Appendix D: Water Balance Model Procedures

Temperature and precipitation data were either the calculated historical values for the study area or the forecast-modified values under SRES scenario A1B. Reference evapotranspiration (ET_o), was calculated using the Turc (1961) model (Jensen et al. 1997, Fontenot 2004). Turc was selected for use over the original Thornthwaite model because of its ability to more closely simulate FAO-56 Penman-Monteith ET_o with a limited set of meteorological data (Fontenot 2004). Allen (2003) defined the Turc equation for operational use:

$$ET_O = a_T\,0.013\frac{T_{mean}}{T_{mean}+15}\,\frac{23.8856R_S+50}{\lambda} \quad \textbf{(1)}$$

where ET_o is evapotranspiration (mm day^{-1}), T_{mean} is the mean daily air temperature (°C), R_s is solar radiation (MJ m^{-2} day^{-1}), and is the latent heat of vaporization (MJ kg^{-1}). The coefficient a_T is a humidity-based value. If the mean daily relative humidity (RH_{mean}) is greater than or equal to 50 percent, then $a_T = 1.0$. If the mean daily relative humidity is less than 50 percent, then a_T has the value of:

$$a_T = 1 + \frac{50 - RH_{mean}}{70} \quad \textbf{(2)}$$

Humidity data (historical or forecast) were not available for the study area, so the assumption was made that the dew point temperature was equal to the mean monthly minimum temperature. This procedure is recommended by Allen et al. (1998) for approximating daily humidity values when measured values are not available. Solar radiation (R_s) was estimated by using the Hargreaves model as described by Allen et al. (1998):

$$R_s = k_{RS}\sqrt{(T_{MAX} - T_{MIN})}\,R_a \quad \textbf{(3)}$$

where R_s is the solar radiation as stated above, k_{RS} is an adjustment coefficient, T_{MAX} and T_{MIN} are the mean daily maximum and minimum air temperatures (°C), and R_a is extraterrestrial radiation (MJ m^{-2} day^{-1}). A value of 0.19 was used for k_{RS} as suggested by Allen et al. (1998) for use in coastal locations. The Turc model was run using the monthly temperature data and radiation data for the 15th – the midpoint – of each month. The values were then multiplied by the appropriate number of days in each month to create a monthly value for ET_o. For simplicity, leap days were not included.

After the basic input variables were prepared, the data were entered into the water balance. First, using the temperature data, the monthly precipitation was partitioned into rain and snow components where:

$$RAIN_M = F_M \bullet P_M \tag{4}$$

$$SNOW_M = (1 - F_M) \bullet P_M \tag{5}$$

Where P_M is the monthly precipitation and F_M is a melt factor which is computed using the following method:

If $T_M \leq 0°$ C: $F_M = 0$
If $0°$ C $< T_M < 6°$ C: $F_M = 0.167 \cdot T_M$
If $T_M \geq 6°$ C: $F_M = 1$ **(6)**

where T_M is the mean monthly temperature (Dingman, 2002). F_M also is used to determine the monthly snowmelt amount:

$$MELT_M = F_M \bullet (PACK_{m-1} + SNOW_m) \tag{7}$$

with $PACK_{m-1}$ being the water equivalent of the snow pack at the end of the previous month and $SNOW_m$ being the snow fall total of the current month. The previous month's pack amount is calculated as:

$$PACK_m = (1 - F_M)^2 \bullet P_M + (1 - F_M) \bullet PACK_{m-1} \tag{8}$$

The overall hydrological input into the model is defined by W_M is:

$$W_M = RAIN_m + MELT_m \tag{9}$$

In this study, the probability of the study region having any significant snow amounts is low, but the variable was included to provide for the possibility in the forecasted model runs.

Changes in soil moisture are calculated using the following logic. If WM $\geq ET_o$, monthly evapotranspiration (ET_M) occurs at the ET_o rate. If ET_M equals ET_o, then soil moisture would then increase or remain steady if the soil moisture already is at field capacity (Dingman, 2002). For the purposes of this study, field capacity ($SOIL_{MAX}$) has been set to 150 mm. The monthly value for soil moisture is therefore:

$$SOIL_M = \min\{[(W_M - ET_O) + SOIL_{m-1}], SOIL_{MAX}\} \tag{10}$$

where the soil moisture value is the lesser of the two values in the equation (Dingman, 2002). If W_M is less than ET_o, then ET_M is equal to the hydrological input (W_M) and a drying factor:

$$ET_M = W_M + \left\{ SOIL_{m-1} \bullet \left[1 - \exp\left(-\frac{ET_{OM} - W_M}{SOIL_{MAX}} \right) \right] \right\} \quad \textbf{(11)}$$

where ET_{OM} is the monthly Turc ET_O value (Dingman, 2002).

After computing soil moisture change, any excess water in the budget was declared as surplus. The monthly surplus parameter is synonymous with runoff in these wetland environments, as long lags are not common between the generation of surplus water and the resultant streamflow. If W_M does not meet the environmental demand, then a deficit is created until W_M meets the environmental demand. In this study, we retained surplus as an index for runoff, and dismissed the modeled runoff term as invalid.

References

Allen, R.G., 2003: *REF-ET User's Guide*. University of Idaho Kimberly Research Stations: Kimberly, Idaho.

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith, 1998: *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements.* FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization. Rome.

Dingman, S.L., 2002: *Physical Hydrology, 2nd Ed.*: Upper Saddle River, New Jersey. Prentice Hall.

Fontenot, R., 2004: *An Evaluation of Reference Evapotranspiration Models in Louisiana*. M.N.S. Thesis, Department of Geography and Anthropology, Louisiana State University.

Jensen, D.T., G.H. Hargreaves, B. Temesgen, and R.G. Allen. 1997: Computation of ETo under Nonideal Conditions. *Journal of Irrigation and Drainage Engineering* 123(5):394-400

Turc, L., 1961: Evaluation des besoins en eau d'irrigation, evapotranspiration potentielle, formule climatique simplifee et mise a jour. (In French). *Annales Agronomiques* 12(1):13-49.