekera, 1995):

$$a_w = 0.1 + 3.0 \times \exp\left[-\left((\text{JD}-173)/58\right)^2\right]$$

and

$$b_w = 0.04 + 0.2 \times \exp\left[-\left((\text{JD}-243)/80\right)^2\right]$$

where,

$$\text{JD} = \text{day of year}.$$
NUMERICAL ESTIMATIONS

Estimations of evapotranspiration were made using daily values of air temperature, water temperature, relative humidity, air pressure, windspeed, total radiation, and net radiation. These measured weather parameters can be obtained from the District database as average daily values, maximum daily values, or minimum daily values. The numerical routine described in this report required daily output for the above parameters from the Internal Value Generator (IVG) program available on District workstations (viz., runivg). A description of input and output requirements for the IVG program is available through the District.

In addition to the weather parameters used in the numerical estimation routine, several other parameters are required a priori to executing the program. These include height of vegetation (H), fraction of vegetation cover (Fv), and ending date for the period under analysis.

The numerical routine to estimate evapotranspiration, based on the above mathematical models, was written in C language. A copy of the program is given in Appendix A. The program prompts the user for several options that are described below. A copy of the program prompts and response examples (in italicized bold type-face) are given in Appendix B for two test cases described below.

The program requires the user to have downloaded, from IVG, the following weather station parameters: Tavf, Tma, Tmj, Tmn, Rhrfn, Rhrn, P.Wi, Rn, Rt, and Wsave (R and R are average daily values). An example of the output downloaded by the IVG program is given in Table 1 for daily average air pressure. The numerical program, etcalcs, requires that the parameters be in this format, and that the names of files representing these parameters are equivalent to the names shown in Table 2. That is, AT corresponds to air temperature, MIN to daily minimum, MAX to daily maximum, and AVE to daily average. AP corresponds to air pressure, TO to water temperature, RH to relative humidity, NR to net daily radiation, RT to total daily radiation, and WS to windspeed. Any missing values from the downloaded IVG results should be estimated using the nearest weather station with valid data. Additionally, tagged numerical entries (for example, E, L, or M) should be removed prior to running the numerical estimation program.

The ENR105 and ENR308 names correspond to the weather stations reporting the values. The program requires that the station name be six characters. The program also requires that the file names be in a generic input file less than 32 characters in length, including file extension. The numerical value 10 must be the first line within the input file. Note that the program is case sensitive and the file names do not have to be in the order depicted in Table 2. However, the first ten files should be representative of weather station parameters for cattail and the second ten files representative of mixed marsh and open water conditions.
### Table 1. Example of average atmospheric pressure values downloaded from IVG.

<table>
<thead>
<tr>
<th>Date Time 1</th>
<th>Date Time 2</th>
<th>Pressure (hPa)</th>
</tr>
</thead>
<tbody>
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<td>199612010000</td>
<td>199612020000</td>
<td>763.328</td>
</tr>
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<tr>
<td>199612180000</td>
<td>199612190000</td>
<td>762.749</td>
</tr>
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</table>

### Table 2. Weather parameter files listed in input file required as inputs to etcalc.

10
ENR105AT.MIN
ENR105AT.MAX
ENR105AT.AVE
ENR105AP.AVE
ENR105TO.AVE
ENR105RH.MIN
ENR105RH.MAX
ENR105NR.AVE
ENR105RT.AVE
ENR105WS.AVE
ENR308AT.MIN
ENR308AT.MAX
ENR308AT.AVE
ENR308AP.AVE
ENR308TO.AVE
ENR308RH.MIN
ENR308RH.MAX
ENR308NR.AVE
ENR308RT.AVE
ENR308WS.AVE
The program assumes that there will be 20 files named within the *input file*. That is, this program was written to estimate ET rates for three wetland conditions. The first ten files (ENR105AA.BBB) contain weather parameters used to estimate ET from cattail wetlands, while the second ten files (ENR308AA.BBB) contain parameters used to estimate ET from mixed marsh and open water/algae wetlands. If one has access to data from only one weather station, then the second ten file names in the *input file* should be somewhat different, but representative of the first ten file names. That is, the program writes ET rates to an output file called, for example, ENR105.out. This output represents ET rates for cattail conditions, while ENR308.out represents ET rates corresponding to mixed marsh and open water/algae systems.

There are several other options and prompts the user must answer during execution. The user must choose to do either, simple ET calculations for each of the three wetland types based on the constant k (described earlier), or simple and complex ET calculations for each of the three wetland types. The user is also prompted for height and fraction of vegetation cover for both cattail and mixed marsh systems. The user has the option to select output as mm d\(^{-1}\) or in d\(^{-1}\). Input weather parameters to the numerical estimation routine may be output in a spreadsheet type format for checking calculations.

During the discussion for the simple ET calculation, it was mentioned that the average daily water temperature is a required input. If this file is non-existent, that is, no water temperature data exists for the site, then the average daily air temperature file should be copied into a file with the average daily water temperature name. The user is prompted for this condition prior to numerical calculations. The final input required from the user is the ending date for the analysis. This date is obtained from any one of the input files listed in the *input file* and must be input as yyyymmd.

Examples of results from executing etcalc are given in Table 3. The results were produced using data from weather stations ENR105 and ENR308. ET output from the numerical program was compared to spreadsheet results for the period 1 December 1996 through 19 August 1997. Results for the last month in this time period are shown to provide users with expected output. Minimal differences exist between spreadsheet calculations and numerical estimates from the C program. These discrepancies are due to numerical round-off error since the respective applications use numbers with different significant digits during calculations.

Appendix C lists information for active weather stations within the District. If data for daily net radiation do not exist for a particular site, the user may contact the author of this document for another program used to estimate this parameter from total solar radiation.
Table 3. Comparison of numerical and spreadsheet results for ET calculations using the Penman-Monteith (cattail and mixed marsh) and Penman-Combination (open water) models.

<table>
<thead>
<tr>
<th>Year</th>
<th>J day</th>
<th>Numerical Simulation</th>
<th>Spreadsheet Calculation</th>
<th>Percent Difference</th>
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<td>Cattail</td>
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*Percent difference was reported to the nearest integer and assumed spreadsheet value as "true" value.
SUMMARY

This document has presented several common equations used in an applied numerical routine to estimate evapotranspiration. The equations estimate ET from cattail, mixed marsh and open water/algae wetlands, typical of the weather conditions in South Florida. Documentation has been provided detailing the parameters, constants, and conversions required to estimate ET from these unique systems using the Penman-Combination, Penman-Monteith, and a simple equation that calculates ET from daily solar radiation.

The numerical application routine processes multiple weather data files downloaded from the District database. These weather parameter files contain the required inputs necessary to estimate ET. Knowledge of system characteristics such as height and vegetative cover must be known prior to running the numerical application. ET estimation results based on the ENR Project weather stations were compared with the current estimation procedure using spreadsheet calculations. Minimal differences were observed, and are due to numerical round-off error.

Access to the executable program for estimating ET for cattail, mixed marsh, and open water/algae systems, typical of South Florida and associated weather conditions can be obtained from the /home/rad/ddowney/etcalculation directory on District workstations. Access on personal computers can be obtained through the Home_rad on B50home2 (H:) location, under the directory ddowney/etcalculation. The examples directory in this location contains the input files used in this report.
REFERENCES


//program written by ddowney 27 may 1998 program used to calculate ET for the cattail,
//mixed marsh, and open water/algae surface areas set parameters et al

main(void){
    char names1[32], names2[32], outfile1[32], outfile2[32];
    char exch[2], yy[4], dd[3], mm[3], lin0[17], lin1[17], lin2[17], lin3[17], lin4[17];;
    char dailydata[32] = "weather.dat";
    int ef, t, kchk, eff, i, j, k, dcalc, dfig, opt, opt1, opt2, opt3, opt4, noyrs;
    int yr[400], mo[400], da[400], jday, leap, day1, day2, daychk, endmo, endda, mochk;
    float tmax[4000], tmin[4000], tavea[4000], taveh[4000], pmin[4000], pmax[4000];
    float a, p[4000];
    float rhmin[4000], rhmax[4000], rhave[4000], rtave[4000], wsave[4000];
    float hitec, hitem, fcc, fcm, rc1, rc2, k1a, k1b, k1c, lambda, gval, atmho, cp, gamma, vpd;
    float rac, ram, zoc, zom, de, dm, ws2c, ws2m;
    float delta, aw, bw, tad1, ea1, ea2, ea, ed, etsim[4000], etsimb[4000], etcimc[4000];
    float etcat[4000], etmix[4000], etope[4000];
    FILE fptr1, fptr2, fptr3, fptr4;
    //print to screen preliminary indications for file usage et al...
    printf("n\n\n\nC PROGRAM: etcales, Version Ln\n\nWritten by D. Downey, July 1998\n\nHydrologic Reporting Unit\n\nResource Assessment Division\n\nWater Resources Evaluation Department\n\nThis program calculates daily ET rates for cattail, mixed marsh\n\nMaximum time period for daily ET calculations is 10 years\n\nNOTE: THIS PROGRAM IS CASE SENSITIVE.\n\nIT IS RECOMMENDED THAT THE USER READ THE ACCOMPANYING\nDOCUMENTATION\n\nThis program prompts the user for an input file, up to 32 characters\nlength, located in the current directory, containing the file names\n\\n\nThe first line of the input should contain a numerical value\n\nCorresponding to the number of input files located in this file\n\nThis program prompts the user for H (height) and Fc (vegetative cover)\nvalues.\n\nPress c to continue, x to exit\n\nif(exch[0] == 'x') exit(-1); if(exch[0] == 'c') ef = -1; }while(ef != -1); ef = 1;
//prompt the user for the input file name containing file names
//open input file containing parmeter input file names
printf("Enter filename containing weather parameter filenames\n\n");
scanf(s, names1); if((fptrl = fopen(names1, "r")) == NULL)
{ do { printf("Can not find input file %s", names1); printf("... Press x to exit\n");
scanf(s, exch); if(exch[0] == 'x') exit(-1); } while(1); }
//prompt user for simple calculations or all three calculations.
printf("Select one of two options:\n");
printf("simple ET calculations for all three scenarios = 1\n");
printf("simple and advanced ET calculations for all three scenarios = 2\n");
ef = 1; do { printf("Enter calculation option 1 or 2:\n");
scanf(d, opt);
if(opt == 1) ef = -1; if(opt == 2) ef = -1; } while(ef != -1); ef = 1;
//prompt user for unit output as in/d or mm/d
printf("Select one of two options:\n");
printf("output as in/d = 1\n");
printf("output as mm/d = 2\n");
ef = 1; do { printf("Enter output option 1 or 2:\n");
scanf(d, opt1);
if(opt1 == 1) ef = -1; if(opt1 == 2) ef = -1; } while(ef != -1); ef = 1;
//read in data
if(opt == 2) {
printf("Enter numerical height, H, for cattail stand:\n\n");
scanf(f, hitec);
printf("Enter numerical constant, Fc, for cattail land coverage:\n\n");
scanf(f, fcc);
printf("Enter numerical height, H, for mixed marsh stand:\n\n");
scanf(f, hitem);
printf("Enter numerical constant, Fc, for mixed marsh land coverage:\n\n");
scanf(f, fcm);
printf("The following constants will be assumed:\n\n");
printf("k1 = 0.54, 0.52, 0.53 for cattails, mixed marsh, or open water/algae,\n\n");
printf("respectively, and rc = 90 for cattails, rc = 70 for mixed marsh.\n\n");}
rc1 = 90.0; rc2 = 70.0; do {
printf("Enter 1 if rc values are acceptable, otherwise enter 2 to change them\n");
scanf(d, opt3); if(opt3 == 1) ef = -1; if(opt3 == 2) {
printf("Enter rc value for cattails\n\n");
scanf(f, rc1);
printf("Enter rc value for mixed marsh\n\n");
scanf(f, rc2); ef = -1;
printf("Mrc for cattails = %5.2f, rc for mixed marsh = %5.2f\n\n", rc1, rc2); }
} while(ef != -1); ef = 1;
printf("Select one of two options:\n");
printf("daily listing of weather parameters used in calculations = 1\n");
printf("no listing of daily weather parameters = 2\n");
do { printf("Enter daily weather output option 1 or 2\n");
scanf(d, opt2);
if(opt2 == 1) ef = -1; if(opt2 == 2) ef = -1; } while(ef != -1); ef = 1;
printf("Select one of two options:\n");
printf("Water temperature file contains water temperatures = 1\n");
printf("Water temperature file contains air temperatures = 2\n");
do{ printf("Enter numerical value 1 or 2 pertaining to water temperature file:\n"); scanf(d, opt4); if(opt4 == 1) ef = -1; if(opt4 == 2) ef = -1; } while(ef != -1); ef = 1; if(opt == 1) { hitec = 0.0; fcc = 0.0; hitem = 0.0; fcm = 0.0; } printf("Enter ending date for current analysis as yyyymmdd\n"); scanf(s, lin0); printf("\n"); //set exit limits based on ending date for analysis for(i=4; i<6; i++) mm[i-4] = lin0[i]; mm[2] = '0'; endmo = atoi(mm); endda = atoi(dd); j = 0; i = 0; ef = 0;
//read in number of files to process and parameter input file names do{ fscanf(fptr1, d, dcalc); fscanf(fptr1, f, names2); printf("Reading input parameters from %s\n", names2); if((fptr2 = fopen(names2, "r")== NULL)) { do{ printf("Can not find input file %skn", names2); printf("...Press x to exit\n\n"); scanf(s, exch); if(exch[0] != 'x') exit(-1); } while(1); } } while(ef != -1); ef = 0; fclose(fptr2);
//name the output file based on the current input file for(i=0; i<6; i++) outfile[i] = names2[i]; outfile[6] = "; outfile[7] = 'o'; outfile[8] = 'u'; outfile[9] = 't'; printf("Begin ET Processing\n\n"); fptr3 = fopen(outfile1, "w"); if(opt == 1) { fprintf(fptr3, "Year\tJ. day\tET Simple-Cattail\n"); fprintf(fptr3, "Year\tJ. day\tTmax\tTmin\tPave\tRhmin\tRhmax\tRnave\tRtave\tWsave\n"); fprintf(fptr4, "Year\tJ. day\tTmax\tTmin\tTave\tPave\tRhmin\tRhmax\tRnave\tRtave\tWsave\n"); ef = 0; i = 0; j = 0; k1a = 0.54; k1b = 0.52; k1c = 0.53; day1 = 0; do{ if((mo[j] == endmo) && (da[j] == endda)) { ef = -1; dfig = 1; }
jday 273 +
mm[k-4]

do{ fscanf(fptr1, //perform
tadl = taveh[j]; j = j + 1; }if(leap == 1) { if(mo[j] == 1) jday = da[j]; else if(mo[j] == 8)
if(opt4 == 1) { if(f[j] == 0) gval = 0; else gval = 4.18*0.14*(taveh[j] - tad1); }if(opt4 == 2) { if(f[j] == 0) gval = 0; else gval = 4.18*0.118153*(taveh[j] + 237.3)*delta/1000; rmax[j] = 2.501 - (0.002398*fmax[j]*taveh[j]); if((ef != -1) && (dflg == 1)) { fprint(fp3, "%.16f\n", yr[j], dal[0], etca[j]); if(opt4 == 2) { fprintf(fp4, ",%.16f,%.16f,%.16f,\n", yr[j], rmax[j], dal[0], etca[j]); }

// determine year month day arrays only in the first file...for(k=0; k<4; k++) yy[k] = lin3[k]; yy[4] = '0'; yr[j] = atoi(yy); for(k=4; k<6; k++) dd[k-4] = lin3[k];
taveh[j] = a;
}
    rhave[j] = a;
}
    wsave[j] = a;
}

//set constants for equations...
pave[j] = 0.1333*paveU[j]; rtave[j] = 24.0*3.6*pave[j]; if(opt1 == 2)
    rhave[j] = 0.002361*taveb[j];

//set julian day counter
if((yr[j] % 4 == 0 && yr[j] % 100 != 0) || (yr[j] % 400 == 0)) leap = 1; else leap = 0;
if(leap == 0) { if(mo[j] == 1) jday = da[j]; else if(mo[j] == 2) jday = 31 + da[j];
else if(mo[j] == 3) jday = 59 + da[j]; else if(mo[j] == 4) jday = 90 + da[j];
else if(mo[j] == 5) jday = 120 + da[j]; else if(mo[j] == 6) jday = 151 + da[j];
else if(mo[j] == 7) jday = 181 + da[j]; else if(mo[j] == 8) jday = 212 + da[j];
else if(mo[j] == 9) jday = 243 + da[j]; else if(mo[j] == 10) jday = 273 + da[j];
else if(mo[j] == 11) jday = 304 + da[j]; else if(mo[j] == 12) jday = 334 + da[j];
}
    if(leap == 1) { if(mo[j] == 1) jday = da[j]; else if(mo[j] == 2) jday = 31 + da[j];
else if(mo[j] == 3) jday = 59 + da[j]; else if(mo[j] == 4) jday = 90 + da[j];
else if(mo[j] == 5) jday = 120 + da[j]; else if(mo[j] == 6) jday = 151 + da[j];
else if(mo[j] == 7) jday = 181 + da[j]; else if(mo[j] == 8) jday = 212 + da[j];
else if(mo[j] == 9) jday = 243 + da[j]; else if(mo[j] == 10) jday = 273 + da[j];
else if(mo[j] == 11) jday = 304 + da[j]; else if(mo[j] == 12) jday = 334 + da[j];
}
//set constants for all equations...
pave[j] = 0.1333*pave[j]; rnave[j] = 24.0*3.6*rnave[j]; rtave[j] = 24.0*3.6*rtave[j];
if(rhmax[j] > 100.0) rhmax[j] = 100.0; lamda = 2.501 - (0.002361*taveh[j]);
etsimb[j] = klb*rtave[j]/lamda; if(opt1 == 1) etsimb[j] = etsimb[j]/25.4;
etsimc[j] = kic*rtave[j]/lamda; if(opt1 == 1) etsimc[j] = etsimc[j]/25.4;
if(opt4 == 1) {if(j == 0) gval = 0; else gval = 4.18*0.14*(taveh[j] - tad1);}  
if(opt4 == 2) {if(j == 0) gval = 0; else gval = 4.18*0.118153*(taveh[j] - tad1);}  
atmrho = 3.486*pave[j]/(1.01*(taveh[j] + 273));
gamma = 1.013*pave[j]/0.001*(0.622*lamda); cp = 0.622*lamda*gamma/pave[j];
e1 = 0.611*exp((17.27*tmax[j])/(tmax[j]+237.3));
e2 = 0.611*exp((17.27*tmin[j])/(tmin[j]+237.3)); ea = (e1 + e2)/2.0;
ed = ((0.5*ea1*rhmin[j])/100.0) + ((0.5*ea2*rhmax[j])/100.0); vpd = ea - ed;
dm = 0.85*fcn*hitem; zom = 0.13*(hitem - dm);
ws2m = wsave[j]*log((2.0-dm)/zom)/log((10.0-dm)/zom);
ram = log((2.0 - dm)/zom) * log((hitem - dm)/(0.1*zom))/((0.41*0.41*ws2m)*0.447);
aw = 0.1+3.0*exp(-((float)jday-173.0)/58.0); bw = 0.04+0.2*exp(-(((float)jday-243.0)/80.0); etmix[j] = (delta*(rnave[j] - gval) + 86400.0*atmrho*cp*vpd/ram)/(delta + gamma*1.0 + (rc2/ram))/lamda; if(opt1 == 1) etmix[j] = etmix[j]/25.4;
etope[j] = (delta*(rnave[j] - gval)+gamma*6.43*(aw+bw*0.447*ws2m)*vpd)/(delta+gamma)/lamda;  
if(opt1 == 1) etope[j] = etope[j]/25.4; if((ef != -1) || (dflg == 1) { 
if(opt == 1)fprintf(fptr3, "%d %d %4.2f %4.2f
", yr[j], jday, etsimb[j], etsimc[j]);  
if(opt == 2)fprintf(fptr3, "%d %d %4.2f %4.2f %4.2f %4.2f %4.2f %4.2f %6.3f
", yr[j], jday, tmax[j], tmin[j], tavea[j], taveh[j], pave[j], rhmin[j], rhmax[j], rnave[j], rtave[j], wsave[j]); } tad1 = taveh[j]; j = j + 1; } while(ef != -1); fclose(fptr3), fclose(fptr4); printf("Finished open water ET calculations...\n\n");
}
APPENDIX B
This program calculates daily ET rates for cattail, mixed marsh and open water/algae surface areas.

Maximum time period for daily ET calculations is 10 years.

NOTE: THIS PROGRAM IS CASE SENSITIVE.

IT IS RECOMMENDED THAT THE USER READ THE ACCOMPANYING DOCUMENTATION EXPLAINING THIS PROGRAM PRIOR TO EXECUTION.

This program prompts the user for an input file, up to 32 characters in length, located in the current directory, containing the file names ZZZ###AA.BBB, where ZZZ corresponds to a three letter moniker for the weather station used for analysis, ### corresponds to station number (depending on ET calculation performed), AA coresponds to AT, AP, etc., and BBB corresponds to MIN, MAX, or AVE depending on the parameter statistic. The first line of the input should contain a numerical value corresponding to the number of input files located in this file.

This program prompts the user for H (height) and Fc (vegetative cover) values.

Press c to continue, x to exit:

```
c
```

Enter filename containing weather parameter filenames

```enrfile```

Select one of two options:
simple ET calculations for all three scenarios = 1
simple and advanced ET calculations for all three scenarios = 2

Enter calculation option 1 or 2:

```
2
```

Select one of two options:
output as in/d = 1
output as mm/d = 2
Enter output option 1 or 2:
2
Enter numerical height, $H$, for cattail stand:
1.5
Enter numerical constant, $F_c$, for cattail land coverage:
0.7
Enter numerical height, $H$, for mixed marsh stand:
0.7
Enter numerical constant, $F_c$, for mixed marsh land coverage:
0.85
The following constants will be assumed:
k_1 = 0.54, 0.52, 0.53 for cattails, mixed marsh, or open water/algae, respectively, and $r_c = 90$ for cattails, $r_c = 70$ for mixed marsh.
Enter 1 if $r_c$ values are acceptable, otherwise enter 2 to change them
1
Select one of two options:
daily listing of weather parameters used in calculations = 1
no listing of daily weather parameters = 2
Enter daily weather output option 1 or 2:
2
Select one of two options:
Water temperature file contains water temperatures = 1
Water temperature file contains air temperatures = 2
Enter numerical value 1 or 2 pertaining to water temperature file:
1
Enter ending date for current analysis as yyyymmdd
19970819
Reading input parameters from ENR105AT.MIN
Reading input parameters from ENR105AT.MAX
Reading input parameters from ENR105AT.AVE
Reading input parameters from ENR105AP.AVE
Reading input parameters from ENR105T0.AVE
Reading input parameters from ENR105RH.MIN
Reading input parameters from ENR105RH.MAX
Reading input parameters from ENR105NR.AVE
Reading input parameters from ENR105RT.AVE
Reading input parameters from ENR105WS.AVE

Begin ET Processing
Finished ET calculations for cattails and mixed marsh

Reading input parameters from ENR308AT.MIN
Reading input parameters from ENR308AT.MAX
Reading input parameters from ENR308AT.AVE
Reading input parameters from ENR308AP.AVE
Reading input parameters from ENR308T0.AVE
Reading input parameters from ENR308RH.MIN
Reading input parameters from ENR308RH.MAX
Reading input parameters from ENR308NR.AVE
Reading input parameters from ENR308RT.AVE
Reading input parameters from ENR308WS.AVE

Begin ET Processing
Finished open water ET calculations...
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### Station 1001
**Lake Okeechobee Tower North**

- **Section**: 0  
- **Town**: 36  
- **Range**: 35  
- **Lat**: 27°08'19.000  
- **XCoord**: 568930.000  
- **Basin**: L OKEE  
- **Quad Sheet**: 27080320  
- **Long**: 804717.000  
- **YCoord**: 1019573.000  
- **County**: OKEE  
- **Land Surface**: 15.00 ft MSL

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<th>REP</th>
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<th>End</th>
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<th>Slot</th>
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</thead>
</table>

#### Weather Data
- **Wind Speed (Mph)**:  
- **Radiation (Kilo Watt/M²)**:  
- **Humidity (Percent)**:  
- **Air Temperature (Degrees)**:  
- **Humidity (Percent)**:  
- **Air Temperature (Degrees)**:  
- **Radiation (Micro Mole/S/M²)**:  
- **Air Temperature (Degrees)**:  
- **Humidity (Percent)**:  
- **Air Temperature (Degrees)**:  

### Station 1002
**Lake Okeechobee Tower North (2)**

- **Section**: 0  
- **Town**: 38  
- **Range**: 35  
- **Lat**: 27°50'07.000  
- **XCoord**: 568143.000  
- **Basin**: L OKEE  
- **Quad Sheet**: 27080322  
- **Long**: 804715.000  
- **YCoord**: 954359.000  
- **County**: OKEE  
- **Land Surface**: 15.00 ft MSL

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<th>Freq</th>
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<th>Strata</th>
<th>REP</th>
<th>Start</th>
<th>End</th>
<th>Gap</th>
<th>Slot</th>
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#### Weather Data
- **Wind Speed (Mph)**:  
- **Radiation (Kilo Watt/M²)**:  
- **Humidity (Percent)**:  
- **Air Temperature (Degrees)**:  
- **Radiation (Micro Mole/S/M²)**:  
- **Air Temperature (Degrees)**:  
- **Radiation (Kilo Watt/M²)**:  
- **Humidity (Percent)**:  
- **Air Temperature (Degrees)**:  
- **Radiation (Micro Mole/S/M²)**:  
- **Air Temperature (Degrees)**:  

### Station 1005
**Lake Okeechobee Tower West (5)**

- **Section**: 0  
- **Town**: 40  
- **Range**: 37  
- **Lat**: 26°57'34.000  
- **XCoord**: 507420.000  
- **Basin**: L OKEE  
- **Quad Sheet**: 26080444  
- **Long**: 804888.000  
- **YCoord**: 954389.000  
- **County**: OKEE  
- **Land Surface**: 15.00 ft MSL

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#### Weather Data
- **Wind Speed (Mph)**:  
- **Radiation (Kilo Watt/M²)**:  
- **Humidity (Percent)**:  
- **Air Temperature (Degrees)**:  
- **Radiation (Micro Mole/S/M²)**:  
- **Air Temperature (Degrees)**:  
- **Wind Speed (Mph)**:  
- **Radiation (Kilo Watt/M²)**:  
- **Humidity (Percent)**:  
- **Air Temperature (Degrees)**:  
- **Radiation (Micro Mole/S/M²)**:  
- **Air Temperature (Degrees)**:  

---

*Note: The data includes various meteorological measurements such as wind speed, radiation, humidity, air temperature, and radiation, along with their respective statistical measures and time periods.*
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STATION 3110W 3-140 WEATHER STATION ON LEVEE L-20 NEAR ALLIGATOR ALLEY

SECTION 3 TOWN 50 RANGE 35

LAT 261116.000 XCOORD 566576.000 BASIN CABA QUAD SHEET 2608030

LONG 804939.000 YCOORD 668931.000 COUNTY BRO LAND SURFACE 100.00 FT MSL

STATION 3311W 5-331 WEATHER STATION ON L-31N

SECTION 2 TOWN 55 RANGE 30

LAT 253830.000 XCOORD 661472.000 BASIN CL QUAD SHEET 2508040

LONG 803036.000 YCOORD 464426.000 COUNTY DAD LAND SURFACE 9.00 FT MSL

STATION WWWX WALKER RANCH WEATHER STATION (DISNEY WILDERNESS PRESERVE)

SECTION 15 TOWN 20 RANGE 29

LAT 280253.000 XCOORD 371069.375 BASIN L HATCHL QUAD SHEET 28081233 LAKE HATCHINEHA

LONG 812353.000 YCOORD 1350330.125 COUNTY POL LAND SURFACE

30